Policy Research Working Paper 6471

Calculating the Carbon Footprint from Different Classes of Air Travel

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May 2013

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Abstract

This paper develops a new methodology for calculating the "carbon footprint" of air travel whereby emissions from travel in premium (business and first) classes depend heavily on the average class-specific occupied floor space. Unlike methods currently used for the purpose, the approach properly accounts for the fact that the relative number of passenger seats in economy and premium classes is endogenous in the longer term, so adding one additional premium trip crowds out more than one economy trip on any particular flight. It also shows how these differences in carbon attributable to different classes of travel in a carbon footprint calculation correspond to how carbon surcharges on different classes of travel would differ if carbon emissions from international aviation were taxed given a competitive aviation sector globally. The paper shows how this approach affects carbon footprint calculations by applying it to World Bank staff travel for calendar year 2009.

This paper is a product of the Environment and Energy Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at jstrand1@worldbank.org.

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Key words: Carbon footprints; carbon taxes; airline fuel consumption; class-specific seating arrangements

JEL codes: H23; L93; Q41; Q54

Sector Board: Environment

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1. Introduction

Measuring and managing the "greenhouse gas (GHG) footprint" (or in the following, "carbon footprint") of air travel involving individual passengers poses challenges at several levels. A major policy challenge arises in the international arena, since emissions from international travel for the most part do not physically take place in any one given country. While various allocation methods to national emissions volumes could in principle be employed, all are in the end ad hoc.[2] Another, related, policy issue is the very mobility of the aviation sector. Any attempt by a particular country to tax fuel used in international aviation which is not matched by similar taxes or charges in other countries could face problems, inducing tax avoidance as airlines may seek to tank up in lower-tax jurisdictions. In practice, moreover, international treaties constrain countries in applying carbon prices or physical emissions quotas to international aviation, though the need for changing this restriction has been the subject of some debate.[3]

Problems of measuring the carbon footprint of aviation arise from several factors, among which we here focus on two.[4] The first is the multiplicity of GHGs resulting from airplane emissions, and the difficulty of actually computing the global warming (or "climate forcing") potential of GHG emissions in the upper troposphere and lower stratosphere (at altitudes of about 9-12 kms, relevant for most sub-sonic air transport). These factors include high-level water vapor release, and catalytic interactions with other GHGs such as ozone and methane. This has resulted in great uncertainty, and controversy, over the total climate forcing effect of aviation activity, which is not yet resolved. A seminal report by the IPCC (1999) raised the issue; for more recent scientific work see Jardine (2005), Kollmuss and Crimmins (2009), Kollmuss and Lane (2009), Lee (2009), Peeters and Williams (2009), and Lee et al (2009). Further discussion is found in Keen and Strand (2007). A widely accepted "radiative forcing index" (RFI; by which regular carbon emissions must be multiplied to arrive at a correct "climate imprint") is 2.7, but with a high range of uncertainty.[5] Several factors are at work, some of which imply positive and others

[2] For example, the emissions could be associated with the nationality of the air carrier, or the nationality of the traveler. Other options could be, for an international flight from country A to country B, to ascribe the entire resulting emissions either to country A or to country B; or perhaps better, ascribe half of the emissions to country A, and half to country B. The first of these alternatives would not, in today's climate policy situation, effectively account for travelers from non-Annex B countries, or air carriers headquartered there. Under the second set of options, a similar problem would arise with flight departure sites and/or destinations being in non-Annex B countries.

[3] For further discussion see Keen and Strand (2007); and Keen, Parry and Strand (2012).

[4] The notion of carbon footprint is here taken to comprise the overall climate impact, or footprint, of aviation, due to increased net emissions also for several other climate gases including nitrogen oxides, ozone, methane, and water vapor; as well as non-conventional effects of carbon emissions such as those accruing specifically with aviation, at high altitudes. See IPCC (1999) for a more detailed discussion of relevant climate gases and their expected impacts.

[5] In particular, Jardine (2005) cites a radiative forcing index (RFI), relative to that of CO_2 alone, of 2-4 as "reasonable", but settles on a (conservative) consensus factor of 1.9. World Bank (2010, p 17) states: "Both the WRI and the EPA are reviewing this issue and may decide to integrate RFI into air travel emissions calculations. If international consensus is reached on the appropriate application of RFI, the WBG will revisit this issue." Note however that caution must be shown in embedding an RFI in such calculations. No technically complete, formal, analysis seems to yet exist in the literature dealing with the issue. It is, in particular, conceivable that the true RFI is

negative climate forcing effects of aircraft emissions. See Box 1 below for an overview. The scientific calculation of net radiative forcing is quite complex and no consensus exists on the overall net effect. One problem is that while the climate effect of carbon is moderate but very long-lasting, several other effects (in Box 1) are much more potent but shorter-lasting.

Box 1: Principal factors Behind (Positive or Negative) Radiative Climate Forcing (RF) Effects of Aircraft Emissions

Emissions of CO_2, resulting in direct positive RF.

Emissions of NO_x result in the formation of tropospheric O_3, with positive RF.

Emissions of NO_x result in the destruction of ambient CH_4 via atmospheric chemistry, with negative RF.

Emissions of sulphate particles arising from sulphur in the fuel result in direct negative RF.

Emissions of soot particles result in direct positive RF.

Emissions of water vapour may cause a small direct positive RF.

Persistent linear contrails may form, resulting on net in positive RF.

Formation of cirrus clouds from spreading contrails result in a net positive RF.

Particles emitted from aircraft engines may act as cloud condensation nuclei and seed cirrus cloud formation, affecting magnitude of ice particles, and the albedo and emissivity of cirrus clouds. The net RF effect is uncertain.

Source: Lee (2009).

The other main uncertainty lies in calculating the actual average GHG emissions per traveled distance – which is key to measuring the footprint of a specific air travel profile. This depends on a wide set of parameters which include a) class of travel (since business and first class seats displaces proportionately more economy seats for the same total aircraft space capacity), b) load factors (the degrees of capacity utilization of given aircraft and flights; which differ by class), c) weight factors (as aircraft fuel consumption ultimately depends on aircraft weight), and d) other flight-specific factors (such as flight length and average altitude). Current standard methods for calculating air travel footprints do not reflect the larger footprint attributable to premium travel (through different load factors and weight factors).

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very close to unity due to all other significant forcing factors being much more short-lived. The forcing factor could also, in fact, in principle be less than unity (so that some of the basic carbon effect is in fact eliminated at high altitude).

We illustrate our approach by applying it to World Bank staff travel for missions by HQ and Country Office staff, in Calendar Year 2009 (CY-09), and again in Fiscal Year 2012 (FY-12). The carbon footprint of air travel is more than half of the organization's total carbon footprint. Moreover, a large share of WBG staff air travel (close to 70%) is on premium classes, which affects the calculations for reasons noted in the previous paragraph.[6] To conclude the paper, we comment briefly on some analytical and conceptual issues that can be raised concerning corporate responsibility in correcting global and local externalities. The international literature on this topic is still small, however, and its findings are ambiguous.[7]

2. Sources of Bias in Calculating Organizational Carbon Footprints from Air Travel Using Current Methodologies

The typical methodology applied (based on standard accepted GHG accounting, e g Bhatia et al (2004); see also World Bank (2010)) is to calculate an average consumption of jet fuel per passenger mile traveled by air, and multiply this figure by the number of passenger miles traveled on missions by an organization's staff in a given year.[8] The climate-related footprint of burnt jet fuel is taken to be simply the carbon released when this fuel is consumed.

Four main issues arise:

1) The carbon footprint of air travel tends to vary systematically and strongly between travel classes (economy, business and first class; perhaps also according to other class categories when these can be specified). An analytical model, presented in section 3 below, will serve as a backdrop for understanding this relationship. We will subsequently present data which, when applying our model, indicate that the average carbon footprint is much higher for business class travel than for economy class travel; and even higher for first class travel. The main reason why the footprint per traveler per distance travelled is greater for business/first class than for economy class, is that a seat in the two former classes takes up a larger than average floor space in a given airplane. This difference can be enhanced by differences in "load factors" (the rate at which available seats are actually occupied on a given flight), which also tend to be lower on average in business class than in economy class, and even lower in first class. The compounding effect of these two factors (the greater floor space per seat and the fewer among available seats that are filled) is that the average number of passengers transported per unit of floor space is far smaller for a plane's business and first class sections. The second main factor is that fuel consumption of commercial airplanes depends only to a small degree on the number of

[6] This is similar to other comparable institutions such as the UN, the IADB and the ADB; but lower than for the IMF where the premium-class share is close to 100%.
[7] See Heal (2005), Brekke and Nyborg (2008), Margolis, Elfenbein and Walsh (2009), and Benabou and Tirole (2010).
[8] See World Bank (2009). A simplified procedure has recently been used where trips are classified into three groups, "short", "medium" and "long", each with a standard length in kilometers. No adjustment is currently made for travel class.

passengers carried on any given flight; passenger weight including luggage comprises in most cases only between 1/5 and 1/8 of total aircraft weight. To the extent that passenger-related weight is important, this weight is also likely higher in premium classes as seats in these classes are far heavier than economy-class seats. In consequence, we demonstrate, using our analytical model developed in Section 3 below, that the carbon footprint ascribed to a business/first class passenger ought to be greater than for an economy class passenger.

2) For organizations whose travel mix differs significantly from the industry average, differences in footprint across travel classes matter for calculating the overall footprint.[9] For air travel involving institutions where the average mix of economy-class and business-class travel is involved is close to the global average for all civil air passenger transport, the differences in footprint according to travel class are not crucial for calculating the institution's overall carbon footprint. For the staff of the WBG, on the other hand, the share of overall air travel in business or first class is much higher than the global average.

3) The footprint per mile for mission air travel is likely to vary systematically also with other flight-specific factors such as average flight length, types of airplanes used, etc. A more precisely calculated footprint related to a given flight activity (involving particular air routes, airlines and equipment) may raise the need for such more specific effects to be calculated separately. WBG mission travel consists predominantly of longer-haul flights. There are also significant differences in per-passenger fuel consumption between plane types and models (for given load factors; where the load factor expresses the percent of available seats that are filled on any given flight).[10] Institutions such as the WBG concentrate their activity to particular airlines that rely on particular plane types and model (and thus not a random selection from the global vehicle fleet), where also average load factors may differ from overall global averages. A more accurate calculation of each institution's footprint then requires that these numbers be calculated separately, for the actual air travel by the institution in a given year.

4) As we have already stressed, the climate forcing effect of emissions from airplanes is likely to differ from that resulting from ground-released carbon emissions due to the altitude at which they are released and to the fact that several types of emissions in addition to carbon are involved. Including such factors is still not standard in carbon footprint accounting, and the factor is at the moment very uncertain. We do not further pursue this issue in this paper, however.

[9] Keen and Strand (2007), table 12, presents data on global averages by travel class in 2004, the last year for which we have good data.

[10] The differences in fuel consumption by plane type and vintage can be substantial, and vary by a factor of 3 or more.

The first two factors are significant and are together likely to increase the calculated footprint relative to currently accepted calculation principles. The fourth factor is likely to further add to such an increase. The third factor, while less significant, could affect relative footprints between different flight lengths and aircraft types given that these distributions vary substantially (across institutions and individuals within institutions). Our calculations reflect some of these concerns, by in particular building on results about the relationship between average aircraft fuel consumption and flight distance, which has a non-linear (u-formed) shape; see Appendix 3.

3. Simple Analytical Model Justifying Differential, Class-Specific, Passenger Carbon Footprints from Air Travel

We will in this section discuss more carefully the relationships between passengers in different travel classes, and their average "carbon footprints". To that end we study a simple analytical model, where two factors are argued to be relevant in calculating such footprints: First, the class-specific seating arrangements which (together with average class-specific load factors) will determine the average space taken up by passengers in the aircraft by class. Secondly, passenger weight (including luggage). We consider a very simple long-run partial equilibrium model of the global aviation market where travelers choose between two travel classes, "economy" (class e) and "business" (class b), and where each business seat takes up $s > 1$ times as much space in the aircraft as an economy seat (assuming identical aircraft). For the sake of simplifying the argument, we assume in this section that all flights are always full.[11] Airlines can and do choose how many economy and business seats to put into any given aircraft; and they also choose the spacing arrangements (although we here, for the sake of simplicity, take the relative spacing parameter s as given). We also assume, for the sake of the current argument, that all passengers have the same weight, and that aircraft fuel consumption depends on total weight of the aircraft but where passengers only constitute a (rather small) fraction, $\alpha < 1$), of total weight.

Define the floor space available to passengers in any given aircraft as constant and denoted by F, and define F_i as space allocated to passengers in class i (= e, b). N is the total number of passengers per flight, where N_i denotes passengers flying in class i. We normalize by setting the amount of floor space for an economy-class passenger at unity. Then the amount of floor space allocated to a business-class passenger equals $s > 1$.

We have the accounting relation:

$$N_e + sN_b = F_e + F_b = F \ . \tag{1}$$

[11] Systematic differences in load factors between travel classes can however easily be accommodated in the model, by simply adjusting the s parameter accordingly.

Thus in particular:

(2) $$N_b = \frac{F - N_e}{s}.$$

Assume that fuel consumption of an aircraft (per unit of flying time which is considered fixed) equals

(3) $$W = W_0 + N,$$

where W_0 is a constant, $N = N_e + N_b$ is the total number of passengers per flight, and where weight is scaled such that an average passenger (including normal luggage) has a unit weight. We will assume that N is a relatively small fraction α of W; indicating that total aircraft weight is determined mostly by other components such as the body of the aircraft and its carried fuel.[12]

Consider now a competitive equilibrium with identical, competitive airlines that offer an endogenous number of economy and business-class seats in their aircraft. The profit per flight unit is given by

(4) $$\Pi = p_e N_e + p_b N_b - C - (q+t)[W_0 + a(N_e + N_b)].$$

In (4), p_i is the ticket price for passenger type i (=e, b). The two first terms thus represent airline revenue and the last two terms represent costs, all per flight unit. C is a fixed non-fuel cost per flight (so that "other fixed costs" per flight are independent of the number of passengers).[13] *q* is a basic fuel price, while *t* is a unit tax or charge on fuel (presumably, to correct for the carbon footprint of the flight). For airlines with any given number of aircraft, the principal resource constraint is floor space for passenger seats in their aircraft. Thus profits are maximized taking this constraint into consideration. This leads to the following Lagrange problem:

(5) $$L = p_e N_e + p_b N_b - C - (q+t)[W_0 + (N_e + N_b)] + \lambda(F - N_e - sN_b),$$

recognizing that each business-class passenger occupies s > 1 units of floor space in the aircraft, while each economy-class passenger only occupies one unit. Maximizing (5) with respect to N_e and N_b yields

(6) $$\frac{\partial L}{\partial N_e} = p_e - (q+t) - \lambda = 0$$

[12] In practice seat weight is also related to passengers and should thus be included in this calculation. However, seat weight varies much more by travel class than passenger weight does. Thus, including a separate calculation of seat weight is not going to fundamentally modify our calculations, as seat weight is much more in proportion to overall class-determined carbon footprints, than passenger weight is.

[13] This implies an assumption that operation costs per floor space unit is constant, so that a business-class passenger costs exactly s times as much to service on a given flight, as an economy class passenger.

(7) $$\frac{\partial L}{\partial N_b} = p_b - (q+t) - s\lambda = 0\,.$$

We find the following relationship between the two ticket prices, p_e and p_b:

(8) $$p_b = sp_e - (s-1)(q+t)\,.$$

We now introduce a measure of passenger weight as fraction of total aircraft weight; this is an important measure in determining how the carbon footprint of passengers depends on passenger weight. When not correcting for this factor, there will be a certain relative over-allocation of carbon emissions units to business-class passengers, and under-allocation to coach-class passengers. In (3), assume that we have approximately

(9) $$W_0 \approx (1-\alpha)W; W_p \equiv N_e + N_b \approx \alpha W\ ,$$

where α and 1-α are total aircraft passenger and non-passenger weight shares, and where we now take both W and α as fixed. This can hold only approximately as the total number of passengers, N, is to some degree variable as it depends on the passenger shares in economy and business classes), but is a good approximation as long as the weight share of passengers is low, and the fractions of economy- and business-class passengers not relatively stable. The overall passenger weight share in total aircraft weight, while depending in aircraft type and whether or not fuel tanks are filled up, is relatively small in most cases (e g around 12% for a fully-fueled Boeing 747).[14]

We now consider long-run industry equilibrium in the aviation sector, given zero profits and endogenous seating arrangements by travel class, and where overall passenger capacity of airlines is endogenous. In the long run, competitive airlines will add capacity as long as profits per flight are positive, and reduce capacity when profits per flight are negative; and will do so for each of the two travel classes. In a long-run steady state, profits are zero, in total and related to passengers on each of the two travel classes. We represent this by setting Π = 0 in (4), and let this relationship, together with (2), (6) and (7), determine the endogenous variables p_e, p_b, λ, and one relationship between N_e and N_b.[15]

Consider now, in (4), total aircraft weight W as (approximately) constant (and independent of the passenger number), and insert from (8) (with Π = 0) into (4), to yield

(10) $$p_e N_e + [sp_e - (s-1)(q+t)]N_b = C + (q+t)W\ .$$

[14] For a fully-tanked Boeing 747, fuel constitutes about half of total aircraft weight. Passenger weight is a larger share of aircraft weight, closer to 20%, with “close to empty” fuel tanks. See Wickpedia (2011).

[15] Note that the levels of N_1 and N_2 are not determined by our model set-up. The reason is that these are given by the relative demand for economy-class and business-class aviation services. No such demand relations are specified here; our model is valid for any such relative demands.

Under our assumptions, (10) can be viewed as one relation in one endogenous variable, namely p_e. Using $N_e = \beta N$, and $N_b = (1-\beta)N$, and set c = C/N, w = W/N, where c and w are interpreted as non-fuel costs per passenger, and total aircraft weight per passenger. We then find the solutions for p_e and p_b, from (10) and (8), as[16]

(11) $$p_e = \frac{c+[w+(1-\beta)(s-1)](q+t)}{\beta+(1-\beta)s}$$

(12) $$p_b = \frac{sc+[sw-\beta(s-1)](q+t)}{\beta+(1-\beta)s}.$$

We may now also consider the impact of changes in (climate-related) aviation fuel charges on class-related ticket prices. We find readily from (11)-(12):

(11) $$\frac{dp_e}{dt} = \frac{w+(1-\beta)(s-1)}{\beta+(1-\beta)s}$$

(12) $$\frac{dp_b}{dt} = \frac{sw-\beta(s-1)}{\beta+(1-\beta)s}.$$

When total unit aircraft weight, w, is very high as compared to unit passenger weight, we find that the ratio of the second to the first of these derivatives equals s in the limit; otherwise the ratio is smaller.

Table 3.1: Individual economy-class and business-class footprints as compared to average passenger footprints, and their ratios

Value of s	Economy class footprint		Business class footprint		Ratio business/economy	
	α = 1/5	α = 1/8	α = 1/5	α = 1/8	α = 1/5	α = 1/8
s = 2	0.93	0.92	1.65	1.72	1.78	1.86
s = 3	0.87	0.85	2.20	2.31	2.53	2.71

To get a feel for a "normal" size of this ratio (call it r) for limited values of w, consider four numerical examples presented in Table 3.1: namely s=2, and s=3 (business-class passengers occupy 2 or 3 times the space of economy-class passengers on average); and w=8, and w=5 (passenger weight constitutes either 1/8, or 1/5, of total aircraft weight).[17] In the case of w=8, r = 1.86 for s=2, and r = 2.71 for s=3. In the case of w=5, we find r = 1.78 for s=2, and r = 2.53 for s=3. The numbers in the first four columns here indicate the absolute footprints of passengers on each of the classes, in relation to the average footprint per passenger on a given flight. The

[16] Note that the scaling of absolute ticket prices here depends on the weight parameter α, so that ticket prices are higher when this parameter is smaller. (11)-(12) are however for us useful mainly for computing the relative values of these prices, not absolute prices; and relative footprints as e g computed in Table 3.1.

[17] The latter examples correspond, roughly, to a Boeing 747 flight with load factors 0.8, and where the aircraft fuel tanks are filled up, and empty, respectively.

numbers in the last two columns indicate the ratios of the respective business- to economy-class footprints.

These "relative footprint" values are somewhat lower than their respective s values (as result of the weighting of the space and weight factors related to individual travelers, with relatively more weight to the former factor), but not dramatically lower. Another finding is that the footprint of economy-class passengers needs to be lower, and for business-class passengers higher, than the overall average footprint per traveler. This is also seen from the table; albeit the reduction (below unity) is small for economy-class (since this class constitutes a very large fraction of overall air travel in terms of traveled distance).

Our argument that weight-related arguments should make average footprint numbers less variable across travel classes, depends on passenger weight (including all weight factors that depend on individual passengers such as their luggage, and their seat) being independent of travel class on average. This is likely not the case. First, seats are heavier in premium classes, more so in first class than in business class. Secondly, passengers in premium classes are allowed to carry more luggage and may thus do so (although we do not have data for the average weight of passenger luggage by class). Thus, most likely, the impact of this factor will in practice be smaller than the numbers reflected in our calculations in this chapter. Put otherwise, the correct relative footprint numbers are closer to being proportional to space allocation, than those shown in Table 3.1.

4. Calculations of Relative Space Requirements by Travel Class

4.1 Step 1: Relative Seat Configurations

We will now go to the more practical footprint calculations, in part with basis in data for WBG travel in Calendar Year 2009 (CY-09). In calculating the carbon footprint from a given amount of air travel one first needs to find the class-specific per-passenger footprint. As noted, seat configurations in airplanes differ between travel classes, with premium-class seats occupying a larger space in a given plane than seats in coach class. Fewer passengers can then fit into a given space in first and business classes than in economy class. It is also crucial to recognize that these seat configurations are endogenous: they are chosen by airlines to maximize profits, and such a procedure implies that more space is generally is given in any aircraft to premium-class passengers. Seats could be spaced differently; as increased premium class passengers are accommodated, coach-class passengers are crowded out more than one-to-one. In addition, load factors are generally lower on first and business classes than on economy class.

The model in section 3 showed that when space and not weight considerations for passengers is the main constraining variable for airlines (so that passenger weight plays a very small role), the correct class-specific carbon footprint is (close to) proportional to the average space taken up by passengers traveling on different classes. When by contrast weight considerations play a larger role, this indicates a more equal footprint across travel classes. Systematic differences in footprints by travel class are today being recognized but treated imprecisely. For example, the standard “ICAO calculator” uses a 2.0 multiplier for passengers in any service class above coach class.[18]

Table 4.1 gives numbers for the average space in aircraft taken up by seats in alternative travel classes, separating between single-aisle and wide-body aircraft. We here find significant and systematic differences in seat size by class and aircraft size. The difference in floor space occupied by premium versus coach seats is much greater for wide-body than for single-aisle aircraft. Wide-body planes are used predominantly for long-haul flights where extra space in premium classes has a higher value for passengers (and greater potential for profit extraction through higher fares), compared to shorter-haul flights.

When comparing business-class to coach-class seating, the standard ICAO 2.0 factor appears as reasonably accurate (our average ratios are 1.89 for single-aisle aircraft, and 2.28 for wide-body planes), given no additional adjustments for differential load factors nor for the weight factor in calculating the footprints, as seen from Table 4.1. The standard factor is more off with respect to first class flights, where the average single-aisle space ratio (relative to coach class) is 2.92, and the average wide-body ratio is 4.53.

Table 4.1: Average Ratio of Space Taken Up by Non-Coach Seats Relative to Coach Seats

Class Type	**Widebody**	**Single Aisle**
Economy Plus	1.24 (max 1.75)	1.11 (max 1.25)
Business	2.28 (max 4.0)	1.89 (max 2.0)
First	4.53 (max 7.0)	2.92 (max 3.3)

Source: Authors’ calculations

Ignoring in the following the distinction between economy and “economy plus” (or “economy extra”) classes, we calculate, in Table 4.2, the fractions of floor space taken up by the respective classes, in wide-body and single-aisle aircraft. Interestingly, for wide-body aircraft the share of passenger floor space taken up by premium classes is about 30 percent; while the share of passengers traveling in premium classes does not much exceed 10 percent.

[18] ICAO Carbon Emissions Calculator, Version 3.0, page 9.

Table 4.2: Average Fractions of Passenger Floor Space taken up by Different Passenger Class Seats, Wide-Body and Single-Aisle Aircraft

Class Type	Widebody	Single Aisle
Economy	0.705	0.756
Business	0.185	0.165
First	0.110	0.078

Source: Authors' calculations

These figures also have implications for the relative floor space taken up by each economy, business and first class passenger seat, as fractions of the average floor space per seat taken up by all passenger seats, for the two main types of aircraft. These numbers are given in Table 4.3 below.

Table 4.3: Average Floor Space Taken up by Each Passenger Seat in Different Classes, Relative to the Average for all Seats, Wide-Body and Single-Aisle Aircraft

Class Type	Widebody	Single Aisle
Economy	0.81	0.87
Business	1.85	1.64
First	3.67	2.54

Source: Authors' calculations

4.2 Step 2: Load Factors by Travel Class

In step 2 of our carbon footprint calculations we expand our calculations by differentiating load factors by route groups, and to reflect passenger aircraft capacity reserved for cargo. Table 4.4 shows average load factors for 2008 for the 17 route groups defined by the ICAO (see Appendix 2 below). We see that load factors vary widely, but they vary less and are generally higher for more traveled routes. The globally average load factor for flights involving WBG travel was about 71 percent in 2008, the year of the ICAO study.[19]

Reliable numbers seem today not to be publicly available for load factors differentiated by travel class, neither industry-wide nor by airline. It is however widely recognized and assumed that

[19] Note that the (unconditional) average load factor for all flights globally in 2008 was slightly higher, near 75 percent.

average load factors for premium classes are lower than for coach class. For business class, a "likely" figure is in the range 0.5-0.6, and for first class perhaps even lower, 0.3-0.4. Since we here do not have definite data on these, we apply alternative assumptions about average load factors by travel class, in the third calculation phase. These calculations confirm that, in particular, business and first class load factors are likely to have a very significant overall impact on footprints due to air travel by WBG staff, given the high share of travel on these classes.

Table 4.4 provides approximate numbers for average load factors by travel route, across all travel classes. We see that these vary, from a low of about 40% to a high of more than 80%. These data however do not tell us the class-specific load factors, for which we have no direct data and which for us are more important.

Table 4.4: Average Load Factors and Passenger Shares by Route Groups and Main Aircraft Type, 2008

Geographical description	Load Factor Widebody	Load Factor Single Aisle	Passenger versus freight share, Widebody*	Passenger versus freight share, Single Aisle*
North America - Central America and Caribbean	77.7	77.0	93.3	99.0
Central America – Caribbean	54.2	59.6	91.1	92.9
Bermuda - Canada, Mexico, US	66.1	72.8	60.1	98.7
North America - Central America - Caribbean - South America	78.6	72.4	80.8	96.0
Local South America	73.1	60.7	76.9	95.2
Local Europe	59.8	73.4	88.3	99.0
Local Middle East	49.2	70.3	83.9	97.8
Local Africa	40.0	63.7	85.9	96.1
Europe - Middle East	67.1	70.4	78.7	97.7
Europe - Middle East – Africa	71.3	66.2	81.1	97.7
North Atlantic	78.7	78.9	82.1	98.4
Mid Atlantic	82.1	82.1	86.5	86.5

South Atlantic	**80.0**	**80.0**	**83.1**	**83.1**
Local Asia	**67.9**	**63.4**	**81.1**	**95.3**
Europe - Middle East - Africa – Asia	**73.6**	**54.2**	**79.5**	**96.9**
North & Mid Pacific	**78.6**	**78.6**	**84.0**	**84.0**
South Pacific	**78.7**	**60.4**	**84.8**	**94.4**

Source: August 2010 documentation of the ICAO Carbon Emissions Calculator, valid for Calendar Year 2008.

*Calculated passenger share of overall aircraft fuel consumption (the rest being the freight share).

Assuming an industry-wide average load factor of 71% for 2008, we can consider impacts of alternative assumptions about the combinations of load factors by class, as is done for the calculations in Table 4.5. We there for each travel class indicate the “average footprint” factors for each of three average load factor assumptions: 0.3 (“very low”), 0.6 (“normal”), and 0.9 (“very high”). We consider the same average class-specific load factors for wide-body and single-aisle aircraft.

The figures in Table 4.5 are notable in particular for first-class travel where the footprint (not corrected for passenger weight) could reach a multiple of 8.96 relative to the average (for wide-body aircraft), far higher than for the other classes; although this number is likely an over-estimate, since the corresponding average load factor of 0.3 for first class is likely an under-estimate. Note however that previous estimates, and our knowledge of the aviation industry, imply that load factors are lower in premium classes (and lower in first than in business class).

Table 4.5: Average Footprints by Travel Class, Relative to Averages Across Classes, As Functions of Load Factors

		Widebody			Single Aisle		
	Load Factor	**.3**	**.6**	**.9**	**3.**	**.6**	**.9**
Class Type	Economy	1.92	0.96	0.64	2.06	1.03	0.69
	Business	4.38	2.19	1.46	3.88	1.94	1.29
	First	8.96	4.34	2.90	6.01	3.01	2.00

Source: Authors' calculations

For business class, the average footprints in Table 4.5 are close to the multiple of 2 currently applied with the ICAO calculator for premium classes, given an average load factor of 0.6 for this class, which is reasonable from past experience. The ICAO calculator today makes no downward adjustment (relative to the "average footprint") for economy class (represented here by these factors being less than unity). The relative factor ratios for business to economy class are thus somewhat greater here (3.04 and 2.51 respectively, instead of 2 as in the ICAO calculator).

Table 4.6: Footprints by Travel Class, Relative to the Footprint of an Average Passenger, assuming Load Factors of 0.40 for First Class, 0.60 for Business Class, and 0.80 for Economy Class

Class Type	Wide-Body	Single-Aisle
Economy	0.76	0.82
Business	2.30	2.07
First	6.89	4.79

Source: Authors' calculations

The average footprints for business and first class travel, relative to economy class travel, can easily be greater than the numbers in Table 4.5. Table 4.6 provides what we view as a plausible example, using the overall load factor estimate of 0.71, and with load factors of 0.4 for first, 0.6 for business and 0.8 for economy class[20]. The ratios of numbers from table 4.6 for wide-body aircraft, for example, show the footprint from business class passengers being 3.04 times that of

[20] These are still hypothetical. The example is however consistent since when an aircraft's relative cabin sizes correspond to industry averages, the overall average load factor is 0.71 given the assumed class-specific factors.

economy passengers; the ratio for first class to economy class is 9.28. Note however that, as for previous calculations, these numbers are not corrected for passenger weight in calculating the footprint. Making such corrections would tend to draw relative footprints somewhat closer together; see Table 3.1 above.

When making average carbon footprint calculations, flight distribution by flight length and aircraft type also matter. Fuel efficiency differs between aircraft, and has generally improved over time so that newer aircraft tend to have higher mileage than older ones.[21]

Our calculations also reflect systematic relationships between average flight distance and average fuel consumption per mile flown for given equipment and passenger number. When combined with differences in equipment used we show, in Figures A3.3 and A3.5 in Appendix 3, that fuel consumption tends to be a U-shaped function of average flight distance: Fuel consumption is very high for very short flights; reaches a bottom for medium-length flights (in the range 1000-1500 nm); and with a gradual rise in fuel consumption for longer flights. The reason for such a relationship is that, for very short flights, high fuel consumption during take-off, and the greater proportion of the entire trip flown at low altitudes (when per-mile fuel consumption is much higher), pulls the average up. For flights longer than about 1500 nm, a factor increasing fuel consumption per distance traveled is the burden of a gradually larger stock of fuel necessary to be carried on the flight. For very long flights, this factor is quite significant.[22]

5. Calculations of Carbon Footprints due to Headquarters-Based Air Travel by WBG Staff for CY-09

5.1 Data Applied in 2009

For headquarters (HQ) based activity of the WBG (including the International Finance Corporation, IFC, the WBG private-sector arm), preliminary calculations of flight records for calendar year 2009 (CY-09) were provided by the American Express (AMEX) travel office. These data consisted of 127,514 records[23], containing about 189,000 trips by air, covering 447 million miles. The data are limited to trips booked by AMEX in Washington D.C., and do not include travel booked in the WBG's country offices (CO). The best current estimate is that, overall, HQ-based booking comprises 64% of all WBG air travel in terms of traveled distance.

[21] One may question the rationale for including such measures in standard footprint calculations. An argument for doing so is that it can give incentives to book flights to a larger degree on efficient aircraft. If many organizations do so, it may give airlines additional incentives to phase out inefficient equipment. This may be a desirable incentive effect when airlines themselves do not face the full global cost of their own emissions.

[22] For some aircraft, at least or more than half of the total maximal gross aircraft weight is the weight of fuel when tanks are filled up. In particular, the Boeing 747-8 has a maximal take-off weight of 450 tons, of which 230 tons are the fuel carried. This excess weight implies a large "drag" on fuel consumption when tanks need to be filled up from the start of the flight.

[23] 1,685 records representing rail travel found in the Amex data were excluded in the calculations, as well as some pertaining to 2010 travel.

Our data consist of primarily the date of the trip, the class of the trip (divided into coach, business, or first), the origin city, the destination city, and the number of flight miles. It is important to note the data do not consistently include the origin or destination airports (rather than cities), and also do not include aircraft types. Also, instant upgrades upon check-in are not reflected in the data.

A second data set was obtained from the World Bank's Diio's SRS database subscription, comprising most scheduled flights globally for CY-09, including the equipment code for each flight. The annual data has 2,122,509 records, reflecting some 26 million scheduled flights world-wide.

In order to obtain the equipment code for an AMEX-booked flight, the origins and destination cities needed to be mapped to their relative origin and destination airport codes, which would then allow mapping the scheduling data with the actual flights using the date, origin, destination, airport code, airline code, and flight number. About 30 cities in the AMEX data (out of 1,049) could not be matched with the SRS data. A total of 108,344 exact matches of flight records could be accomplished, representing 157,297 trips as the sample was prepared for Phase I. These flights were than matched with tables provided by ICAO mapping most of the flights to an aircraft code that had a total fuel consumption value for a given distance.

5.2 Features of HQ-Based Travel in CY-09

Three steps can be identified in the calculation of the carbon footprint of headquarters (HQ)-based WBG staff air travel for CY-09, as follows:

Step I: Calculations were first made using a random sample of the cabin class configurations of aircraft used for the relevant flights. By using detailed information from several websites where such data are available, a fairly accurate match between the flights and the configuration of the aircraft used by the specific airline was made.[24] Of 1,219 airline/aircraft combinations, 304 could be directly verified, covering 123,972 flights. Estimates were made by counting the number of seats occupied in the same sized space between classes, which meant that multiples based on economy seats could be established for business and first class seats, reflecting not only the dimensions of the seats themselves, but also isle width and row spacing. From the 304 verified configurations, assumptions were made regarding the remaining 915 airline/aircraft configurations, making a total of 157,297 flights usable for analysis. These were then matched with known fuel consumption factors with tables provided by the International Civil Aviation Organization (ICAO). In this phase of the calculations a single industry standard load factor of 71 percent (corresponding to the overall industry average for 2009) was applied for the carbon footprint calculations.[25]

[24] The information sources included seatguru.com and seatmaestro.com.

[25] The "load factor" corresponds to the share of available seats that is actually occupied on any given flight. Load factors can vary widely, by travel route and not least by flight class.

Step II: ICAO's own carbon footprint calculator provides passenger to freight factors and actual, average, passenger load factors, by region pairs, for 2008. These factors are used in order to adjust down the share of an aircraft's fuel that is spent transporting passengers (as opposed to transporting freight). The calculations were refined to include these regional breakdowns. The load factors were applied evenly throughout all three classes of service. The sample size remains the same 157,297 flights as in Step I above. These represented a total passenger flight distance of roughly 341 million miles. Note that, in the first and second phases of the calculations, since these did not represent all HQ-booked air trips in that year, a factor of 1.31 was necessary for scaling up this number, to the set of total HQ-booked trips(as our sample represented about 76% of total flown distance on HQ-booked flights in that year).

Step III: Calculations under Steps I and II were based on an assumption that load factors are the same in all travel classes. More likely, as argued above, business and first classes have lower load factors than economy class. Since the even distribution of load factors could present an underestimating bias, calculations were made using alternative load factors by travel class, and a matrix developed showing this would affect the overall footprint. The economy class load factor was adjusted to make the overall aircraft load factor match that of the regional load factors applied in Step II of the calculations. We unfortunately do not have direct observations of class-specific load factors (as such data are no longer reported by airlines, and are neither available from the ICAO); assumptions about these had to be made by us.

Since the airline/aircraft class configurations, extrapolated in Steps I and II above, could yield illogical or unreasonable results when applying this calculation methodology, only flights using verified configurations were used, reducing the sample size to 123,922 flights. This is thus a smaller subset of trips than those used under Steps I and II. The scaling-up factor, necessary to represent all HQ-booked air travel in CY-09, was correspondingly higher, 1.55.

Table 5.1: Distribution of Trips Booked at HQ in CY-09, by Travel Class and Trip Length

Class	Trips	Miles	Avg. Length	% of Miles
Coach	53,535	87,442,266	1,643	19.5%
Business	124,516	329,138,314	2,323	73.6%
First	11,418	30,797,763	2,627	6.9%
Total	**189,469**	**447,378,343**	**2,361**	**100.0%**

Table 5.1 shows features of air trips booked through AMEX by HQ-based staff for CY-09 by travel class and average trip length, assuming that figures from our available sample can be scaled up proportionately for all these categories. We see that about 20% of trip length was traveled in coach class, 74% in business class, and 7% in first class. The relative frequency of first class travel in overall WBG travel was five times that for all air travelers (about 1.4 %). For

business class, which represents only about 8.5 percent of global passenger kilometers, the WBG share is more than 8 times as high.

5.3 Total Footprint Calculation for HQ-Booked WBG Air Travel in CY-09

Our final step is to derive the overall carbon footprint of HQ-based WBG air travel for CY-09. Note that ICAO‘s method for calculating the footprint relies on (a) obtaining fuel consumption figures of the aircraft involved, (b) making adjustments for the overall distance traveled in the flight, (c) multiplying the fuel burnt by a factor of 3.157 (which is the number of tons of CO2 released when burning one ton of jet fuel), (d) applying the appropriate load factors (see table 5 above), and (e) assigning the seat portion of this footprint. Our calculated fuel consumption is based on 48 known and specified aircraft types. Other aircraft types, that have similar consumption patterns to specific known aircraft types, are assigned a related "equivalency" code, yielding a total set of 196 aircraft types to be included.[26] This means, for example, that a 737-300 or 737-500 will be treated identically to a 737-400. Trips are also placed in 16 distance classes ranging from 125 nautical miles to over 6,000 nautical miles, with (as noted above) consumption per distance reduced by trip length up to a limit, and increased beyond that limit.

The formula for computing the average carbon footprint related to air travel is then:

CO_2 per pax = 3.157 * (total fuel*pax-to-freight factor)/(number of y-seats*pax load factor).

In ICAO's emissions calculator, a multiplier of 2 is added at the end of the calculation for passengers in premium classes. In our calculations, the proportion of a class's contribution to the footprint was established earlier, and is also adjusted proportionally to the overall (and in Phase III, class-specific) load factor. The important distinction is that in simply using a class multiplier as in the current ICAO methodology, the calculation ignores the shift in load factors from one class to another, which alters each class's overall multiplier. In addition, though ICAO's average multiplier of 2 appears to be not very biased on the average, first class passengers should have a multiplier of around 4.5 or higher.

Applying a hybrid of the ICAO calculation combined with the parameters of the three phases, calculations for overall footprints for HQ-based travel were calculated, and presented in Table 5.2. Since we as noted have no definitive data available on load factors by class, we need to make assumptions about these in Table 5.2. The table shows how different combinations of average load factors in first and business class, with the known overall regional load factor applied in step 2, affect the overall footprint. For obvious reasons, the highest impact depends heavily on average load factors in premium classes; both business class (due to the large share of flights in this class), and first class (due to the high footprint per mile on that class). For a business class load factor of 0.6 and a first class load factor of 0.4 (which are reasonable

[26] ICAO bases this methodology on the European Environment Agency's EMEP/CORINAIR Emission Inventory Guidebook of 2006.

conjectures based on past experience, as noted in Section 4), the relevant figure from Table 5.2 is about 185,000 metric tons. If both load factors are 0.6, the figure is about 165,000 metric tons. Our calculations for the overall footprint for CY-09, in Table 5.2, are seen to vary from a low of about 137,000 metric tons to a high of about 262,000 metric tons of CO_2. It should however additionally be stressed that these calculations are not corrected for any impact of passenger weight on the footprint, which could be the case as discussed in Section 3 above.

These calculations can be compared to numbers found using the Bank Group's current internationally recognized methodology, which gives a total carbon footprint of about 98,000 metric tons for HQ-based air travel for CY-09.

Table 5.2: Overall Footprint for HQ-Based Travel in CY-09 (Kg CO2)

		First Class Load Factor			
		.30	.40	.50	.60
Business Class Load Factor	.40	262,475,888	242,524,540	230,607,655	222,644,261
	.60	205,282,248	185,332,854	173,417,098	165,455,261
	.80	173,431,699	156,901,823	144,990,993	137,029,700

The numbers in Table 5.2 should be treated with some caution, for several reasons among which we here mention four.[27] (a) Class-specific load factors are not observed, and must be estimated or guessed. (b) The characteristics of the trips distribution among classes are assumed to be the same for CO-booked flights in 2009 (for which we do not have such data) as in 2012 (for which we have data), which may be incorrect. Note that for 2009 we observe the HQ-based travel class distribution, but not the CO-based distribution. (c) We do not observe and thus do not account for on-the-spot upgrades to higher travel classes (economy to business, and business to first). Separate data made available to us show that automatic upgrades on preferred carriers at HQ in CY-09 were likely to increase the carbon footprint for such travel by another approximately 5 percent. Such an addition would bring the total footprint due to HQ-based travel in CY-09 to about 174,000 tons, when still assuming 60% load factors for both business and first class. (d) We take no account of the passenger weight factor in calculating relative class-specific footprints. This factor would, according to our calculations in Section 3, reduce the relative footprint of premium classes somewhat, and increase that for economy class. If passenger weight constitutes 1/8 of total aircraft weight (a reasonable assessment in our view), this factor eliminates roughly 1/8 of the difference in footprints caused by space-related concerns; as seen from Table 3.1. In Section 3 and elsewhere we however also argue that these correction factors might be less significant, as certain weight components (luggage and seat weight) are likely to be higher in premium classes than in economy class. We thus argue that it is unclear how large the downward correction factor of the footprint of premium-class passengers ought to be, on the

[27] It is here useful to remember that the "forcing" element discussed in section 1 above, ignored here, implies that our numbers are likely to be biased downwards.

basis of such arguments. We have correspondingly chosen to ignore this factor here and in the following.

6. Final Comments and Discussion

In this paper we have derived carbon footprint measures for different classes of air travel, based on assessments of travel-class-related footprints. We also have shown how these footprint calculations are dual to the optimal pricing carbon emissions from aviation when airlines endogenously determine the relative allocation of economy and premium class seats to maximize profits. We illustrate the approach with calculations of footprints for WB staff travel for headquarters (HQ)-booked travel in calendar year 2009.

In Appendix 1 and Appendix 2, we also provide additional, indicative (but less definite) calculations of the overall carbon footprint from both HQ-based and CO-based mission air travel, for both calendar year 2009 and fiscal year 2012. These calculations indicate that there has been a drop in the overall footprint of WBG staff air travel over that period, by about 13.5 percent. Most of this drop seems to be due to two factors: 1) a virtual elimination of first-class travel from 2009 to 2012; and 2) a higher share of CO-booked travel in 2012 than in 2009, and where the (more carbon intensive) premium travel classes are used relatively less frequently by CO-based staff. Our preliminary, albeit less conclusive, calculations for these two periods indicate that the overall share of travel booked on premium classes fell over the period, from about 69% to about 66% of overall WBG air travel.

Air travel is a so-called "scope 3" activity that need not strictly be included when calculating the carbon footprint of an institution such as the WBG, when using the internationally accepted GHG Protocol.[28] Several international organizations, including both the WBG and the IMF, still however do so. Air travel comprises a very large share of the overall GHG emissions for such institutions, so any attempt to offset emissions would be of limited consequence without consideration of this emissions category.

While standard accepted methods for calculations of air travel carbon footprints assume a given footprint due to given trip length regardless of travel class, our calculations indicate a footprint per mile for premium (business and first) classes substantially greater than for economy class. The main reason is that aircrafts' fuel consumption to only a small degree depends on the number (or weight) of passengers; and that an average premium-class passenger takes up a larger than average space in an aircraft, reducing the number of passengers that can be transported on a given flight. This is a relevant consideration since, we argue, aircrafts' class-specific cabin sizes are not exogenous but instead reflect airline decisions to maximize profits (where premium-class passengers pay more, a major reason for which is to have more available space provided in the aircraft). The footprint is increased the most for first class, where seats are most dispersed and average load factors tend to be lower than in business class. Such factors turn out to make a

[28] See WRI (2002).

great difference for the overall footprint calculations for institution in which a very large fraction (70-80%) of staff air travel takes place in premium classes.

The ICAO calculator (used for individuals to calculate their footprints) includes one refinement of standard procedure, by using a factor of 2 for the footprint of premium (business and first) classes relative to economy class. We have gone a step further in this direction by attempting to calculate this factor more precisely than has been done previously in the literature. But more can be done to make such calculations even more precise. One such factor is more precise (flight-specific) information. In addition, the climate forcing issue (where we have assumed only a basic, unit, forcing factor) could by in principle imply a higher footprint from air travel more generally (we do not in our calculations adjust for additional forcing factors).

This leads in turn to issues related to offsetting that are potentially important but beyond the scope of this paper. As with other international institutions, the World Bank Group (WBG) is concerned with the GHG emission impacts of its overall institutional activity.[29] A correct measurement of aviation-related emissions is essential for keeping track of the institution's total contribution to global GHG emissions.

The WBG has an expressed policy to be at the forefront in areas of environmental sustainability, which includes a proper carbon footprint measurement, and the ability to correctly offset these emissions.[30] While most similar institutions today accept the principle of offsetting of GHG emissions from staff air travel, no major institution, including the WBG, has to date any offset program based on calculations developed in this report. Indeed, our approach is radical in the sense that it in some respects extends well beyond currently accepted standards for measuring carbon footprints of air travel, by making them more precise. The WBG could, by its approach to measuring its own footprint, lead the way in establishing more accurate such measures.

Aside from how much to offset – an issue with philosophical and political as well as economic and environmental dimensions – a second consideration is how to offset. A relevant current issue in this regard is that the European Union, from 2012 on, has embedded all flight activity within and to and from the EU countries in the EU-ETS, which requires all airlines to hold quotas to cover the respective assessed emissions. Appropriately embedding the WBG's flight activity to and from the EU area in the EU-ETS would be one way for the WBG to mitigate its air travel emissions, as distinct from only purchasing offsets for this activity. The ultimate status of this EU initiative is currently uncertain, however, and we are currently awaiting initiatives

[29] For an overview of the WBG's carbon footprint and how this is currently measured, see: http://crinfo.worldbank.org/wbcrinfo/node/23#MeasuringGHG. For a presentation of the WBG's more general offsetting policy in the context of corporate responsibility, see http://crinfo.worldbank.org/wbcrinfo/node/7.

[30] For extensive information on these issues, see the WBG's corporate responsibility website: http://crinfo.worldbank.org/wbcrinfo/.

from ICAO, concerning a possible common agreement for how to handle emissions from this sector.[31]

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[31] The EU's enforcement of its inclusion of non-EU airlines in the EU-ETS has currently been put on hold, until the end of 2013, awaiting ICAO's decision on a possible global scheme for handling airlines' carbon emissions.

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Appendix 1: Carbon Footprint Calculations for WBG Air Travel for Fiscal Year 2012 (FY-12) [32]

We have had available about 90 percent of the total data for the air travel activity for the entire WBG, both for headquarters and for field offices, for the period March 2011 – February 2012. This data set contains a total of 322,331 trips covering about 642 million miles, of which roughly 57% were trips ticketed by Amex at headquarters.[33] The actual, total traveled distance by the entire WBG in FY-12 (July 2011-June 2012) was 677 million miles, or about 3.2 percent lower than the 699 million miles flown in CY09. Here, all calculations are made on the (slightly more limited) data set available to us. When making the carbon footprint calculations for FY-12, in Section 5.4, our calculated data are scaled up with an expansion multiplier of 1.055 (the relative increase necessary to represent the entire FY-12 flight activity).

The breakdown of FY-12 travel by class can be found in Table A1.1 below. For FY-12 there is very little known first class travel, in contrast to CY-09 where such travel comprised almost 8 percent of all HQ-booked trips by WBG staff. This is due to a changed and standardized policy whereby first-class travel is authorized only in extremely few cases. "Economy" and "economy plus" trips are combined under the single category "Coach". We have no information about the "unknown" class category, and simply assume that its class-specific distribution is the same as for the "unknown" category.

In 2012 only 0.1% of miles traveled by WBG staff were, officially, on first class (assuming again that first class does not appear more frequently in the "unknown" category).[34] This almost disappearance of first class as a separate flight class category for WBG staff is treated by us, for practical purposes, by simply calculating the footprint with one common load factor for both business and first class. The mistake made when doing this will be very small, on the order of less than 1 percent of the overall footprint.

In Table A1.1, the "unknown" category implies that we cannot be certain about the overall distribution of travel by class. We however find no reason to assume that the distribution of the "unknown" category is different from that for known categories. On this premise, 48.4% of miles on CO-booked travel, 79% on HQ-booked travel, and 66.1% of total miles traveled were in business class, so that the complements (51.6%, 21% and 33.9%) were in coach class (ignoring as noted first-class travel which constituted only about 0.1% of total travel). For HQ-based travel in CY-09, in Table 5.1, comparing to numbers in Table A1.1 we find a slight reduction in the fraction of business class in 2012 (79%), as compared to the aggregate of business and first

[32] In WBG terms, this fiscal year starts July 1, 2011, and ends June 30, 2012.
[33] In addition there are approximately 60 million traveled miles, where we do not have this detailed breakdown. We will in the following simply assume that these "unknown" miles have the same relative distribution, by traveled length, class and by HQ- and CO-base, as those accounted for.
[34] Note however that we only have information about booked travel, and not actual flight activity. In practice there may be some on-the-spot upgrading both from coach class to business class, and from business class to first class. To the extent that this takes place, this factor will also bias our figures downward relative to their true values.

classes in 2009 (80.5%). The share to premium class trips in FY12 is far lower for CO-based travel; reasonably, a similar relationship existed also for CY09.

Table A1.1: Breakdown of WBG Travel Data by Booked Seat Class for FY 2012.

Trip Origin	Class	Trips	Total Miles	Avg Length	% of Miles
CO	Economy	85,678	113,975,613	1,330.3	41.07%
CO	Business	55,683	107,057,207	1,922.6	38.58%
CO	First	118	202,132	1,713.0	0.07%
CO	Unknown	34,087	56,270,643	1,650.8	20.28%
CO Sub-Total		175,566	277,505,595	1,580.6	100.0%
HQ	Economy	31,477	63,421,648	2,014.9	17.39%
HQ	Business	91,089	238,565,602	2,619.0	65.43%
HQ	First	194	459,406	2,368.1	0.13%
HQ	Unknown	24,005	62,175,433	2,590.1	17.05%
HQ Subtotal		146,765	364,622,089	2,484.4	100.0%
Combined	Economy	117,155	177,397,261	1,514.2	27.63%
Combined	Business	146,772	345,622,809	2,354.8	53.82%
Combined	First	312	661,538	2,120.3	0.10%
Combined	Unknown	58,092	118,446,076	2,038.9	18.45%
TOTAL		322,331	642,127,684	1,992.1	100.0%

As the FY-12 data include neither flight number, airline, nor equipment flown, we simply assume the same basic flight distribution for FY12 as for CY09. Table A1.1 provides these distributions for the flights for which we have data (and, note, these data need to be scaled up by a factor of 1.055 to reach the correct overall total activity in FY12).

Carbon Footprint Calculations for FY12

Table A1.2 provides calculations for the overall footprint of WBG air travel for FY-12, based on numbers in Table A1.1 scaled up with an expansion factor of 1.055 (to correct for the slightly greater flight volume in FY-12 compared to our sample period). The calculations are done for alternative assumptions about average load factors in premium classes for the flown aircraft (as these are particularly uncertain since they are not provided by airlines). Throughout we assume that the average load factor for coach class is 0.8, in accordance with reported industry averages.

The main purpose of the table is to span out the range of possible "carbon footprints" as premium-class load factors change. While not fully known, it is highly likely that the average load factor for business class (the relevant category in FY12) is no higher than 0.7, and no lower than 0.5. A reasonable compromise, used in the continuation, is to assume a load factor of 0.6 for business class. In this case the combined carbon footprint of air travel in FY12 would be about 195 million tons CO2.

Table A1.2: Footprint Calculations for the Overall Population of Air Travel for FY12, as Function of Average Load Factors. 1000 Tons CO2.

Origin	**Average Business and First Class Load Factors**				
	0.5	**0.6**	**0.7**	**0.8**	**0.9**
CO	79.1	69.6	63.1	58.2	54.6
HQ	147.9	125.2	109,1	97.2	87.9
Combined	**227.0**	**194.9**	**172.2**	**155.4**	**142.5**

Appendix 2: Expanding Footprint Calculations to All WBG Air Travel in CY-09

In this appendix, we consider a hypothetical expansion of our calculations by adding a hypothetically assessed volume of CO-booked air travel, by travel class, in CY-09. Note that for CO-booked travel in CY-09, we have no direct figures for the distribution by travel classes. This implies that we cannot make a precise assessment of that travel. We do however have data for this distribution for FY-12, as reported in Appendix 1. We here create a numerical example for this travel class distribution for CY-09, by simply assuming the same distributions of CO-booked flights by travel class (economy, business and first) in CY-09 as in FY-12. Taking then the (reasonable) assessment that load factors in premium classes were 60% on average both in FY-12 and in CY-09, we found overall footprint of that travel, at 59,800 tons CO2, in Table A2.1.[35]

[35] This constitutes a "conservative" calculation for CO-based travel in CY-09. As we have seen, the use of premium classes, notably first class, dropped, overall, from CY-09 to FY-12 for HQ-based travel, from 80% to. We here assume that this frequency has not dropped for CO-based travel. If it had actually dropped also for CO-based travel, the footprint due to this travel would have been greater than what we assume in CY-09; and the overall drop in the footprint from CY-09 to FY-12, reported in Table 5.3, would have been greater.

Table A2.1: Consolidated Assessed Carbon Footprints From Air Travel by WBG Staff, CY-09 and FY-12, in Total and as Change. Tons CO2 and Percent.

Travel category	CY 2009	FY 2012	Change from CY-09 to FY-12	Relative change, percent
CO-based	59,800	69,600	9,800	16.4
HQ-based	165,500	125,200	-40,300	-24.4
Combined	225,300	194,800	-30,500	-13.5

Source: Authors' calculations.

Table A2.1 provides an assessment of the overall footprints for both CY-09 and FY-12 using this numerical example. Using these assumptions, we find a substantial drop the overall footprint due to HQ-based air travel from CY-09 to FY-12, by 24.4%. There are two main factors behind this drop. First, there was a drop of more than 14% in distance traveled on trips booked at headquarters. Secondly, travel on first class, which constituted about 7 percent of overall travel in CY-09, was virtually eliminated by FY-12. Since first-class air travel is far more emissions intensive than business class travel (in particular for wide-body aircraft where premium class travel is most prevalent; see Table 4.6), this factor explains, roughly, the remaining about 11 percentage points in this drop.

For CO-booked flights we have, as mentioned, assumed the same class distribution in CY-09 as that observed for FY-12. The 16.4 percent increase of CO-based travel footprint is then in its entirety based on an increase in flight distance (from 252 million miles in CY-09, to 293 million miles in FY-12). Note also that for CY-09, CO-booked travel made up 26.5 % of the overall footprint, while it for FY-12 made up 35.7 % of the total footprint. [36]

This implies a shift of the overall travel activity of the WBG, from HQ-based travel to more CO-based travel. The reduction in HQ-based travel has however been slightly greater than the increase in CO-based travel; and thus a slight a reduction in the entire WBG travel activity. This shift has also resulted in an overall drop in the ratio of premium-class travel, due to the lower frequency of such travel booking for CO-based travel, from about 69% to about 66%; see Table A2.2 below. The shares of the overall footprint represented by CO-based travel (26 percent in CY-09, and 36 percent in FY-12), are lower than the respective shares of traveled miles (34 and 43 percent) in the same periods.

[36] Note however that the latter assessment is uncertain as the CO figure for 2009 is highly uncertain; see comment in section 3.5 above, and below.

Table A2.2 provides an assessment of the shifts in overall travel class use by WBG staff in CY-09 and FY-12, for CO-based and HQ-based travel as well as combined travel, given these particular assumptions (notably, that the travel class frequency for CO-based travel was the same in CY-09, for which we do not have these data, as for FY-12, for which we have such data. In this case, the use of premium-class traveling has been reduced for WBG staff over this period, in part because the frequency of premium-class use in HQ-based travel has been reduced slightly, from 80,5% to 78.9%, but more because a larger share of overall travel was CO-based in FY-12, and such travel is, generally, less intensive in the use of premium classes. Overall, by our assessment the use of premium class in the overall WBG travel budget was reduced by about 3 percentage points over the period, from about 69% to about 66%. Even more important for the footprint, first-class travel, which in CY-09 comprised 6.9% of HQ-based travel (and an estimated 4.4% of overall travel),[37] had been virtually eliminated by FY-12.

Table A2.2: Estimated shares of travel by travel class, CO- and HQ-travel and combined, for CY-09 and FY-12. Percent.

Year		Economy-class travel	Business-class travel	First-class travel	Premium-class travel, combined
CY-09	CO	51.5	48.5	0	48.5
	HQ	19.6	73.6	6.9	80.5
	Combined	30.1	64.5	4.4	68.9
FY-12	CO	51.5	48.5	0	48.5
	HQ	21.1	78.8	0.1	78.9
	Combined	33.9	66.0	0.1	66.1

Source: Authors' calculations.

Some reservations are here in order. Limitations on available data have prevented a full overview of the travel class distribution for CO-booked travel in CY-09. We have simply assumed that the class distribution of CO-based travel in CY-09 was the same as in FY-12. Possibly, premium classes could have been used more for CO-based travel in CY-09, in the same way as was documented for HQ-based travel. This would not affect our calculations for FY-12, but would increase somewhat the CO-based number for CY-09, as well as the reduction from CY-09 to FY-

[37] This assessment is based on an assumption that no first-class CO travel was booked in CY-09, which may be inaccurate.

12. The shares of premium-class travel in CY-09 would then have been higher than the numbers in Table A2.2, and the drop in this share, from CY-09 to FY-12, would have been greater.

Remember also that if the load factor for first class had been lower than the assumed 60% in CY-09 (which was quite probable), the footprint would have been higher in CY09. The drop in the footprint from CY-09 to FY-12 would then have been greater than what is presented in Table 4.6.

It is not entirely clear (to us) what lies behind the reduction in overall WBG staff travel over the period, as the group's activity (in particular, its loan volume) has been increasing. Reduced travel budgets may have played a role. But new technology (such as more advanced video conferencing options) may also have reduced the need for travel in some cases.

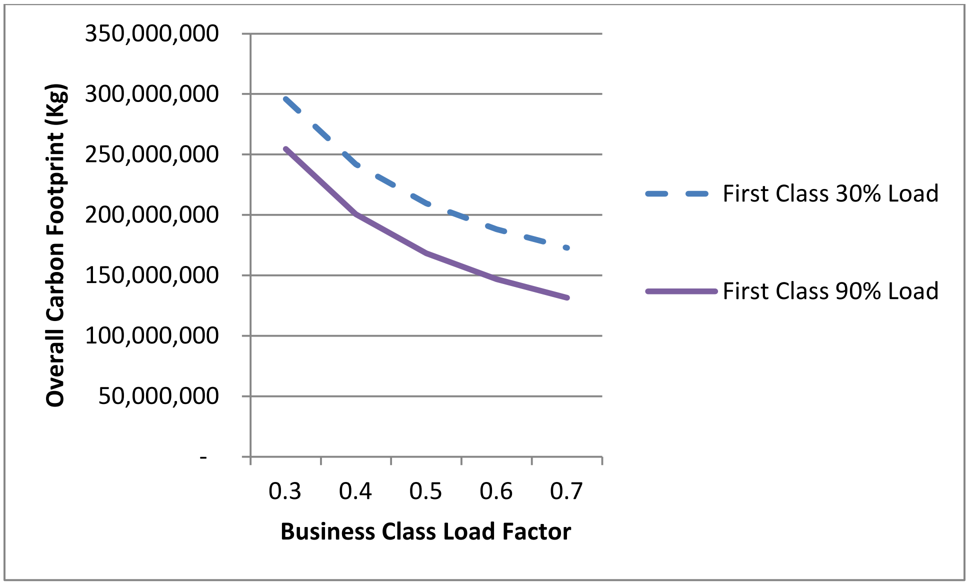
We may now compare our footprint calculations to the Bank's own official calculation. The number for the latter was 128,000 tons CO2 for FY-12.[38] Consequently, our "chosen" number is 52% higher; or alternatively the Bank's number is 36% lower than ours. This discrepancy is in its entirety due to our higher footprint calculation per business class traveler.

Note a few additional caveats. First, we know only classes booked and not classes flown. What matters for the footprint is not booked but rather the flown travel class. To the extent that staff enjoy on-the-spot class upgrades (not reflected in bookings), actually flown class is on average higher than booked class. This leads us to *underestimate* the footprint. Secondly, our numbers do not reflect possible improvements in fuel economy of air carriers over this period. Such improvements would, in case, lead to further footprint reductions, relative to Table 5.3. This implies that we are *overestimating* the true footprint for 2012. It is difficult for us to know the net effect of these opposing factors. Finally, we did not know the class distribution of CO-booked flights in CY-09 (which was assumed to be the same as for HQ-booked flights). The FY-09 footprint may then have been over-estimated by placing too many flights in premium classes. If so, the drop in the footprint from CY-09 to FY-12 would have been greater than that registered in table 11, due also to this factor.

[38] Adam Rubinfield, personal communication.

Appendix 3: Additional Figures and Tables

Figure A3.1: Impact of Changes in Load Factor Combinations on Carbon Footprint of HQ-Based WBG Staff Air Travel, 2009



Figures A3.1-A3.2 serve to support the calculations in section 5.4 (table 5.3) for the overall carbon footprint from HQ-based air travel by the WBG in CY09, by indicating ranges of these numbers for alternative (extreme) values of average load factors by class. In figure A3.1, the two curves provide this range when the first-class load factor take extreme values of 0.3, and 0.9, respectively. In figure A3.2, it is business-class travel that take these alternative values, for the two curves drawn. In this way, we see that the range of possible carbon footprint values is from about 120,000 tons CO2, to about 300,000 tons. In both cases, the minimum possible number (clearly an under-estimate) is more than 20% higher than the official footprint number for CY09, which was about 98,000 tons CO2.

Figure A3.2: Impact of Changes in Combinations of Load Factors for Business Class on Carbon Footprint of HQ-Based Bank Staff Air Travel, 2009

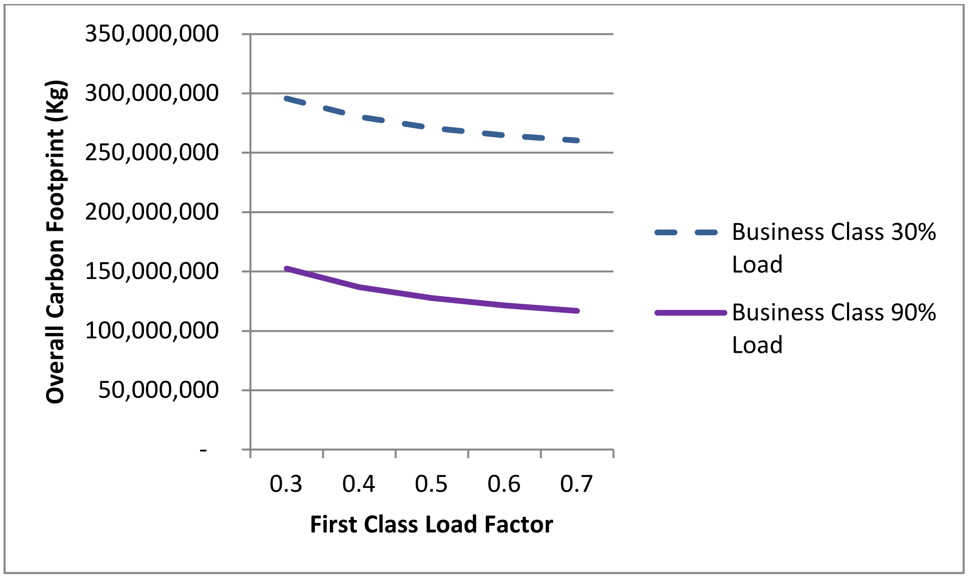


Figure A3.3 charts the average passenger footprint per mile found across all distance classes and all aircraft in the sample used for the Phase III calculations, assuming a 60% load factor for both business and first classes. Figure 3 also shows the average fuel consumption per seat mile of those same flights, based on aircraft types found both in the ICAO base tables in their own methodology, which are again based on the modified CORINAIR tables in Version 3 of ICAO's Carbon Emission Calculator.

The chart points out in both datasets that at first, as distances increase, the consumption per mile and resultant footprint goes down. As the distances increase, the consumption then increases again, because of the weight of the additional fuel to be used for the longer trip. A significant increase is seen between distance classes 7 (1,501 nm to 2,000 nm) and 8 (2001 nm to 2,500 nm), and 8 and 9 (2,501 nm to 3,000 nm). Between CY2009 and FY2012 a reduction of average distance per flight has occurred, making the average distance go from class 9 to class 8, reducing the per mile fuel burn.

In figure 3.3, the line representing fuel burn assumes an even distribution of fuel consumption among all seats, occupied or not, regardless of size. The average footprint per passenger mile however also reflects the distribution by class, combined with load factors (here, 60% for first and business class, with the remainder determined by regional load factors and passenger to freight distributions). The line representing the footprint would look identical to the per seat consumption if it were based just on the number of seats, with the values represented by the line being simply a multiple of the fuel burn.

Figure A3.3: Average Per Passenger Mile Fuel Consumption According to ICAO Distance Classes of All Aircraft in ICAO Methodology in Phase III Sample (60% first class and 60% business class load factors assumed).

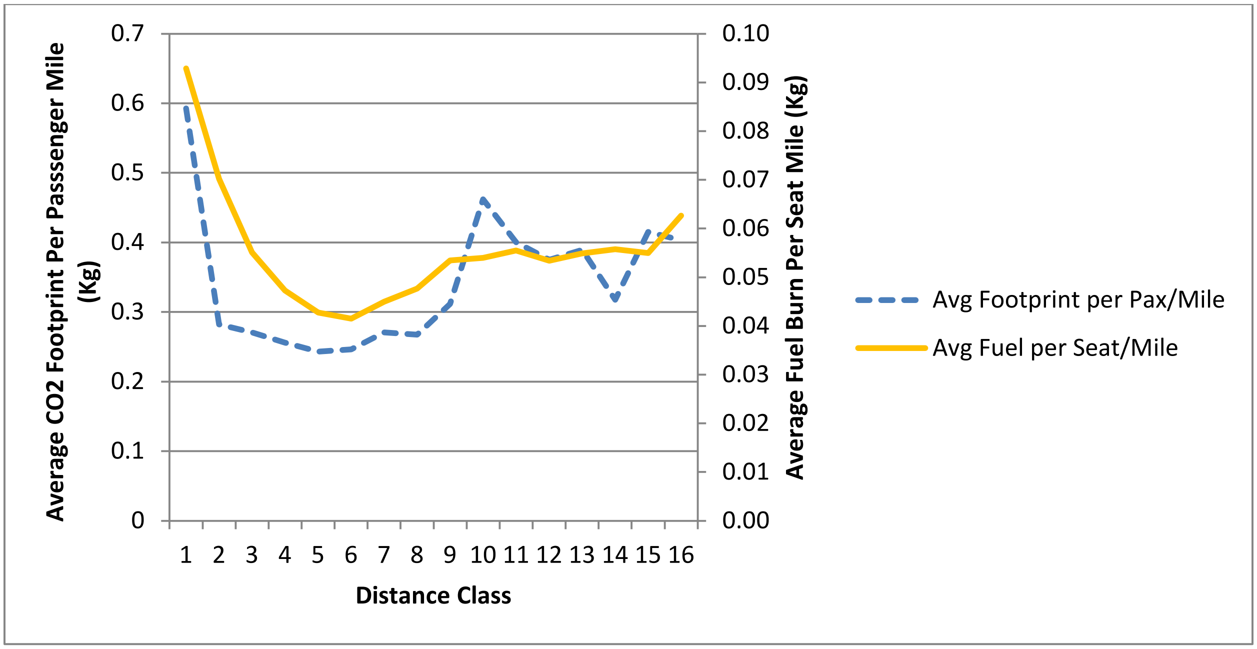


Figure A3.4: Bank Carbon Footprint by Business and First Class Load Factors, FY12

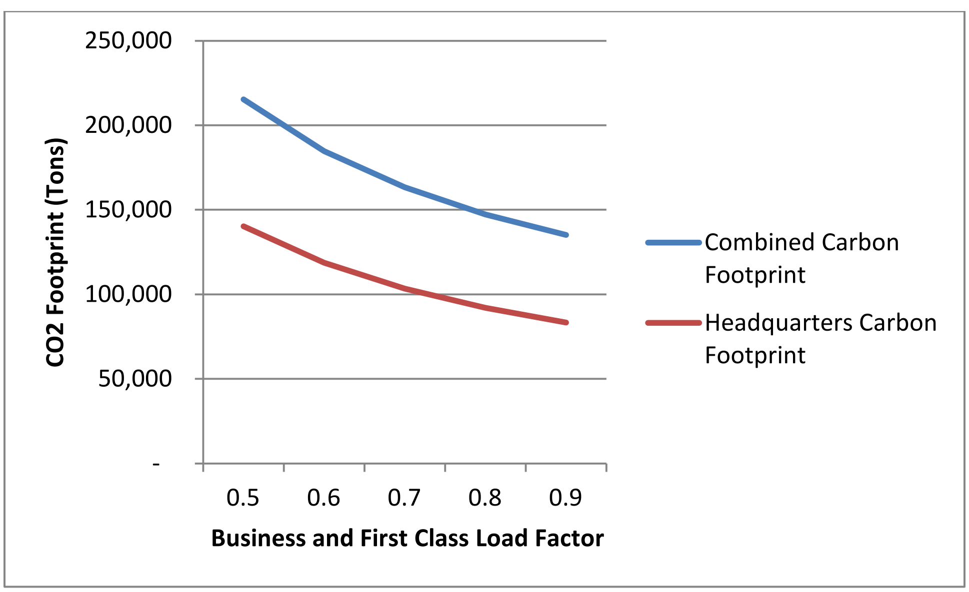


Figure A3.4 shows an analogous chart for FY-12, to figures A3.1-A3.2 above. We here need just one figure (as we have dropped first class as a separate category due to very few flights in this class). Depending on average load factors in premium classes, the combined carbon footprint from all air travel in that year is shown to vary from about 85,000 tons CO2 (for average load factors of 0.9; clearly an overestimate); and up to about 220,000 tons CO2 (for average load factors of 0.3; clearly an underestimate).

Figure A3.5 shows the distribution of flights by flight length and by flown class, for the two years in question, and corresponding footprints per passenger mile flown; in similar way as for figure A3 above, again assuming average load factors in premium classes of 0.6.

Figure A3.5: Footprint for CY 2009 and FY 2012 per Distance Class Compared, With Average Fuel Consumed per Passenger Mile From Figure 3.

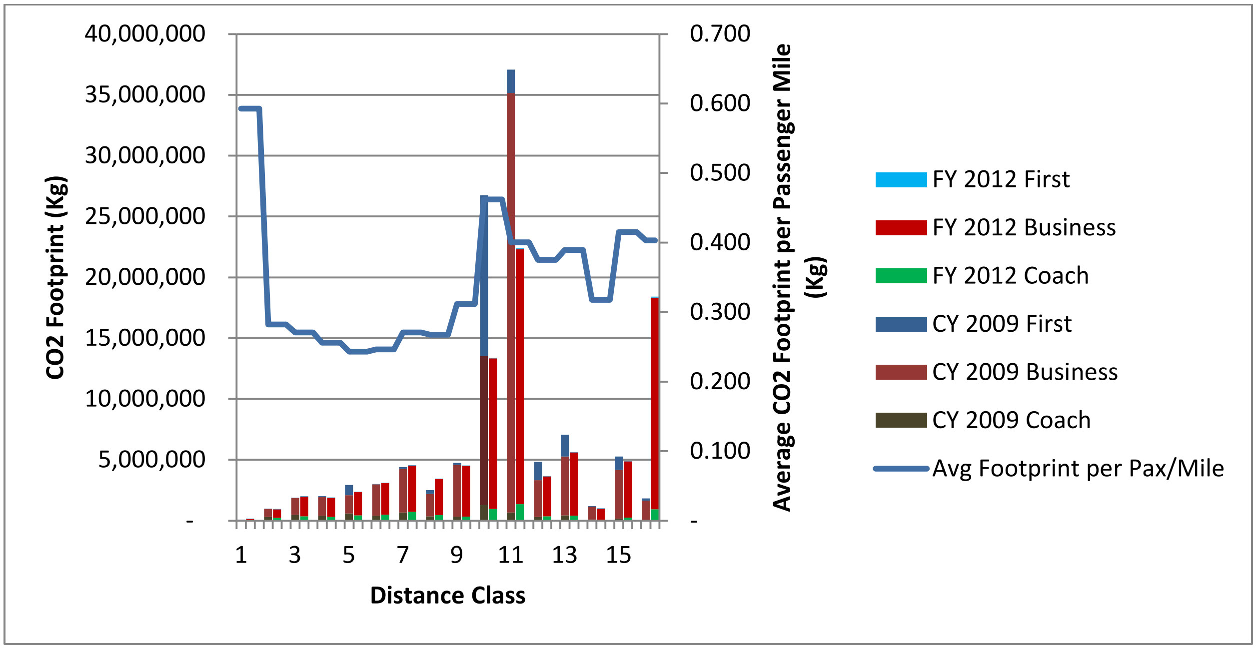


Table A3.6 below shows the distribution of footprints as calculated by distance class for HQ-booked trips in CY-09 and FY-12, for the sample of trips in our data set. The most interesting issue here is the substantial change in the distribution of flight activity over this period, with fewer flights in distance classes 10-11 (in the range 3,450 - 4,600 miles), and more flights in particular in class 16 (the longest flights, above 6,900 miles).

Future improvements in calculations of the carbon footprint load of WGB air travel can be made on several fronts, including the following. (a) Match the American Express data set with the purchased scheduling data published by companies such as Diio or OAL to find the equipment actually used, and the distance between origin and destination. (b) Use available information sources to collect the more specific cabin configuration information. (c) Seek more precise numbers for load factor of relevant flight groups, by travel class; and for climate forcing implications of aircraft activity at different altitudes and along alternative flight routes. The latter is a complicated issue on which no consensus exists today; but should remain a high priority for future research.

Table A3.6: Net Change in Carbon Footprint From CY-09 to FY-12 By Distance Class in Adjusted Samples for Both Years. (Figures in parentheses represent negative values.)

Distance Class	Range in Standard Miles	Fooprint Sample CY 2009 (Kg)	Footprint Sample FY 2012 (Kg)	Difference (Kg)
1	Up to 144	47,658	150,144	102,486
2	145 – 288	968,621	944,851	(23,770)
3	289 – 575	1,892,181	1,997,983	105,802
4	576 – 863	2,021,596	1,883,550	(138,046)
5	864 – 1,150	2,943,219	2,345,399	(597,820)
6	1,151 – 1,725	3,019,594	3,096,756	77,162
7	1,725 – 2,300	4,408,136	4,554,853	146,717
8	2,301 – 2,875	2,499,085	3,436,814	937,729
9	2,876 – 3,450	4,742,553	4,526,415	(216,138)
10	3,451 – 4,025	26,741,487	13,384,291	(13,357,196)
11	4,026 – 4,600	37,066,649	22,387,482	(14,679,167)
12	4,601 – 5,175	4,816,334	3,649,066	(1,167,268)
13	5,176 – 5,570	7,048,664	5,638,348	(1,410,316)
14	5,751 – 6,325	1,190,357	987,446	(202,911)
15	6,326 – 6,900	5,258,919	4,906,047	(352,872)
16	6,901 +	1,832,029	18,402,756	16,570,727
Sample Total		**106,497,082**	**92,292,200**	
	Total Change from 2009 to 2012			**(14,204,882)**
	Percent change from 2009 to 2012			**(13.3%)**

The following five considerations would facilitate such future work:

1. If the American Express data set were to include both the distance between the points traveled, and the IATA equipment code, the entire global scheduling data set would unnecessary, thus simplifying the data preparation work.

2. It would be helpful if the American Express data could show actual IATA airport (not city) codes for the flights.[39]
3. Load factors by flight class should be investigated further, possibly through IATA which is likely to have the required information. For this report, our attempts to find actual load factors by class have proved fruitless because IATA is not making such data freely available to the public. The required data might however be available at a cost.
4. On-the-spot upgrades (coach to business, and business to first class) are not reflected in our data, and could further increase the correct carbon footprint.[40]
5. Moving toward a more detailed approach using the modified ICAO emissions calculator procedure applied here, and incorporating hopefully available load factors by class, would bring about more rigorous footprint estimates. An issue then is the increase in precision of the institution footprint, due to such more detailed information; relative to e g using industry averages for load factors and basic aircraft fuel consumption.

[39] The scheduling data uses airport codes, such as IAD for Dulles Airport and JFK for John F. Kennedy International Airport. However, the American Express data often shows city pairs as, for example, WAS-NYC (for Washington, D.C. to New York City), which requires substantial additional processing of data in order to match these with the Diio scheduling data.

[40] For example, most Lufthansa flights over 2,000 nautical miles are marked business class. However, with United Airlines roughly 4,400 flights out of 15,000 with stage lengths of 2,000 nautical miles or more are marked coach, most of which most likely have received on-the-spot upgrades at check-in. This is not registered in our data.

Appendix 4: Description of Route Groups

ICAO uses a set of 17 route groups between regions that have been applied to this data set, with some modifications as noted in the footnotes below. The groups carry numbers and are defined follows in Appendix 1 of ICAO Circular 255-AT/105:

1. *Between North America and Central America/Caribbean.* Includes routes between on the one hand Canada and/or the United States (including Alaska and Hawaii) and on the other hand Central America and the Caribbean. Routes between the United States and Puerto Rico /Virgin Islands are considered domestic and are excluded. Central America/ Caribbean is defined as the geographical area covered by route group 2 but excluding Mexico.
2. *Between and within Central America and the Caribbean.* Includes routes between or among the Bahamas, Belize, Bermuda, Costa Rica, El Salvador, Guatemala, Honduras, the islands of the Caribbean Sea (including Puerto Rico and the Virgin Islands), Mexico, Nicaragua and Panama.
3. *Between Canada, Mexico and the United States.* Includes routes between or among the above States. The United States includes Alaska and Hawaii but excludes Puerto Rico and the Virgin Islands[41].
4. *Between North America/Central America /Caribbean and South America.* Includes routes between the geographical areas defined on one hand by route group 1 and /or Mexico and on the other hand by route group 5 (“local South America”)
5. *Local South America.* Includes routes between or among the following States: Argentina, Bolivia, Brazil, Chile, Colombia (including the San Andres Island), Ecuador, Falkland Islands (Malvinas), French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay and Venezuela.
6. *Local Europe.* Includes routes between or among the States of geographical Europe, Algeria, Azores, Canary Islands, Greenland, Iceland, Madeira, Malta, Morocco, Tunisia and Turkey.
7. *Local Middle East.* Includes routes between or among the following States: Bahrain, Cyprus, Egypt, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Sudan, Syrian Arab Republic, United Arab Emirates and Yemen.
8. *Local Africa.* Includes routes between or among the States of continental Africa and offshore islands, but excluding Algeria, Azores, Canary Islands, Egypt, Madeira, Malta, Morocco, Sudan, and Tunisia.
9. *Between Europe and the Middle East.* Includes routes between the two geographical areas defined by route group 6 (“local Europe”) and route group 7 (“local Middle East”) respectively.

[41] The August 2010 version of the ICAO Carbon Emissions Calculator, in Appendix A on page 12, Bermuda is included in this group. Bermuda has thus also been included in the calculations presented here.

10. *Between Europe/Middle East and Africa.* Includes routes between on the one hand the geographical areas defined by route group 6 ("local Europe") and/or route group 7 (local Middle East") and on the other hand the geographical area defined as route group 8 ("local Africa").
11. *North Atlantic.* Includes routes between on the one hand Canada and/or the United States (including Alaska and Hawaii) and on the other hand geographical areas defined by IATA Tariff Conference 2 ("local Europe" and/or "local Middle East" and/or "local Africa").
12. *Mid Atlantic.* Includes routes between on the one hand gateway points in the geographical areas defined by route group 2 and/or route group 5 ("local South America") but north of Rio de Janeiro and on the other hand the geographical areas defined by IATA Tariff Conference 2 ("local Europe" and/or "local Middle East" and/or "local Africa").[42]
13. *South Atlantic.* Includes routes between on the one hand Rio de Janeiro or any other gateway south thereof in route group 5 ("local South America") and on the other hand the geographical areas defined by IATA Tariff Conference 2 ("local Europe" and/or "local Middle East" and/or "local Africa")[43].
14. *Local Asia/Pacific.* Includes IATA Tariff Conference 3, that is international routes within Asia to the east of the Islamic Republic of Iran and of the Ural Mountains, Australia, New Zealand, Papua New Guinea, the islands of the Pacific Ocean excluding the Hawaiian Islands, Midway and Palmyra.[44]
15. *Between Europe/Middle East/Africa and Asia/Pacific.* Includes routes between the geographical areas defined by IATA Tariff Conference 2 on the one hand and that defined by IATA Tariff Conference 3 on the other hand.
16. *North and Mid Pacific.* Includes routes via the North and Mid Pacific Ocean between on the one hand points in the Americas (i.e. IATA Tariff Conference1) and on the other hand Asia and/or the islands adjacent thereto (i.e. IATA Tariff Conference 3 except Australia, New Zealand, Papua New Guinea and the islands of the South Pacific).
17. *South Pacific.* Includes routes via the South Pacific Ocean between on the one hand points in the Americas (i.e. IATA Tariff Conference 1) and on the other hand Australia, New Zealand, Papua New Guinea and the islands in the South Pacific.

[42] Since splitting the data again by regions *within* a country would have been highly time consuming, for the calculations at hand the region below Rio de Janeiro has been simplified as Uruguay, Paraguay, Argentina, and Chile.
[43] See previous footnote.
[44] The grouping "international routes within Asia" removes all domestic routes, which is inconsistent with the definitions of the other groups bearing the word "local" in their label. Since this would have left a large number of routes not covered, for the purposes of this exercise domestic routes that would otherwise have fallen into this definition but for the "international" clause are included.