ANALYSIS OF A PROPOSED MECHANISM FOR CARBON-NEUTRAL GROWTH IN INTERNATIONAL AVIATION

Parth Vaishnav[a, *]

Annie Petsonk[b]

Rafael Alberto Grillo Avila[b]

M. Granger Morgan[a]

Paul S. Fischbeck[a]

[*] Corresponding Author; email: parth.vaishnav@gmail.com

[a] Department of Engineering and Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh PA 15213

[b] Environmental Defense Fund, 1875 Connecticut Avenue NW, Washington, DC 20009

Abstract

In October 2013, the International Civil Aviation organization (ICAO) announced that it would put in place a market-based mechanism to cap net greenhouse gas emissions from international civil aviation at 2020 levels. This paper analyses the obligations that would be placed on real airlines under an initial draft "Strawman" proposal that was originally formulated as a starting point for discussions within ICAO, and the extent to which such a proposal would succeed in keeping emissions at or below the desired level. The provisions of the ICAO proposal were then applied to more than 100 existing airlines. In order to protect commercial sensitivities, we used hierarchical cluster analysis to identify groups of different types of airlines. We report the results for these groups rather than for individual airlines. While ambiguities in the Strawman proposal complicated the analysis, we found that, depending on their size and rate of growth, airlines will be required to offset very different proportions of their emissions from international flights. A system of *de minimis* exemptions, as currently proposed, would benefit some rich countries as well as poor ones. Targeting such exemptions more narrowly would raise practical difficulties, which we describe. We conclude by recommending that ICAO design and implement a much simpler system; and propose one alternative.

1 Introduction

In October 2013, the International Civil Aviation organization (ICAO) resolved to finalize, by its October 2016 Assembly, a market-based measure (MBM) to address greenhouse gas emissions from international civil aviation. (ICAO, 2013a) ICAO's Council, a 36-member Executive Body, has formed a subsidiary Environmental Advisory Group (EAG) to consider, among other issues, options for the structure of the MBM. In May 2014 an initial "Strawman v.1.1" document (hereinafter referred to simply as "the Strawman")[1] was circulated outlining one possible structure for the MBM; various nations are in the process of formulating their own proposals. The Strawman and the various national proposals provide alternatives for structuring a mechanism in which airlines would offset their emissions in such a way that "net" sectoral[2] emissions (actual emissions less offsets) would remain capped at 2020 levels.

The purpose of the Strawman is to generate "discussion on advantages and disadvantages of its design elements and allowing for the improvements of the Strawman." (ICAO, 2014a) Such an "iterative" approach is meant to "ensure the full engagement of States and other stakeholders, taking into account inputs from different sources." (ICAO, 2014b, p. 3) It is in this spirit of providing inputs into an iterative process that the present analysis was undertaken during an internship, in summer 2014, at the Environmental Defense Fund, which – through the International Coalition for Sustainable Aviation (ICSA) – participates as an observer in the ICAO's Committee on Aviation Environmental Protection (CAEP).

This analysis estimates the volume of offsets (in kilotonnes of carbon dioxide) that a large number of real airlines are likely to have to procure during the years 2021-35 if the MBM as

[1] This text of this document is available from: http://clacsec.lima.icao.int/Reuniones/2014/GEPEJTA33/NE/NERstgd/33GENE18.pdf

[2] In this case, the "sector" is defined as international civil aviation, including passenger and freight transport. The Strawman defines international flights as those "departing from an airport of a State and arriving at an airport of another State."

described in the Strawman were to apply. The text of the Strawman indicates that as a structural matter, it aims to preferentially lower the offset obligations of airlines that are new, particularly efficient, or growing very fast. The latter accommodation is made, presumably, in order to address the special circumstances in which, depending on the structure of the MBM, capping emissions at 2020 levels might place a larger offset burden on fast-growing but historically underserved developing regions of the world. (ICAO, 2010, pp. I–70) Our analysis of airline obligations examines whether and to what extent, the Strawman's presumed objectives would be met by the current proposal.

Due to commercial sensitivities, in this analysis, airlines have been anonymized; pseudonyms such as A_1, A_2, etc. will be used to refer to them. Hierarchical cluster analysis is used to identify airline types. The characteristics (e.g., size and growth rate) and offset obligations of different clusters of airlines are then compared to study the systematically different obligations that different *types* of airlines would face under the provisions of the Strawman.

Finally, we will propose alternatives to certain aspects of the Strawman.

2 Methods and Analysis

2.1 Description of Strawman v1.1

The Strawman Version 1.1 text (under Section 4, Quantities of Offset for Each Operator) and accompanying sample calculations describe the method by which the offset obligations of an airline would be calculated in any given year.

The Strawman defines *de minimis* exemptions in the following way.

(a) States are listed in increasing order from the lowest to the highest amount of emissions generated by all international flights to and from individual States.

(b) Flights to and from the States in this list are exempted from the top State down to the State where the cumulative amount of emissions reaches [a currently undefined] *y% of global emissions in the reference year.*

(c) This list is established in the first year of application, and revised after 5 years.

(d) The exempted emissions are not included in the reference year and in the current year.

We discuss the implications of this *de minimis* exemption in terms of how it would affect the coverage of the mechanism; that is, what proportion of current global emissions would be exempt for different values of "y". We do not attempt to forecast how this would affect individual airlines going forward because doing so would require forecasts at the level of individual airlines and routes.

The Strawman as currently drafted would also exempt emissions from airlines whose flights collectively emit less than 10 kilotonnes of carbon dioxide each year, aircraft with a maximum take-off mass of less than 5.7 tonnes, as well as humanitarian, medical and fire-fighting operations. These are called "technical exemptions."

For the rest of the sector, the Strawman begins by defining reference year emissions as the average of emissions in 2018, 2019, and 2020. This number is calculated for the sector, as well as for individual airlines.[3] For the sector, the difference between reference year emissions and 2020 emissions is held as a notional reserve. This reserve is defined at the start of the mechanism's implementation period (that is, by the end of 2020) and does not change throughout its life.

In the first instance, the reference year emissions are treated as a "cap". Each year, an airline's offset obligations are calculated as the average of (a) the airline's percentage share of sectoral emissions in a particular year times the absolute growth in sectoral emissions since the reference year, and (b) the absolute growth in the airline's own emissions relative to the reference year.

[3] For an airline that does not exist in these years, reference emissions are zero for the first five years of its existence, after which "reference year" emissions are assumed to be the average of the airline's fourth and fifth year emissions.

New entrants are exempt from having to offset their emissions for a period of five years after they begin operations, or until their annual emissions reach a certain, as yet undefined, fraction of the global emissions in the reference year.[4] The Strawman explicitly says that other exemptions (e.g., the *de minimis* exemptions listed above) are not included in the sectoral reference emissions and in the annual emissions of the sector in each subsequent year. This suggests that emissions from new entrants must be included in the sectoral emissions for a particular year, and this analysis will proceed under that assumption.[5]

The Strawman then adjusts this calculation to account for special categories of airlines. The effect of this adjustment is that the obligations of fast growers (defined in the Strawman as airlines whose percentage growth relative to the reference year is twice or more the percentage growth of the sector) are somewhat reduced. The obligations of early movers, defined in the Strawman as those whose fuel efficiency is more than 10% higher than the global fuel efficiency,[6]would also be somewhat reduced for the period between 2021 and 2025. If the sum of all the obligation reductions (termed as "compensation" by the Strawman) offered to fast-growing airlines and early movers in

[4] The Strawman text does not make it clear whether this threshold will be set for *all* new entrants at a given time (i.e., the total exemptions granted to new entrants in a particular year cannot exceed x% of the reference year emissions) or for *each* new entrant.

[5] If new entrants' emissions *were* included in calculating the annual sectoral emissions, they would represent a growth in sectoral emissions relative to the reference year and would therefore have to be offset by other airlines, even if the new entrant itself were temporarily exempt. If these emissions *were not* included in calculating the sector's annual emissions, no one would have to offset them. That is, unless (a) an upper limit were set to the volume of exemptions that all new entrants could collectively claim in a particular year, or (b) the emissions of new entrants were included in calculating the total sectorial emissions for a particular year, the sector would be obliged to offset less than the actual growth of emissions since the reference year, and net emissions would, in fact, keep growing.

[6] The Strawman does not define what fuel efficiency means, or what global fuel efficiency means. Furthermore, airline and sectoral fuel efficiencies are very difficult to determine based on the data we have available. As such, we do not analyze the impact of the "early mover" clause.

any given year exceeds the size of the notional reserve, the Strawman requires that these obligation reductions be proportionally trimmed so that their total magnitude is equal to that of the reserve.[7]

As such, the mechanism is designed to ensure that net emissions from international aviation stay capped at the sum of (a) emissions in the reference year, (b) emissions in the notional reserve, (c) emissions from other *de minimis* exemptions (small airlines and airplanes) and humanitarian missions. For this to be an effective cap, several aspects of the mechanism – see, for example, Footnote 5 and Footnote 6 – need to be fully defined.

2.2 Data collection and verification

Our analysis depends critically on knowing each airline's annual emissions during the period that the mechanism is applied. As a starting point, we use a dataset of aviation activity for the year 2012, assembled by an industry expert. (Southgate, 2013)[8] The data contain actual information about the number of non-stop flights for each combination of origin airport, destination airport, airline, and aircraft operated. We partially validated Southgate's data against external sources where such sources were available. The data were found to be a reasonably complete record of civil passenger aviation activity in 2012 (Figure S.1 and Figure S.2 in the supplementary materials).

To broaden the analysis, we added data for emissions from the carriage of freight to Southgate's estimates of the emissions from passenger aviation. We obtained data for ton-miles of freight carried by airlines flying in and out of the United States from form T-100 records maintained by the Bureau of Transportation Statistics (2014). For US airlines, both passenger and cargo, we assumed that this

[7] The text of the Strawman suggests that the reserve is available to offset the obligations of both fast growers and early movers, and no specific allocation is made between these two categories of airline. However, an accompanying sample calculation suggests that half the reserve is allocated to fast growers and the other half to early movers. Our analysis was conducted using that assumption.

[8] "From 2004 to 2012 Dave [Southgate] was the Australian Government representative on the United Nations International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP). He pursued his interest in carbon footprinting while on CAEP and was a member of the group that oversaw the development of the ICAO Carbon Calculator." (Southgate, n.d.)

represented the total volume of freight they carried.[9] Carbon dioxide emissions were estimated from this number by assuming that all airlines operated as efficiently as Federal Express (FedEx, 2012) in terms of CO_2 emissions per *available* ton-mile, and at a load factor of 60%, which was the US average in 2010 (Donatelli and Belobaba, 2014). For US airlines, it was possible to obtain these data for each combination of origin and destination country pair and airline. For other major carriers, information on revenue ton-miles was obtained from Donatelli and Belobaba (2014), and the same assumptions made as for the US airlines. Finally, for Cargolux (2014) and DHL (2013), data on emissions were obtained directly from publications by these companies.

In addition to data on activity, we gathered information about airline fleets. This included the size of the fleet, the average age of the fleet, and the number of aircraft on firm order (options were ignored). These data were gathered from airlines' webpages, investor relations materials, and Airbus and Boeing's publicly available order books.

2.3 Projection of emissions

To assess the obligations that each of these airlines would face, it was necessary to forecast their emissions. Two approaches were considered in order to do this.

The first approach was based on growth in traffic in the regions in which each airline chiefly operates. For each airline, identified the regions in which the airline was active. We then identified the traffic growth rate for these regions based on Airbus's estimates for growth in 2012-32. (Airbus, 2013) The traffic-based estimate of airline's annual growth rate was calculated as the weighted

[9] Our implicit assumption is that US airlines only carry freight in or out of the US, and not between two destinations within a second country or between a second and third country. Carriage between two destinations within a second country is called cabotage (or the eighth freedom of the air), and is extremely rare outside the European Union. Carriage between a second and third country, called the seventh freedom of the air, is also rare outside Europe. Accordingly, we assumed that these activities do not take place to a significant extent. See: http://www.icao.int/Pages/freedomsAir.aspx

average of these various regional growth rates, with the number of revenue passenger kilometers (RPKs) flown by the airline in a particular region in 2012 acting as the weight.

The second approach was to estimate the growth in RPK based on the projected growth in the fleet. The rate of growth of the fleet was calculated slightly differently depending on whether the ratio of the number of aircraft on order to the number of aircraft in the fleet was less than or greater than 0.75.[10] For airlines for whom the ratio was greater than 0.75, it was assumed that all the aircraft on order would be delivered by 2025. It was assumed that all carriers operate aircraft until they reach an age of 25 years (e.g. (Jiang, 2013, p. 6). This "target" age was combined with the average age of the current fleet to calculate the annual rate of retirement. Consider an airline that aims to retain aircraft until their age is 25 years, whose current fleet has an average age of 13 years. Each aircraft in its fleet would, on average, have twelve additional years of life. As such, one can estimate that each year, one-twelfth (or 8%) of its fleet would retire. Based on this assumption, the total number of retirements up to 2025 were calculated, and subtracted from the sum of the number of aircraft in the current fleet and the number of aircraft on order. The resulting number was an estimate of the number of aircraft the airline would operate in 2025, and the growth rate in the RPK between now and 2025 was calculated on this basis. For airlines where the ratio of the number of aircraft on order to that in the fleet was less than 0.75, an analysis similar to the one described above was applied, except that it was assumed that all aircraft currently on order would be delivered by 2020.

In these calculations, it was assumed that the airline would grow at the larger of the two rates calculated above. This is akin to saying that if the routes on which the airline operates grow faster

[10] Our results are not sensitive to the choice of this threshold. With this assumption and the assumption that aircraft are operated for 25 years, we estimate that there will be about 20,000 jets in passenger service in 2020. By comparison, our analysis of forecasts by Airbus (2014) and Boeing (2014a) suggests that both anticipate that there will be about 24,000 jet aircraft operating in that year. Allowing for the fact that some part of the global fleet is dedicated freighters (1,700 today and 2,730 forecast in 2033 according to (Boeing, 2014b), there is general agreement between our projection and that of the airframe manufacturers.

than its fleet, then it will acquire the aircraft necessary to serve those routes; and if the fleet grows faster than the routes, then the airline will fill its aircraft, perhaps at the expense of its competitors. Growth rates were assumed to fall to 80% of those assumed for 2013-2025 after 2025.[11]

This calculation produced forecasts of the growth in RPKs flown by each airline. It was assumed that if the age of an airline's fleet was less than five years, its emissions would grow at an annual rate that was 0.5% slower than its RPK. If the fleet was between 5-10 years old, we assumed that emissions would grow 1% per annum slower than RPK. If the fleet was more than 10 years old on average, we assumed that emissions would grow 1.5% slower per year than RPK.[12] As such, it was assumed that airlines with older fleets had a greater potential to grow more efficiently in the future by switching to newer airplanes.

Estimates of regional growth rates for freight were also obtained from Airbus (2013). For US cargo airlines, an average growth rate that was weighted by their regional footprint in 2012 could be obtained and was used in projecting emissions. For the two European cargo airlines, a simple average of all regional growth rates for routes in and out of Europe was used.

2.4 Hierarchical cluster analysis

To extract generic airline types from these data, we used a hierarchical cluster analysis, implemented in R, an environment for statistical computing. (Müllner, 2013) Cluster analysis has been used to identify groups of airlines in the literature for market segmentation (Robles and Sarathy, 1986) and the identification of strategic groups (Kling and Smith, 1995). Hierarchical clustering (as opposed to, say, k-means) was used because this approach makes it possible to

[11] This was based on assumptions made in Airbus fleet forecasts (Airbus, 2014).

[12] See, for example, (Lee and Mo, 2011, p. p3780). Between 1959 and 2000, aircraft efficiency improved by 1.5% per year, but the rate of improvement has slowed in recent years. Owen, Lee, and Lim (2010) assume that fuel efficiency will improve by 1% per year to 2020, and 0.5% per year thereafter.

visualize the structure of the cluster hierarchy and exercise judgment in defining each cluster at the appropriate level.

The following variables were included in the analysis for each airline: the number of international revenue passenger kilometers, the average age – in years – of the fleet, the fleet size, the number of airplanes on order for each airline, the maximum and average distances of the airline's services, the number of domestic and international destinations served by the airline, the number of aircraft variants operated by the airline, and the proportion of the airline's total RPK that were international. We had data for 111 airlines, but combined airlines that have merged and operate as single entities (e.g., American Airlines and US Airways) since 2012. After these combinations were made, 106 airlines remained.

		INTL_RPK	AVG_FLT_AGE	FLT_SIZE	FLT_ORDERS	MAX_DIST	AVG_DIST	NUM_INTL_RTS	NUM_DOM_RTS	NUM_VARIANTS	PROP_INTL_RPK
INTL_RPK											
AVG_FLT_AGE	|r|	16%									
	p	0.11									
FLT_SIZE	|r|	70%	14%								
	p	0.00	0.15								
FLT_ORDERS	|r|	51%	10%	66%							
	p	0.00	0.32	0.00							
MAX_DIST	|r|	49%	21%	33%	11%						
	p	0.00	0.03	0.00	0.28						
AVG_DIST	|r|	4%	19%	22%	14%	31%					
	p	0.67	0.05	0.02	0.16	0.00					
NUM_INTL_RTS	|r|	42%	10%	79%	35%	29%	29%				
	p	0.00	0.28	0.00	0.00	0.00	0.00				
NUM_DOM_RTS	|r|	55%	7%	52%	44%	11%	18%	26%			
	p	0.00	0.49	0.00	0.00	0.25	0.06	0.01			
NUM_VARIANTS	|r|	75%	34%	69%	30%	56%	16%	51%	34%		
	p	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00		
PROP_INTL_RPK	|r|	4%	18%	37%	32%	4%	39%	54%	7%	11%	
	p	0.67	0.06	0.00	0.00	0.66	0.00	0.00	0.46	0.28	

Figure 1: Pearson correlations between the z-scores of the variables used in the analysis. High absolute pair-wise correlations (|r|) are shown with a dark background, as are those with high significance (low p-value). As such, cells where both the upper and lower numbers are shaded with a dark color indicate pairs of variables with high, significant correlations.

Since the variables span an enormous range of values (of the order of 10^{11} for international RPK and 1 for proportion of revenue passenger kilometers that were international), the data were normalized by conversion to z-scores. A Pearson correlation matrix (Figure 1) was then generated to see which variables were strongly correlated with each other. This correlation matrix is complex, with a number of variable pairs showing high, significant correlations. We therefore applied principal component analysis to generate mutually independent components that could be used in the cluster analysis. The resultant components are shown in Table 1.

Table 1: Results of a principle component analysis performed on the airline data. We retain the first four components, which explain 80% of the variation found between the airlines. They pertain to the size, network structure, and fleet characteristics of the airline. The variables with the highest absolute weight in each of the components are highlighted.

Component	1	2	3	4	5	6	7	8	9	10
Variable	Size	Network structure	Size	Fleet	Fleet	Size	Network structure	Network structure	Size	Size
INTL_RPK	-0.41	0.23	-0.22	0.08	-0.14	-0.18	0.30	-0.36	0.67	-0.11
AVG_FLT_AGE	-0.10	0.38	0.31	-0.60	0.55	-0.11	-0.20	0.04	0.17	-0.05
FLT_SIZE	-0.47	-0.09	0.01	0.01	0.14	0.08	0.28	0.15	-0.36	-0.72
FLT_ORDERS	-0.33	-0.18	-0.35	0.31	0.44	-0.46	-0.17	0.35	-0.01	0.29
MAX_DIST	-0.25	0.40	0.30	0.37	-0.34	0.08	-0.55	0.32	0.10	-0.13
AVG_DIST	0.11	0.50	0.03	0.52	0.45	0.25	0.20	-0.30	-0.23	0.12
NUM_DOM_RTS	-0.38	-0.21	0.35	-0.01	0.05	0.50	0.34	0.29	0.18	0.45
NUM_INTL_RTS	-0.30	0.03	-0.58	-0.24	0.01	0.54	-0.41	-0.20	-0.12	0.10
NUM_VARIANTS	-0.41	0.19	0.17	-0.18	-0.32	-0.35	0.09	-0.28	-0.53	0.38
PROP_INTL_RPK	0.17	0.51	-0.40	-0.20	-0.20	0.01	0.37	0.57	-0.07	0.08
Standard deviation	2.01	1.39	1.08	0.96	0.83	0.67	0.60	0.50	0.36	0.26
Proportion of variance	40%	19%	12%	9%	7%	4%	4%	2%	1%	1%
Cumulative proportion	40%	60%	71%	81%	87%	92%	96%	98%	99%	100%

Deleted:

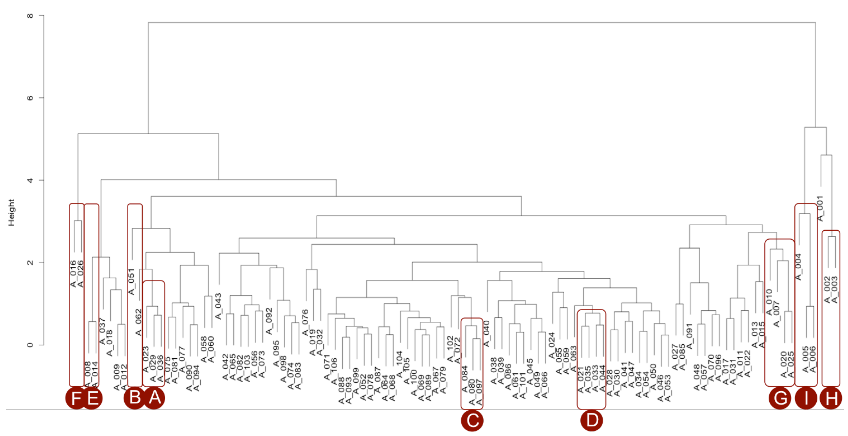

Figure 2: Clustering of airlines. Clusters extracted based on the dendrogram produced by hierarchical clustering. Clusters are selected so that a diversity of airline types is represented.

Table 2: Nine airline clusters that were extracted from the dendogram in Figure 5. The international RPK for each cluster is a simple sum of all the airlines within each cluster, and the fleet ages and growth rates are weighted averages.

Cluster	Network Footprint	Growth rate	Avg. age of fleet *(years)*	International RPK (2012) *(billions)*
A	90% Dom – 10% Intl	< Industry average	< 10	15
B	90% Dom – 10% Intl	> 2x industry average	< 5	5
C	100% Intl	> 2x industry average	< 5	14
D	20% Dom – 80% Intl	No growth	< 10	11
E	70% Dom – 30% Intl	~ Industry average	< 10	53
F	10% Dom – 90% Intl	< Industry average	~ 5	11
G	100% Intl	> Industry average[13]	< 10 years	37
H	50% Dom – 50% Intl	< Industry average	> 10 years	30
I	10% Dom – 90% Intl	< Industry average	> 10 years	60

We then performed a hierarchical cluster analysis, retaining only the scores for the first four components identified in the principal component analysis for all airlines. The results of this cluster analysis are as shown in Figure 2. The individual clusters were selected in order to represent a diversity of airline types. The resultant clusters are presented in Table 2. Cluster D is composed of a group of airlines, which – based on their fleet orders – might be expected to shrink over the next 20 years. We have imposed an exogenous assumption that this cluster does not grow, to assess the impact of the Strawman on such airlines.

3 Results

The first question to ask of the Strawman is whether it does what it is primarily designed to do: restrict net emissions (actual emissions less offsets) for international aviation to 2020 levels or below. With the assumptions made above (that new entrants' emissions are accounted for when total sectorial emissions are calculated and that *de minimis* exemptions are kept small), Figure 3 suggests

[13] While the weighted average growth rate of the cluster is greater than the industry average but less than twice industry average growth rate, two of the airlines in this cluster are forecast to grow at twice the industry average. These would therefore be eligible for the reduction offered fast growers.

that it does. Figure 3 also gives an early glimpse of the obligations that the Strawman places on different airlines. By forcing the very large airlines of clusters H to slightly reduce their emissions relative to 2020, the mechanism creates room for smaller, faster-growing airlines such as those in groups B, C, and G to increase their emissions quite substantially.

Deleted: and I

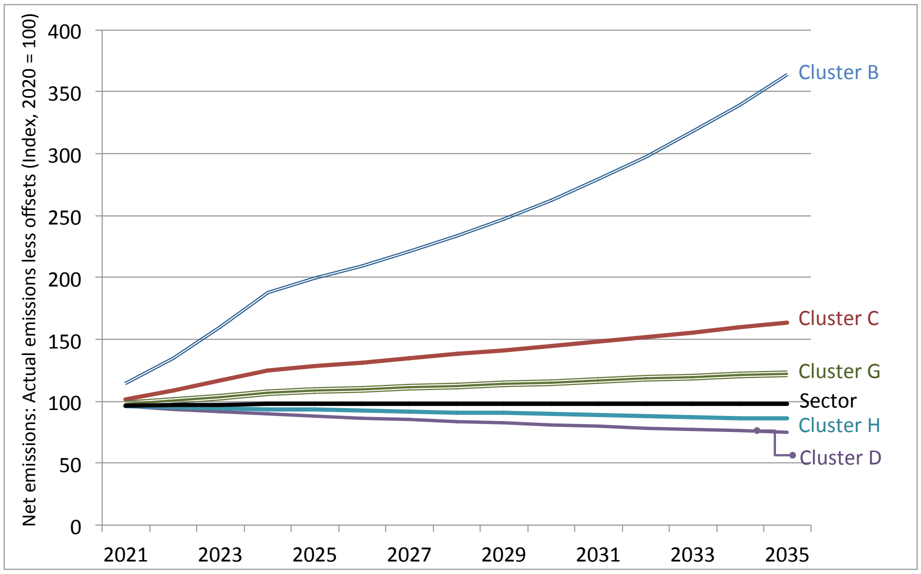

Figure 3: Emissions relative to 2020. Assuming *de minimis* exemptions are kept small and new entrants' emissions are added when calculating the sectorial total, the Strawman would cap emissions at or below 2020 levels. It would also create room for fast-growing airlines, whose current contribution to emissions from international aviation is small, to increase their net emissions very substantially by requiring much larger airlines to push their net emissions somewhat below 2020 levels. To prevent visual clutter, not all clusters are shown in this figure.

The Strawman imposes very different offset obligations, when expressed as a percentage of total international obligations, on different types of airlines. The trajectory taken by these obligations also varies greatly between clusters; for example, the airlines in Cluster B offset a comparatively small proportion of their international emissions in 2021; but, by 2035, are required to offset a larger proportion of their emissions than any other cluster of airlines Figure 4.

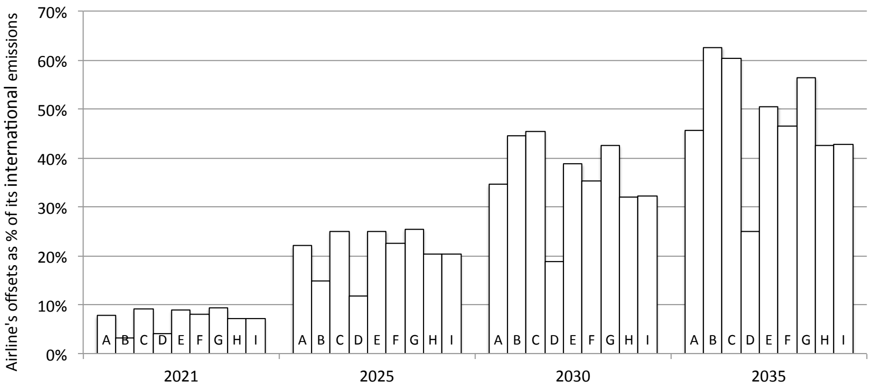

Figure 4: Cluster offset obligations as percentage of cluster international emissions. Different types of airlines are required to offset very different proportions of their emissions in each year. The trajectories that airlines' offset obligations follow over time are also very different: the airlines in Cluster G are obliged to offset among the highest proportions of their emissions in each of the years, whereas the airlines in Cluster B start off offsetting a comparatively small proportion of their emissions in 2021; but, by 2035, are responsible for offsetting a higher proportion of their emissions than any other cluster.

This trajectory is explained by the fact that the airlines in Cluster B are eligible for reductions in their offset obligations due to their exceptionally fast growth. Until 2024, the total of such reductions is below the limit set for it in the Strawman – that is, 50% of the emissions held in reserve (see Section 2.1) – and all airlines receive all the compensation for which they are eligible. After 2024, this limit is breached, and airlines' total offset obligations grow while the reductions offered to them stay constant. As such, their offset obligations as a share of their international emissions rise rapidly after 2024 (see Figure 5).

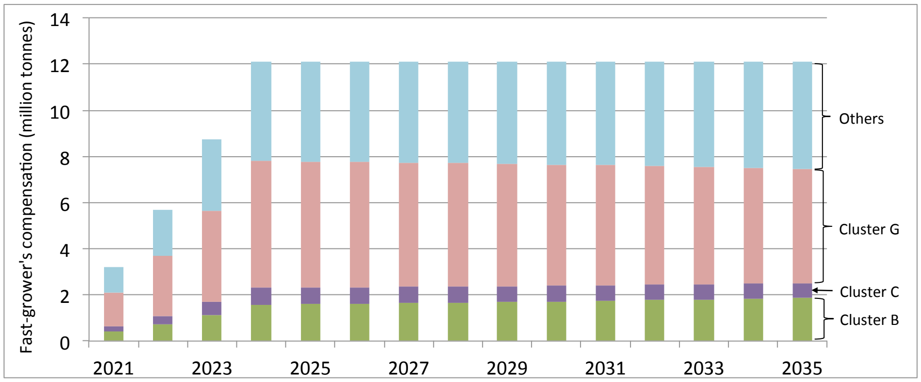

Figure 5: Distribution of fast-grower's compensation. Most of the reductions due to fast growers are received by airlines that belong to clusters B, C, D, and G. The fast-growers reduction is such that it depends on its growth since the reference year as well as the absolute magnitude of its emissions in the reference year. As such, a bulk of this compensation is given to the relatively large airlines in Cluster G, rather than the small, but faster-growing, airlines in Clusters B and C. The reduction is limited by the size of the reserve allocated to fast growers. This limit is breached in 2024. Before this year, the airlines receive "full" reduction. After it, the reductions are trimmed to ensure that total compensation does not exceed the 50% of the reserve allocated to compensate fast growers.

It is possible that the purpose of the fast-grower's compensation is to ensure that small, rapidly growing airlines are not overly burdened by the need to buy offsets. Indeed, this compensation is a form of burden-sharing offered to fast-growing (presumably fledgling) airlines by their slower growing (presumably mature) competitors since it comes out of a reserve created by tightening the cap to below 2020 levels for airlines that receive no compensation. An interesting observation that can be made in Figure 5 is that a very large portion of the reductions goes to the relatively large airlines in Cluster G. This is a consequence of the fact that fast-grower's reductions are calculated based on both the growth rate and the size of the airlines emissions in the reference year. Note that even after adjusting for the compensation they receive, the airlines in Cluster G offset a larger proportion of their international emissions than their larger or similarly sized competitors in other clusters.

One criticism of our argument could be that airline growth rates tend to slow as carriers become larger: few airlines would remain eligible for fast-growers compensation, as they grew larger. This line of reasoning would contend that we are being too optimistic in assuming that the comparatively large airlines of Cluster G will continue to grow rapidly enough to be eligible for reductions. While this is a reasonable argument, we note that there have been historical outliers. One is Ryanair, which, in 2013, was the world's largest airline in terms of passengers carried. (IATA, 2014) In terms of revenue passenger kilometers, Ryanair grew at an annual average rate of 28% between 1998-2013. Its growth slowed dramatically in 2012 and 2013.[14] Even so, during many of the years between 1998 and 2011, it was both a large, profitable airline and one that was growing fast enough to be eligible for a reduction in its obligations under the Strawman.[15] Its competitors would not have been cheered by such a result.

Figure 6 sheds additional light on the issue. It shows that airlines that are growing faster than the sector (that is, airlines that are gaining market share) would be required under the Strawman to offset a larger share of the sector's growth after 2020 than are airlines that are losing market share. The exceptions to this rule are the very fast-growing airlines in Cluster B, which until 2026 would, under the Strawman, receive enough of a reduction in their offset obligations for their share of offsets to be lower than their share of international emissions.

The analysis so far suggests that the Strawman has produced diverging (i.e., different airlines are affected very differently) and complex outcomes, not all of which may have been anticipated by the document's designers. In this context, it may be useful to consider counterfactuals to different elements of the Strawman, as is done in Figure 7. The exercise illustrates that the Strawman may be understood as a compromise.

[14] Source: Ryanair's Form 20-F filings with the US Securities and Exchange Commission.

[15] In fact, since the reductions are based on percentage cumulative growth since a reference year, Ryanair would have remained eligible well after its growth slowed to, or below, industry average.

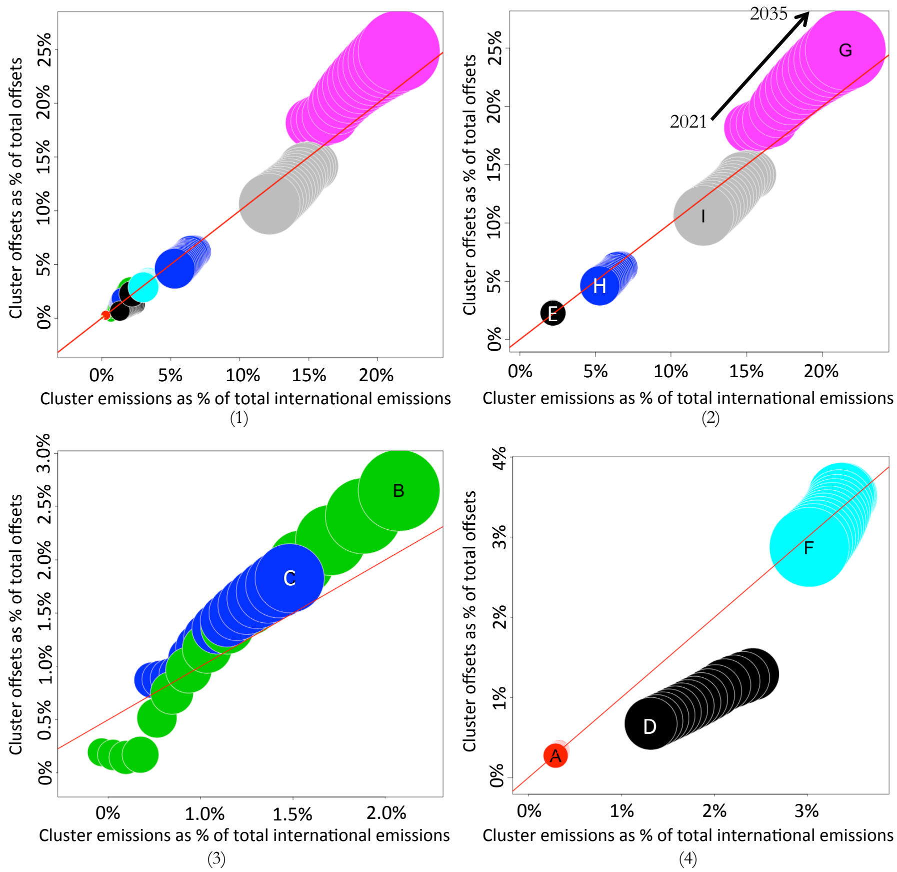

Figure 6: Cluster's share of emissions against share of offsets. These plots show, under the Strawman, the relationship between a cluster's share of sectoral international emissions (x-axis) and its share of sectoral offsets (y-axis). The plots also show the evolution of this relationship: each bubble corresponds to the cluster's position in a particular year. In plot (1), the clusters are shown in different colors. In plots (2), (3), and (4), the clusters are named. The bubble containing the cluster's name indicates that bubble's position in 2035. If a bubble lies above the red 45 degree line, it suggests that, at that time, that cluster will be responsible for purchasing a larger share of sectoral offsets than its share of sectoral emissions. The area of the bubbles in each plot is proportional to the cluster's emissions. Note that the scale is constant within a plot, but not across plots. The plots indicate that airlines that gain are gaining market share will be responsible for offsetting a larger proportion of the sector's emissions growth than is their market share at any given time. An exception is cluster B, which – until 2024 – receives significant reductions in its obligations, and is share of offsets is consequently much smaller than its share of emissions. The situation is reversed after 2026-27.

The simplest starting point might have been Figure 7(1), in which each airline would be required to offset a portion of the industry's growth since the reference year that was directly in proportion to the airline's share of emissions in the current year. The fact that such an arrangement would resemble a Pigovian tax would make the approach attractive to economists. The approach might also be criticized for basing the penalty (i.e., the offset obligation) on the absolute size of the airline rather than its contribution to the sector's growth since 2020, when the latter might seem more salient in a mechanism designed to cap industry growth at 2020 levels.

This criticism could be addressed by adopting the approach in Figure 7(2), where each airline is made to offset its own growth since the reference year. Such an approach would place a disproportionate burden on fast-growing (usually small) airlines, while letting airlines that are no longer growing (like those in Cluster D) completely off the hook, regardless of their current or past contributions to greenhouse gas pollution. Such an approach might be criticized because it penalizes (and might suppress) industry growth, and is likely to penalize fast-growing airlines, which are predominantly (though not exclusively) based in developing countries. One possible compromise is to simply calculate offset obligations both ways, and to set actual obligations as the average of the two. In its basic calculation, this is precisely the compromise that the Strawman seeks to make (Figure 7(3)). This arrangement would still place a comparatively onerous burden on fast growers. To partially correct this, the Strawman adds a further embellishment: the reduction in offset obligations offered very fast growing airlines. Figure 7(6) shows the effect that this adjustment has: fast growers offset a smaller proportion of their emissions initially, but this rises steeply in later years – for reasons discussed above – until, by 2035, such airlines are responsible for offsetting a much larger proportion of their emissions than are slower-growing rivals. This form of compensation shifts the burden from slow-growing airlines to fast-growing ones.

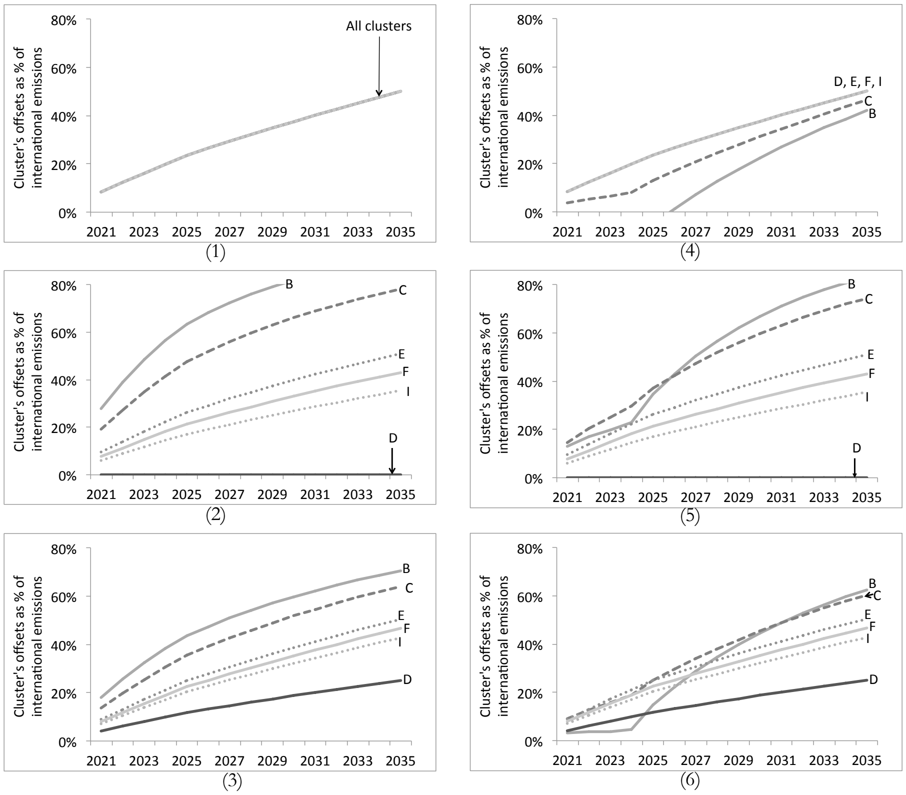

Figure 7: Cluster offset obligations under alternatives to Strawman. (1)-(5) illustrate the fraction of their international emissions that different airline clusters would have to offset under different alternatives to the Strawman, while (6) represents the Strawman. (1), (2), (3) are scenarios where compensation is not made for fast growth, the remaining charts show scenarios where it is made. For visual clarity, only five of the nine clusters have been shown. <u>(1)</u> In this case, total sectoral growth since 2020 is calculated. Each year, each airline is required to offset a share of that growth equal to its share of sectoral emissions in that year. There is no compensation for fast growers. If the airlines were assumed to have access to a very large pool of identically-priced offsets, this situation closely resembles what would happen if a uniform carbon tax were imposed on airlines' international emissions: each airline's costs would be proportional to its international emissions. <u>(2)</u> If each airline simply offset *its own* growth in emissions since the reference year, the fast growers would be very hard hit, whereas airlines that did not grow would not have to offset anything. (3) represents a compromise – in fact, a literal averaging – of the approaches in (1) and (2). While this raises the obligations for slow-growers and reduces them for fast-growers, the burden on the latter is still comparatively high. <u>(4)</u> is a version of (1), but one in which the obligation of fast growers is reduced, possibly to a point where they have no net obligation. <u>(5)</u> bases the offset obligation entirely on an airline's own growth since the reference year, but compromises by offering some relief to fast growers. <u>(6)</u> is a compromise – again, a literal average – between (4) and (5). (6) represents the Strawman.

It may be that - assuming that most of the airlines that are eligible for such compensation are from (and serve) the developing world - this compensation is a way for ICAO to implement some form of common but differentiated responsibilities, while also adhering to the principle of non-discrimination by not explicitly making the benefit of the burden-shifting available to only airlines from the developing world. (ICAO, 2013b, pp. A38–18, Annex, Paragraph (p))

We end this section with a discussion of the *de minimis* exemption of the Strawman. Its provisions are described in detail in Section 2.1. Because of the way the exemption is worded, exempting flights in and out of the lowest-emitting states with cumulative emissions of X% of the total would exempt X% of global emissions.

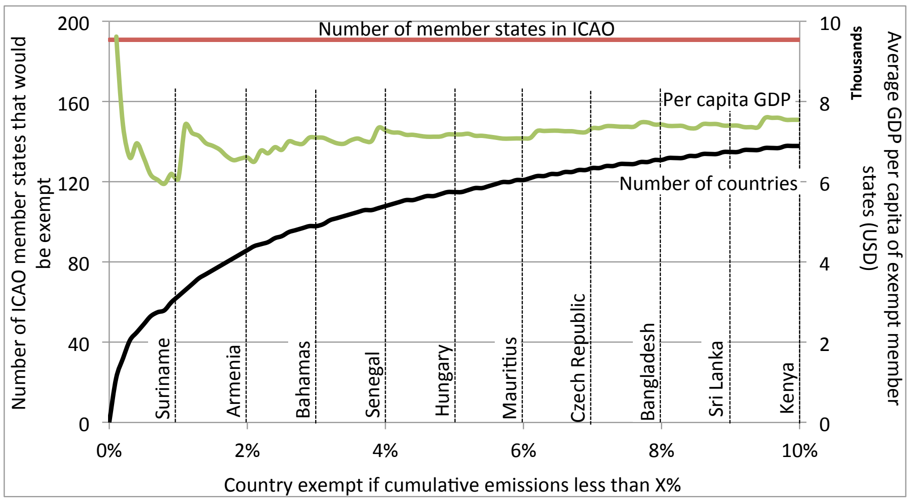

Figure 8: Analysis of *de minimis* exemption. If the threshold for *de minimis* exemption were set at more than 4%, over half the member states of ICAO would be exempt from participation in the system. The "marginal" member – the member state with the highest emissions that still received an exemption - would be Senegal. For X>0.5%, the average GDP per capita of exempt states would be over US$8,000. The GDP per capita data are from the World Bank's 2013 statistics, or the latest year available. They are in 2013 US$, calculated at market exchange rates.

The list of exempt states would be updated every five years, which would ensure that this would remain the case. Figure 8 is drawn by applying the *de minimis* exemption rules to 2012 passenger data.

While this limits its validity to the discussion of ICAO's market-based mechanism, the central point it makes still holds.

The figure shows the "marginal" state that would be exempt at different levels. Setting X at greater than 4% would exempt traffic in and out of over half the ICAO's 191 member states. Even a 2% threshold would exempt Armenia, a European country, but not Ethiopia. A 5% threshold would exempt Hungary, a member of the European Union. It is also clear that, while some of the countries (e.g., Afghanistan) that would be exempt are poor, making exemptions in this way does not exclusively relieve poor countries. For X>0.5%, the average per capita GDP of an exempt state exceeds $8,000 per year. A cumulative threshold of 0.5% would exclude EU countries such as Slovenia and the Slovak Republic. As such, while in theory having a *de minimis* threshold that is agnostic to which state is being exempted is compatible with ICAO's non-discrimination principle (ICAO, 2013b, pp. A38–18, Annex, Paragraph (p)), the structure of the provision as proposed in the Strawman does not appear to achieve its apparently intended results.

4 Discussion

4.1 Comparison with the EU-ETS

The Strawman appears to draw several of its structural elements from the European Union (EU) directive integrating aviation into the EU's Emissions Trading System (ETS). For example, the EU-ETS set aside a reserve for fast growing airlines (also set at 3% of the emissions of a reference year), as well as *de minimis* exemptions for small aircraft and airlines. (The European Parliament and Council, 2008)

The EU mechanism, whose implementation for flights into and out of the EU has been paused pending ICAO's agreement on a global MBM in 2016, but which resumes effect in 2017 if ICAO fails to reach that agreement (European Parliament and Council, 2013), is designed to calculate offset requirements based entirely on growth, with reductions offered to fast growers. That is, it resembles Figure 7(5). This is instructive: the complexity of the Strawman's provisions is easier to understand if it is assumed that the EU-ETS served as a template and, as a consequence, Figure 7(5) was a starting point for its design rather than Figure 7(1). It is possible that the Strawman started with the mechanism represented by Figure 7(5), and sought to make it less harsh on fast growers.[16] At the same time, if further discussions proceed in ICAO on the basis of the Strawman's structural template, several useful features of the EU ETS are not (but perhaps ought to be) included.

First, the EU ETS includes a disincentive for airlines to split off their fast-growing operations as subsidiaries: the EU ETS restricts access to fast-growers' compensation to activities "not in whole or in part a continuation of an aviation activity previously performed by another aircraft operator." (Article 3f of Directive 2008/101/EC of (The European Parliament and Council, 2008)

Second, for the purpose of calculating the exemptions for fast growers, the EU ETS is defines growth in terms of air transport service provided rather than emissions. An operator whose tonne-miles grow by 18% per year would qualify for a reduction even if its emissions grew by only 16%. This output-based metric creates an incentive for even fast growers to reduce emissions as much as possible.

Third, the EU ETS took a more nuanced approach in granting *de minimis* exemptions, saying that the functioning of the directive "should consider the structural dependence on aviation of countries which do not have adequate and comparable alternative modes of transport and which are therefore highly dependent on air transport and in which the tourism sector provides a high contribution to those countries' gross domestic product." Taking such a deliberative approach is clearly easier in the context of a mechanism formulated by one subset of sovereigns, as compared to a structure that must be developed in the context of a multi-lateral forum such as ICAO. Nonetheless, as shown in

[16] Under the EU ETS, an airline would have to meet a much higher bar – an annual growth rate of 18% – to qualify as a fast grower.

Figure 8 and discussed in Section 3, the Strawman's structural approach produces some counter-intuitive outcomes. Possible alternatives are considered in Section 4.2.

4.2 Alternatives

Economists have discussed the merits of introducing a carbon tax on aviation and using the revenues to compensate states that are hardest hit by such a tax, as well as by climate change in general. (AGF, 2010) In the unlikely event that objections from the industry could be overcome,[17] such a mechanism would raise the impossible question of whom the resulting revenues belong to, and how they ought to be spent.

Section 4.1 speculates that the Strawman might have started with the EU-ETS and sought to tweak that mechanism so as to be less burdensome for fast-growing airlines. Policy-makers might wish to consider the sort of mechanism outlined in Figure 7(1), whereby an airline's offset obligations would be calculated as the product of its sectoral emissions share and the growth of the market since the reference year. Assuming that all airlines have access to a large and competitively priced pool of offsets, such an approach could ensure that they all face the same average cost per tonne of emissions reductions. This approach would do away with the gyrations the Strawman goes through to get to a mechanism that is not overly burdensome on new or fast-growing airlines and to ensure that most airlines (including those whose emissions are flat or falling) are brought under the system. As the ongoing discussion demonstrates, the current proposal is complex enough that the text of the Strawman is unequal to the task of describing it precisely and fully. Numerous assumptions are needed to work out what impact it would actually have on airlines (See footnotes 4-7). The mechanism could be made simpler, and therefore less contentious and possibly fairer.

[17] The International Air Transport Association (IATA), which represents the industry in these negotiations, has said (IATA, 2013) that a market-based mechanism "should not be designed or used to raise general revenues," and is likely to remain opposed to a revenue-generating system.

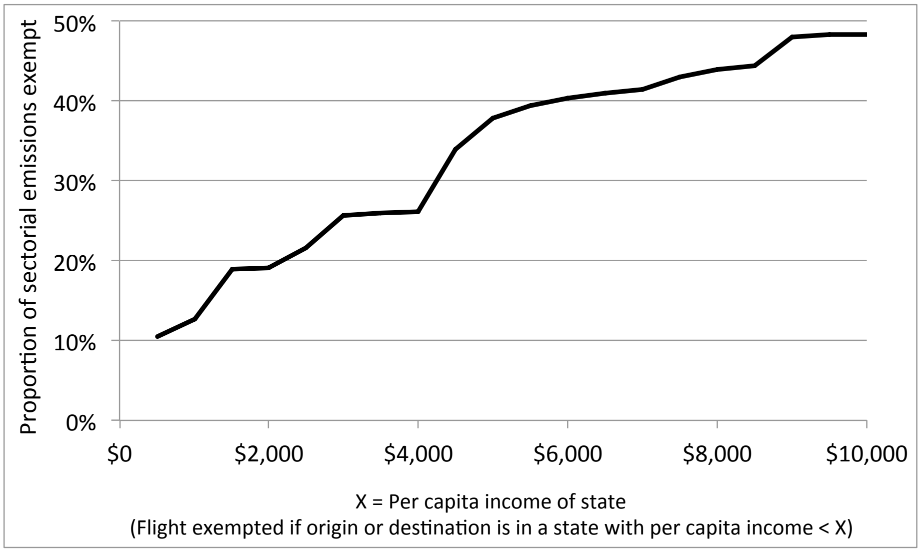

Figure 9: Proportion of emissions from international aviation that would be exempt if flights in and out of countries with different levels of GDP per capita were exempt. The GDP per capita data are from the World Bank's 2013 statistics, or the latest year available. They are in 2013 US$, calculated at market exchange rates.

In principle, the Strawman's provisions could also be improved by targeting the *de minimis* exemption more precisely towards poorer countries. The Strawman's current proposal for *de minimis* exemptions would exclude countries with an average GDP per capita of $8,000 per year for a wide range of exemption thresholds (see Figure 8). If all flights going in and out of countries with an income of less than $8,000 were excluded, that would translate to exempting 44% of global emissions. Note too that many of these countries have high gini coefficients; so while the country may be poor, people flying in and out of it may not be.

One way of targeting the *de minimis* exemption more precisely would be to apply an income threshold below which traffic in and out of a country would become exempt. The advantage of such a system is that, so long as the threshold was held constant in, say, real 2020 US dollars, countries would automatically become ineligible as they grew richer. Over time, the system would cover an increasing proportion of the emissions from international aviation. The impact of this form of *de-minimis* exemption is shown in Figure 9. It is interesting to contrast Figure 9 with Figure 8, which shows that the average income of the countries that are exempt would be around $8,000 per capita per year. Figure 9 shows that if traffic flying in and out of *all* countries with this level of income or lower were made exempt, over 40% of the sector's emissions would be affected. If the threshold for exemption were held at $500 per year per capita, 10% of global emissions would qualify.

An even more refined approach might be to consider not only how poor a country is, but also how well it is served by airlines. This is especially relevant because 2012 data indicate that, of 13,200 routes, nearly 8,900, or well over half, are served by only one airline. If only routes that went either to or from countries with per capita income less than $500 per year *and* that were served by only one airline were exempt, the total size of the exemption would be 2% of total global emissions (see Table 3). This approach makes it possible to target exemptions at individual routes, rather than at entire countries. This might encourage airlines to expand to hitherto underserved routes in poor countries.

However, the approach described above presents at least two practical problems, which may make an agreement formulated on the basis of GDP per capita difficult. First, nations often find it difficult to agree on what GDP numbers to use, and on where to set GDP-based thresholds for exemptions. Second, an approach that uses the number-of-airlines as a proxy for whether a country is well-served, runs the risk that it might also spawn a commercially sub-optimal route-structure. On eligible routes served by two airlines, it might encourage predatory behavior, where one player seeks to drive the other out of the market and thus have its own emissions on that route be made exempt. Indeed, there are almost no examples of binding, GDP-based international rules. (Salsa, n.d.)

Table 3: Income and service-based exemptions. Proportion of sectoral emissions that would be included if routes where either origin or destination were in countries with per capita income less than certain thresholds, and which were served by fewer than a certain number of airlines. Only two routes – Singapore-Jakarta and Hong Kong-Bangkok – are served by 12 airlines; none is served by exactly 11.

If served by X or	Annual per capita income less than									
fewer airlines	$500	$1,000	$1,500	$2,000	$2,500	$3,000	$3,500	$4,000	$4,500	$5,000
X = 1	2%	3%	5%	6%	7%	8%	8%	8%	11%	12%
2	5%	7%	10%	11%	12%	14%	15%	15%	20%	23%
3	7%	9%	14%	14%	16%	19%	19%	19%	26%	29%
4	8%	10%	15%	16%	17%	21%	21%	21%	29%	32%
5	9%	11%	16%	17%	19%	23%	23%	23%	31%	34%
6	9%	12%	18%	18%	20%	24%	24%	25%	32%	36%
7	10%	12%	18%	18%	21%	25%	25%	25%	33%	36%
8	10%	12%	19%	19%	21%	25%	25%	26%	33%	37%
9	10%	13%	19%	19%	21%	25%	26%	26%	34%	37%
10	10%	13%	19%	19%	21%	25%	26%	26%	34%	37%
12	10%	13%	19%	19%	22%	26%	26%	26%	34%	38%

5 Conclusions and recommendations

The Strawman proposes a complex mechanism, which it fails to adequately specify. We recommend that it be replaced with a much simpler mechanism, and we have made suggestions about the contours of such a mechanism in the previous section.

We demonstrate that the proposed approach to *de minimis* exemptions could produce counter-intuitive results, and describe the practical difficulties associated with implementing a more nuanced approach. As such, we recommend that ICAO consider a design that excludes any *de minimis* exemptions.

The current text is also not explicit in saying that emissions by new entrants will be included when calculating sectoral emissions for each year. This is needed to ensure that emissions do, in fact, stay capped at 2020 levels.

Growth, when determining eligibility for the fast growers allowance, should be calculated based on service provided (revenue tonne kilometers) rather than emissions. A revised proposal should make it clear than new entrants and fast growers cannot simply replace activities that were previously performed by another operator.

Finally, the Strawman does not even attempt to address several crucial questions. How much credit should airlines receive for the use of various alternative fuels? How should an airline's fuel burn (and therefore emissions) be calculated: is an airline required to accurately measure and report its fuel use, or will fuel use be estimated by models based on, for example, radar or satellite data on flight paths? Our preference is for the former approach as the latter removes any incentive for airlines to do better than the model. The Strawman would regulate operating entities; that is, airlines. However, the relationship between airlines and the economic entities that own them, whose shareholders would have to pay for offsets, and who might well make strategic decisions that determine the long-term trajectory of the airline's emissions, is extremely complex. The Strawman is also aimed at achieving IATA's short-term goal of carbon-neutral growth by 2020. It does not, however, even hint at how the industry might go about achieving its much more challenging long-term goal of a 50% reduction in net emissions relative to a 2005 baseline by 2050.

These questions are all ripe for further research.

Acknowledgements

This work was supported by the center for Climate and Energy Decision Making (SES-0949710), through a cooperative agreement between the National Science Foundation and Carnegie Mellon University and by Academic Funds through the Department of Engineering and Public Policy from the Carnegie Institute of Technology Dean's Office. The analysis was conducted during an internship at the Environmental Defense Fund (EDF), which was supported by the chief scientist of the EDF.

References

AGF, 2010. Paper on Potential Revenues from International Maritime and Aviation Sector Policy Measures. Secretary-General's High-Level Group on Climate Change Financing.

Airbus, 2014. Global Market Forecast 2014-2033.

Airbus, 2013. Global Market Forecast 2012-2032.

Boeing, 2014a. Current Market Outlook 2014-2033: Long-term forecast [WWW Document]. URL http://www.boeing.com/boeing/commercial/cmo/ (accessed 12.26.14).

Boeing, 2014b. World Air Cargo Forecast 2014-15: Freighter Fleet Development.

Bureau of Transportation Statistics, 2014. Air Carriers : T-100 International Segment (All Carriers). United States Department of Transportation, 2014.

cargolux, 2014. cargolux Annual Report 2013.

DHL, 2013. Corporate Responsibility Report 2012.

Donatelli, D.J., Belobaba, P., 2014. Evolution of US Air Cargo Productivity.

European Parliament and Council, 2013. Decision No 377/2013/EU of the European Parliament and of the Council of 24 April 2013 derogating temporarily from Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community.

FedEx, 2012. Environment & Efficiency Metrics: Aircraft Emissions.

IATA, 2014. Scheduled Passengers Carried.

IATA, 2013. Resolution on the Implementation of the Aviation "CNG2020" Strategy.

ICAO, 2014a. Statement by the International Civil Aviation Organization (ICAO), to the Fortieth Session of the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA40).

ICAO, 2014b. Emissions from fuel used for international aviation (No. FCCC/SBST A/2014/MISC.9). Subsidiary Body for Scientific and Technological Advice, Lima, Peru.

ICAO, 2013a. Report of the Executive Committee on Agenda Item 17.

ICAO, 2013b. Assembly Resolutions in Force (as of 4 October 2013).

ICAO, 2010. Assembly Resolutions in Force (as of 8 October 2010) (No. 9958).

Jiang, H., 2013. Key Findings on Airplane Economic Life.

Kling, J.A., Smith, K.A., 1995. Identifying Strategic Groups in the U.S. Airline Industry: An Application of the Porter Model. Transp. J. 35, 26–34.

Lee, J., Mo, J., 2011. Analysis of Technological Innovation and Environmental Performance Improvement in Aviation Sector. Int. J. Environ. Res. Public. Health 8, 3777–3795. doi:10.3390/ijerph8093777

Müllner, D., 2013. Fast hierarchical clustering routines for R and Python.

Robles, F., Sarathy, R., 1986. Segmenting the commuter aircraft market with cluster analysis. Ind. Mark. Manag. 15, 1–12. doi:10.1016/0019-8501(86)90039-8

Salsa, R., n.d. GDP-based Targets in International Organisations.

Southgate, D., 2013. Aviation Carbon Footprint Global Scheduled International Passenger Flights - 2012.

Southgate, D., n.d. About. Transp. Carbon Footpr. Air EV.

The European Parliament and Council, 2008. Directive 2008/101/EC of the European Parliament.

Formatted: Bibliography, Widow/Orphan control, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Field Code Changed

Deleted: AGF, 2010. Paper on Potential Revenues from International Maritime and Aviation Sector Policy Measures. Secretary-General's High-Level Group on Climate Change Financing. ... [1]

Page 29: [1] Deleted	Parth Vaishnav	1/15/16 5:17 PM

AGF, 2010. Paper on Potential Revenues from International Maritime and Aviation Sector Policy Measures. Secretary-General's High-Level Group on Climate Change Financing.

Airbus, 2014. Global Market Forecast 2014-2033.

Airbus, 2013. Global Market Forecast 2012-2032.

Boeing, 2014a. Current Market Outlook 2014-2033: Long-term forecast [WWW Document]. URL http://www.boeing.com/boeing/commercial/cmo/ (accessed 12.26.14).

Boeing, 2014b. World Air Cargo Forecast 2014-15: Freighter Fleet Development.

Bureau of Transportation Statistics, 2014. Air Carriers : T-100 International Segment (All Carriers). United States Department of Transportation, 2014.

cargolux, 2014. cargolux Annual Report 2013.

DHL, 2013. Corporate Responsibility Report 2012.

Donatelli, D.J., Belobaba, P., 2014. Evolution of US Air Cargo Productivity.

European Parliament and Council, 2013. Decision No 377/2013/EU of the European Parliament and of the Council of 24 April 2013 derogating temporarily from Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community.

FedEx, 2012. Environment & Efficiency Metrics: Aircraft Emissions.

IATA, 2014. Scheduled Passengers Carried.

IATA, 2013. Resolution on the Implementation of the Aviation "CNG2020" Strategy.

ICAO, 2014a. Statement by the International Civil Aviation Organization (ICAO), to the Fortieth Session of the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA40).

ICAO, 2014b. Emissions from fuel used for international aviation (No. FCCC/SBST A/2014/MISC.9). Subsidiary Body for Scientific and Technological Advice, Lima, Peru.

ICAO, 2013a. Report of the Executive Committee on Agenda Item 17.

ICAO, 2013b. Assembly Resolutions in Force (as of 4 October 2013).

ICAO, 2010. Assembly Resolutions in Force (as of 8 October 2010) (No. 9958).

Kling, J.A., Smith, K.A., 1995. Identifying Strategic Groups in the U.S. Airline Industry: An Application of the Porter Model. Transp. J. 35, 26–34.

Müllner, D., 2013. Fast hierarchical clustering routines for R and Python.

Robles, F., Sarathy, R., 1986. Segmenting the commuter aircraft market with cluster analysis. Ind. Mark. Manag. 15, 1–12. doi:10.1016/0019-8501(86)90039-8

Salsa, R., n.d. GDP-based Targets in International Organisations.

Southgate, D., 2013. Aviation Carbon Footprint Global Scheduled International Passenger Flights - 2012.

Southgate, D., n.d. About. Transp. Carbon Footpr. Air EV.

The European Parliament and Council, 2008. Directive 2008/101/EC of the European Parliament.