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Planes, ships, and taxes: Charging for international aviation and maritime emissions

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PLANES, SHIPS, AND TAXES: CHARGING FOR INTERNATIONAL AVIATION AND MARITIME EMISSIONS

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I. Introduction

International aviation and maritime transport account for a large and growing share of global carbon emissions. Yet these emissions are explicitly excluded from current mitigation schemes (they are carved out of the Kyoto protocol, for instance). Moreover, they are not even subject to ordinary excise taxes of the kind that are routine for almost all other transportation fuels. And the consequent tendency to excess emissions—and loss of tax revenue—is exacerbated by other distinct and substantial tax privileges enjoyed by these sectors: for international aviation, exclusion from the value-added tax (even, in some cases, subsidies);[1] for international maritime, unique and very light forms of corporate taxation.

The aim of this paper is to elucidate these anomalies, assess their significance, and set out ways in which they could be overcome.

These issues have been rising up the political agenda, and seem set to become more heated still. For several years—far too long, many argue—both the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO), which are the UN bodies charged with oversight of these sectors, have been working to come up with schemes to charge a price for carbon emissions pricing schemes (more often referred to in this area as 'market-based mechanisms,' the leading forms being a carbon tax and an emissions trading scheme (ETS)[2]). Frustrated with this lack of progress, the European Union included flights to and from the EU in its ETS (the 'EU-ETS') from the start of 2012. Faced with a sharp outcry from the United States,[3] China and others, and fears of prompting a trade war, this plan was suspended for one year in November 2012, with the explicit indication that it will be revived unless the ICAO produces a proposal for some global mechanism at its General Assembly in Fall 2013. The stage is thus set for another turning point in late 2013.

In parallel, charges on international air and maritime transport have attracted increasing attention as one of the ways in which developed countries could go some way toward meeting their commitment to mobilize $100 billion a year (in some unspecified mix of public and private finance) from 2020 onwards for climate mitigation and adaptation projects in developing countries.[4][5] As the deadline looms, if the developed countries are to keep their promises, this debate too must become more intense. Our concern here is not with the case

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[1] Some Caribbean countries, for instance, guarantee revenues or provide other forms of subsidies to airlines.

[2] A carbon tax simply charges a tax on carbon emissions; an ETS places a limit on total emission and establishes a market in which permits to emit, up to that cap, can be traded. So long as permit rights are auctioned under the ETS, and leaving aside uncertainty and imperfect information, the two are completely equivalent in that the effects of, for instance, a carbon tax, could be exactly replicated by setting the cap under an ETS at the level of emissions generated by the tax. In practice there are important differences between the two approaches, as will be discussed later.

[3] Congress has passed bipartisan legislation prohibiting U.S, airlines from participating in the scheme.

[4] The term 'developing countries' is used here quite broadly, excluding all but the advanced economies.

[5] Assessments of fuel charges in this context are provided by an advisory group to the UN Secretary General (AGF, 2010a and b), focusing on revenue potential, and in a report to the G20 by the IMF and World Bank (2011). This paper draws on the latter.

for using the revenue from such charges a source of collective climate finance (it is not clear, for instance, why meeting these commitments should require earmarking some new "innovative" source of finance). The use made of the proceeds does, however, have implications for the practicalities of implementing these charges, and these will need close attention. And even without allocating any of the proceeds to this purpose, moreover—the dire fiscal needs of many advanced economies heightens the search for new and relatively efficient sources of revenue.

Despite their evident importance, however, these issues have attracted almost no attention from public finance economists.[6] They have been left instead to industry specialists, their consultants, and civil society organizations. The issues are not easy ones, either politically or technically. Beyond the lobbying for sectoral or national interests are deep issues of international competition and coordination, as well as very practical challenges of implementation. And these are complicated by the need to reconcile the principle of equal treatment of carriers and nations that is fundamental to the operations of both the ICAO and IMO with the principle of "common but differentiated responsibility" that is embedded deep in international climate negotiations. Reconciling the two appears to require pricing schemes with wide participation, combined with some form of compensation to developing countries participating in pricing schemes.

Our aim in this paper is to show that, while it does not resolve all issues, applying the tools of tax analysis—thinking through, for instance, issues of incidence and the implications of other tax distortions—can go a long way towards identifying mutual beneficial and practically feasible reforms to undo, or at least lessen, the massive anomalies in the tax treatment of these key sectors.

The plan of the paper is as follows. Section II describes key features of the two sectors and the various anomalies in their tax treatment; though they are commonly lumped together in discussions such as the present, there are important differences between them. The potential environmental, revenue, and welfare gains from alternative response to these anomalies are addressed in Sections III and IV, dealing with the two sectors in turn. Section V considers issues of implementation, and Section VI concludes.

II. BACKGROUND

A. Emissions and their (Non-) Pricing

In 2007, international aviation accounted for about 1.5 percent of global (energy-related) CO_2 emissions and international shipping for about 2–3 percent.[7] Without mitigation measures,

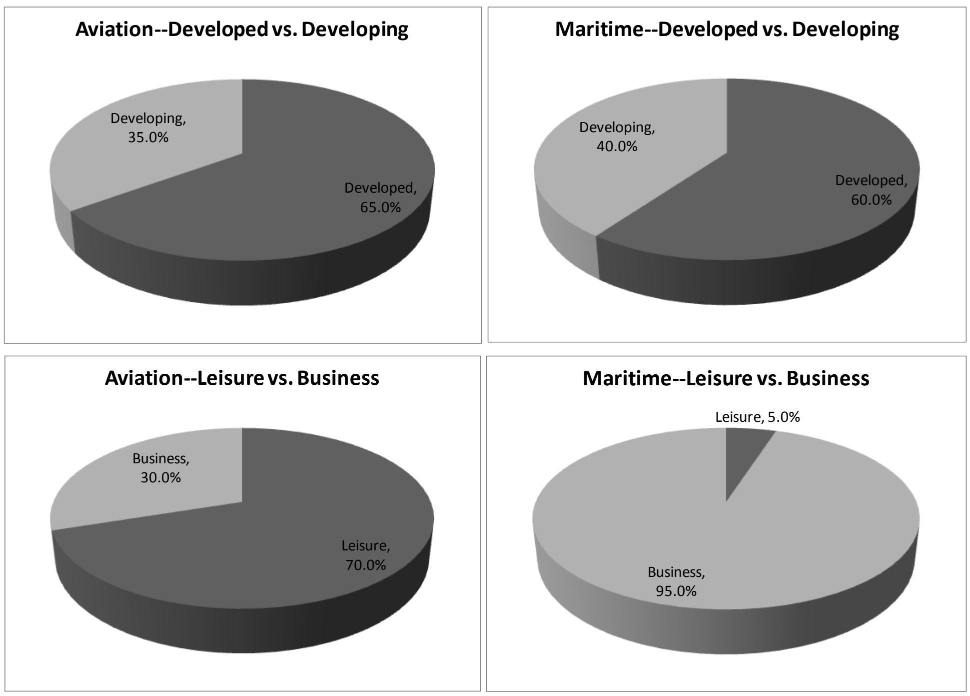
[6] An exception is Keen and Strand (2005).

[7] Aviation emissions may have a still larger warming effect because fuel combustion at high altitude may have a greater 'forcing effect' on climate through the effect of non-CO_2 gases on forming cirrus clouds and ozone (both of which trap heat). This is ignored in what follows, however, since the magnitude—and even the direction—of this effect is uncertain (IPCC, 1999; Kollmuss and Crimmins, 2009; Kollmuss and Lane, 2009).

the share of these sectors in global emissions is expected to expand rapidly (with potential for substantial air traffic growth in Asia, for instance);[8] on some estimates, the collective share could rise to 10–15 percent of global energy-related emissions, on a climate forcing basis, by 2050.[9] (There are other non-carbon related environmental problems associated with these sectors, but for brevity we ignore these).[10]

Figure 1 illustrates two features of fuel use in the two sectors that will prove important: the upper panels show, in each case, a large part of all fuels used in these sectors, 35–40 percent, is taken up in developing countries; the lower shows a great difference between the two, however, in the importance of leisure-related travel; this accounts for about 70 percent of international aviation emissions, but only 5 percent of those from international maritime.

Figure 1. CO_2 Emissions from International Aviation and Maritime, 2007



Sources. ICAO (2009), IMO (2009, 2010 a), and authors' calculations.

Notes. For maritime, fishing (though largely conducted in international waters) is considered a domestic activity. Most ferry and cruise trips are counted as international. There is some disagreement over the share of emissions attributable to developing countries. AGF (2010b), Table 6, for example, puts this share at 50 percent. The leisure/business split for aviation is for passenger traffic alone, representing a simple average of calculations for the U.K., Australia, and Norway,

[8] See AGF (2010b), IMO (2009).

[9] For the predictions to 2050, see (AWG-LCA, 2008).

[10] Other externalities from air travel include local pollution, noise, and congestion at, or in proximity to, airports, while for shipping they also include local pollution (to the extent emissions are blown on-shore) and oil spills (e.g., Brueckner, 2002; Corbett and Fishbeck, 2001). If fuel taxes are the only available instrument, these broader externalities warrant higher corrective tax levels (Keen and Strand, 2007; Parry, Harrington, and Walls, 2007), though ideally more finely-tuned instruments would be combined with CO_2 charges (see Section 6). Gauging efficient tax levels is, however, hampered by lack of analytical work on externality assessment.

and based on data collected by the authors. For maritime activity, this split is even more uncertain but is below the 9.5 percent passenger share.

In both sectors, many non-pricing measures can and have been undertaken to reduce emissions. These include fuel-saving technology adoptions (such as use of lighter materials in plane frames and ships, more efficient engines, smoother surfaces to reduce drag); retirement of older (more polluting) vehicles and vessels; more efficient operations (better scheduling to reduce idling at ports and runways, optimizing routes and speeds to economize on fuel use, better maintenance of engines and frames).[11] Under the auspices of the ICAO, industry standards are being implemented to improve new-plane fuel economy and promote more efficient operations. And the IMO has adopted mandatory regulations, such as progressively rising emission standards for new vessels (of 400 gross tonnage and above), to reduce projected CO_2 emissions from international shipping by about 10 percent by 2020 (IMO, 2011b).

Nonetheless, it is widely recognized that explicit pricing of emissions is needed both to strengthen such measures and to ensure that mitigation is achieved in the least costly way (by equating the marginal cost of alternative emissions reductions policies). Global progress on carbon pricing has of course been slow in general, but especially so in relation to international aviation and maritime.

In terms of pricing measures actually taken, potentially something of a precedent is provided by the 'Air Ticket Solidarity Levy' (ATSL) now imposed by eleven countries—including several developing countries—on airline tickets for outbound international flights, proceeds from which are earmarked to finance health improvements in low-income countries.[12] But by far the most significant measure has been the hotly debated inclusion of aviation in the EU-ETS[13]—with the EU also indicating its intention to include international maritime in the EU-ETS, too, if progress is not forthcoming in the IMO. This, as noted above, has now been suspended for one year to allow the ICAO to move forward with a global-based alternative.

Deliberations within the ICAO have, so far, produced a set of principles and a preference for three possibilities: an 'emissions trading scheme' (ETS)—a scheme, that is, under which a fixed cap for emission from the sector is fixed, and associated rights to emit freely traded—combined with generous 'offset' provisions (by which expenditures leading to emissions reductions outside the system give corresponding rights to emit); and pure offsetting schemes with and without levies on transactions to raise revenue (see WWF, 2012). Strikingly, these

[11] For further discussion of fuel-saving possibilities see, for example, McCollum, Gould, and Greene (2009), IMO (2009, 2011), World Bank (2012).

[12] Receipts from the levies, which vary from US $1 for economy tickets, $10 for business tickets and $40 for first-class tickets, are passed to UNITAID. See www.unitaid.eu/about/innovative-financing-mainmenu-105/163.

[13] Under the EU plan, which would cover about 4,000operators, emissions from all flights that arrive at or depart from a European airport would be capped at 95 percent of industry average emissions for 2004–06 out to 2020; 82 percent of the allowances would be given away for free.

ICAO principles rule out a tax on emissions, even though, as emphasized later, this option is on economic grounds an especially attractive one. On the maritime side, the IMO has also assembled a set of pricing proposals (IMO, 2011a), which are still under consideration by an expert group; again, a tax is not among the options identified. Both ICAO and IMO envisage that some part of the proceeds of any charge would be earmarked to support technological developments in the sector.

The exclusion of international aviation and maritime emissions from carbon pricing initiatives to date and the absence of country-level emissions targets under the 1997 Kyoto Protocol[14] reflect the difficulty of agreeing to principles on how to allocate them for inclusion in national targets—a conceptual ambiguity that, by the same token, increases the appeal of charges on such emissions as a common rather than a national source of revenue, and so as a natural source of meeting climate finance pledges set out above.

Even more striking—since it is not clear that this theoretical ambiguity need constrain the practical exercise of sovereign tax powers—is that, in contrast to common practices for highway fuels, international aviation and maritime fuels are not subject to national excise taxes (which would in effect be a form of carbon pricing, there being a mechanical link between the burning of fuel and the emission of CO_2.[15] The reasons for this, however, are somewhat different in the two sectors.

For aviation, a proximate cause lies in the 1944 Chicago Convention and various bilateral air service agreements that present legal obstacles to taxing fuel.[16] Even in the absence of such restrictions, however, fuel tax rates might be expected to be inefficiently low: partly because of the standard free rider problem in addressing global environmental problems—if one country sets a sub-optimal emissions charge, the resulting environmental damages are largely borne by other countries—but, also, and perhaps more to the point, because of international

[14] Article 2(2) explicitly refers the search for mitigation strategies in these sectors to the ICAO and IMO.

[15] For simplicity, we treat fuel and emissions charges as equivalent instruments, which is appropriate in the absence of possibilities for blending non-oil based fuels (e.g., bio-fuels) to lower average CO_2 emissions. The future viability of non-oil based fuels for both forms of transport is uncertain, and measuring lifecycle emissions associated with their production (especially if increased biofuel production results in land-use changes that produce offsetting emissions) can be contentious.

[16] The Chicago Convention itself prohibits only the taxation of fuel arriving in aircrafts' tanks. But subsequent ICAO resolutions, consolidated in 1999—having essentially the same effect as treaty provisions—enjoin contracting States to grant reciprocal exemption of fuels taken up for international aviation (commercial and private). Amendment requires approval by a two-thirds majority (128 States), and would not be binding on States that did not subsequently ratify it. The terms of bilateral Air Service Agreements—of which there around 4,000—vary, but generally provide similar exemption. Amending these BSAs to allow for the reciprocal taxation of fuels can be straightforward—it would not be necessary to reopen or renegotiate them all. Where a BSA is silent over its own amendment (as for instance is the model US BSA), Vienna Convention rules apply and reciprocal taxation could simply be introduced by mutual consent. EU Member States have the right to tax fuel used on flights between them, by mutual consent (Directive 2003/96/EC).

tax competition: the pressure that national governments would be under to set relatively low rates to preserve or enhance their receipts from an internationally mobile tax base (AGF, 2010b; IMO, 2010b; Keen and Konrad, 2012). The pressures are moderated, however, by the high cost of diverting to other airports for re-fueling (which requires additional stops or carrying more fuel). Moreover, tourist destinations (which have been a particular concern) have some elements of uniqueness, so charging for fuel used in flights to these countries may cause only a moderate relocation of flight activity.

For maritime transport, there appear to be no legal obstacles to taxing fuel.[17] That no country does so appears to reflect pressures of international tax competition that are in this case extraordinarily intense. Large ships—which are the ones that matter in terms of sectoral emissions—can undertake very long voyages on a single bunkering of fuel, allowing them to tank up in ports with competitive fuel prices. A panamax bulk carrier, for example, can travel between Sydney and Singapore four times on a single fueling (AGF, 2010b), and (in contrast to planes) container and other volume ships can happily carry large quantities of fuel for ballast, replacing it with water as it is used. This means that no country can raise taxes on its own maritime fuel disbursements without risk of substantially eroding the tax base: the only attempt to impose a tax on international maritime fuels appears to have been that in California in 1991, when an 8.5 percent sales tax was imposed; within two months, fuel disbursements in California fell 70 percent as ships switched to fuelling elsewhere (notably in Panama), and the tax was removed in 1992 (Michaelova and Krause, 2000).

B. Other Tax Privileges[18]

International aviation and maritime transport are almost unique in being routinely excluded from the value added tax (VAT)[19]—more precisely, being 'zero-rated' (meaning that those providing the service charge no tax on sales, but receive a full refund of VAT charged on the inputs used to provide those services).[20] This may have reflected some presumption that they are exports—which are indeed universally zero-rated, the objective of the VAT being to tax domestic consumption. But this is not a convincing rationale, since the converse of zero-rating exports is the full taxation of imports, and there is no such taxation for international aviation and maritime.

[17] Rodriguez (2012), for instance, concludes that there would be no legal obstacle in including maritime in the EU-ETS.

[18] The absence of taxes on aviation tickets may come as a surprise to readers who have looked at the breakdown of the prices they are charged. But it is common to lump under this heading charges that are really fees for services, such as security, and that do not raise revenues on net for the government.

[19] Or from sales taxes in the few countries—notably the United Sates—that do not apply the VAT.

[20] Application of the VAT or sales tax to domestic tickets is common, though usually at reduced rates (Keen and Strand, 2007).

The more fundamental reason for this practice is instead that these sectors are a classic instance of the more general conceptual and practical difficulties of taxing border-crossing services. The difficulties are twofold. The first is that of deciding on the 'place of supply', meaning the jurisdiction that has the right to levy that VAT: quite 'where' a supply of international transport occurs is far from obvious (where the journey begins or ends; where the purchaser is registered or resides?). The second is that of providing arrangements to ensure that, in line with the logic of the VAT as ultimately bearing only on final use by consumers, the tax does not bear on business purchases. Substantial effort has gone into developing guidelines for the VAT treatment of international services in recent years, in both the OECD and European Commission, the general principles emerging being to zero-rate purchases by registered businesses but tax sales to final consumers taxed according to where the consumer resides. The latter, in particular, is not easy: the seller must levy a different VAT rate according to where the consumer resides (even if it has no physical presence there itself) and transfer the proceeds to the consumer's government. In the development of these guidelines, however, little thought seems to have been given to the application of these principles in the specific case of international aviation and maritime transport. No doubt that largely reflects the mind-set that these are conventionally not taxed. The complexity of the international relations involved in their commercial activities (especially, perhaps, aviation) does mean, however, that application of the VAT in these is likely to be especially challenging—and remains, in any event, a somewhat remote prospect.

Whatever the rationale, the failure to levy VAT on international aviation and maritime is a potential concern in terms of both the implied increase in the demand for these services[21]—and hence in associated emissions—and the revenue foregone. Exclusion of services provided to businesses, it should be stressed, is not a particular problem, since it is a general principle of tax design[22] to credit or refund charges on inputs purchased by businesses (other than those reflecting externalities from their activities—precisely the purpose of a carbon charge): such taxes distort input choices and can lead to tax-driven vertical integration. What is a problem, however, is the non-taxation of purchases by final consumers. This is a far greater problem for aviation than for maritime: leisure-related travel accounts for about 60 percent of international aviation emissions; for international maritime emissions, in contrast, less than 10 percent (on a fuel-consumption basis) is passenger-based (Figure 1).[23]

[21] Relative, that is, to taxation of all goods and services at a uniform rate. The implication of the large theoretical literature on when uniformity is optimal that is most relevant here is that efficiency generally requires a higher rate on items more complementary with leisure (to ease disincentives to market work). This makes leisure travel a candidate for differentially high taxation so that in taking uniformity as the benchmark, we err on the side of conservatism in the later discussion of the proper level of tax rates.

[22] Based on the results of Diamond and Mirrlees (1971). Formally, these rest on quite restrictive assumptions (such as the ability to tax pure profits at any preferred rate); for practical purposes, they simply create a presumption that it is best not to tax intermediate unless some good reason is given to do so.

[23] The distinction between leisure- and work-related travel is distinct from that between formal travel classes (economy, business, and first). For example, while most business class travel is likely business related, many business-related trips are made on economy class. Keen and Strand (2007, Table 12), provide a distribution of overall air travel for 2003 by travel class as defined by airlines, showing that about 8 percent of total air

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More striking in relation to the maritime sector is the unique form of corporate income taxation that commonly applies. Shipping is now often subject not to the normal corporate tax regime based on some measure of profits, but to 'tonnage' tax regimes: a presumptive charge related to a vessel's net tonnage.[24] These special regimes are in practice seen as more favorable than the normal corporate tax regime, potentially implying an average effective tax rate of less than one percent.[25] They have become increasingly common, and are now applied by several major countries (including, for instance, Denmark, Greece, the Netherlands, Norway, the United Kingdom, and the United States). The proliferation of these regimes—recognized as a form of state aid in the European Union, but permitted under stated conditions—is a clear and in many cases explicit response to intense tax competition in the sector, initially in reaction to favorable tax regimes in countries maintaining open registers but now more general. Their implication is a relatively low marginal effective rate that encourages investment in these sectors and a relatively low average effective rate that may encourage entry; meaning a misallocation of capital toward shipping and away from other activities and, once again, both a loss of revenue and a tax bias toward higher output—and emissions.

The general context is thus one in which emissions from these sizable sectors are not only subject to no charge, but also in each case further encouraged by tax provisions that create further distortions.

C. Fuel Charges and other Tax Instruments

Addressing these several anomalies generally requires deploying or reforming several tax instruments. Efficient taxation will generally involve, for instance, both a VAT (or other tax on final sales)—at a rate reflecting revenue needs, preference, and production structures and the availability of tax-transfer or other devices to address equity concerns—and a corrective charge on fuel use—at a level reflecting the external damage associated with its use and the distortions created by its interaction with other taxes: details are in Keen and Strand (2007). Since the nature of optimal policy when the VAT is applied is well understood, and because, nonetheless, application of the VAT to these sectors appears even more remote than some form of carbon pricing, it is assumed in what follows that only a fuel charge (or simple tax on all ticket sales) can be employed. This lends an important role to carbon pricing beyond that of mitigating emissions: that of serving as an imperfect device to correct other tax distortions.

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passenger travel that year was in business class, about 1.5 percent in first class, and the rest in economy class. Airlines' revenue share from premium classes was however larger, about 30 percent.

[24] Net tonnage refers to a ship's displacement space for holding cargo. The precise form of tonnage taxes, and conditions attached, vary, but common features include a rate that falls with tonnage (a rough proxy for profits). Many countries also provide exemptions for capital gains on sales of ships, and preferential personal and payroll taxes for shipping labor.

[25] See Ernst and Young (undated) for a listing of countries with tonnage taxes.

D. Carbon Prices, Fuel Prices, and Product Prices

In the illustrative calculations that follow, we mostly focus on policies—whether emissions taxes or an emissions trading scheme (ETS)—applying a charge equivalent to $25 per (metric) ton of CO_2 in year 2020, though we also examine other cases (all monetary figures here are in year 2011 US$). $25 per ton is broadly consistent with a recent US interagency assessment of climate damages (US IAWG, 2010) though some would argue for much higher damage values based on lower discount rates or extreme climate risks.[26]

The incidence of emissions pricing of this kind may of course in part be on oil producers and refiners, to an extent that depends on the ease of substituting in production away from aviation and bunker fuels.[27] To the extent that this results in a reduced price of other forms of oil, any reduction in emissions from aviation and maritime fuels could be offset, at least in part, by increased emissions from other hydrocarbons. This issue is explored in IMF-World Bank (2011), the conclusion being that the effect is likely to be modest at reasonable values of the elasticity of substitution in production and of the derived demands for alternative fuels.[28] In what follows, it is simply assumed that emission prices are fully passed on into the fuel prices paid by purchasers.[29]

It is also assumed throughout that increased fuel prices are fully passed on into air ticket prices and maritime transport charges. This puts aside, in particular, the possibility of 'over-shifting' the price to the purchaser increasing by more than the amount of the tax—created by imperfections of competition.[30] This does not seem to be a major concern in international aviation[31] but may be an issue in some segments of international maritime industry.[32] The

[26] See Pindyck (2012) for an even-handed discussion of the key controversies.

[27] Jet fuel is the same as kerosene which has several other uses, in particular for heating and lighting in many low-income countries; and can be produced by refineries in alternative quantities such that its basic price (net of taxes and handling costs) would tend to follow that of crude oil. Bunker fuel for shipping is a relatively low-grade refinery product, but can also in principle largely be processed into other uses such as diesel, with the same basic effect.

[28] The simulations there suggest that, for quite a wide range of parameter values, a $1 charge on production of these fuels might lead crude oil prices to fall by around 5 cents.

[29] More fundamental incidence issues potentially arise from the exhaustibility of hydrocarbon resources-a long run inelasticity that can in some cases imply that the incidence would be fully assed back into their selling prices, eliminating any cumulative effect on emissions (corresponding to Sinn's (2008) "green paradox"). How likely this is—given for instance the vast stocks of coal—remains contentious.

[30] As analyzed, for instance, in Stern (1987).

[31] See in particular Brueckner (2002), Bruckner et al (2011), who argue that the formation of airline alliances (three of which cover close to 90 percent of total international air passenger traffic) has increased competition by facilitating more than one connected route between remote destinations.

[32] Hummels, Lugovskyy, and Skiba (2008) argue that imperfect competition in shipping significantly raises shipping costs for developing countries. This appears to be an issue mainly for international container traffic, dominated by a small number of groups, Maersk alone holding a more than 20 percent market share. The

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neglect of any such effect would tend to be offset, to some degree, by the neglect of potential pass back of a charge on these fuels onto crude oil prices.

III. Policies for International Aviation Emissions

This section considers the impacts of aviation fuel charges (and air travel taxes) on emissions, revenue, and welfare, before considering wider issues of cross-country incidence; the next section provides a parallel treatment for international aviation.

Analysis

To analyze—and, especially, quantify—the implications of the considerations raised above, we start by setting out some simple formulae and plausible values for the critical parameters that emerge.

Fuel and emissions

Total CO_2 emissions from international aviation are simply $E = eF$, where e denotes (fixed) tons of CO_2 emissions from combusting a liter of fuel, which we take to be 0.0025 tons (EIA, 2011a, Table 2). We assume baseline emissions from international aviation in 2020 of 500 million tons,[33] implying (dividing by e) initial fuel use of 200 billion liters. We take the initial price of aviation fuel to be 90 (US) cents per liter, based on the US price in 2011 (EIA, 2012).

Denoting by A and p_A respectively the quantity and consumer price of, air travel, the own-price elasticity of the demand for fuel, assumed to be a constant η_{FF}, can usefully be decomposed as (Parry and Small 2005; Small and Van Dender, 2006):

$$\eta_{FF} = \frac{dF}{dp_F}\frac{p_F}{F} = \beta\eta_{AA} - \eta_{FE}, \qquad \beta = \frac{p_F F}{p_A A} \tag{1}$$

where p_F denotes the proice of fuel, β the share of fuel costs in the price of travel services(which, from GAO (2009) we take to be 0.3--ignoring the small changes in β in response to fuel charges); $\eta_{AA} < 0$ is the own-price elasticity for air travel services, reflecting substitution between air travel and other transport modes and products, but not (since we focus on globally applied charges) inter-regional relocation of flight activities; and $\eta_{FE} > 0$

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problem is particularly serious for the smaller and more remote developing countries, in particular small-island states which are often served by only one shipper, and goods volumes are low. Wang (2010), in particular, estimates that these costs are particularly high for Antigua, Tonga, and the Marshall Islands. See otherwise Cristea et al (2013).

[33] Based approximately on ICAO (2009) and making a downward adjustment of 20 percent to allow for ICAO's recent emission reduction pledges (see above).

is the elasticity of aircraft fuel economy with respect to fuel prices.[34] An important role will also be played by

$$\sigma = \frac{(F/A)dA/dp_F}{dF/dp_F} \equiv \frac{\beta\eta_{AA}}{\eta_{FF}} \ , \qquad (2)$$

which is the fraction of the (marginal) reduction in fuel use that is due to reduced travel demand (rather than increased fuel economy).

Based on studies on the price-responsiveness of air travel demand, summarized in Table 1, we take a benchmark case with η_{AA} = -1. There is a good deal of evidence on the fuel economy elasticity for cars—a widely cited study for the US by Small and Van Dender (2006) suggests a value of around 0.2—but as noted in Morris et al. (2009), there appear to be none for aircraft. We use a benchmark value for η_{FE} of 0.2, though we discuss the implications of other values. Lower values in particular might be appropriate given, for example, already strong incentives for airlines to economize on fuel (which is very expensive to carry) and ongoing efforts to promote better fuel economy (noted above). These benchmark assumptions imply η_{FF} = -0.5 and σ = 0.6; for sensitivity analysis we consider cases where η_{FF} = -0.25 and -0.75, and $\sigma = 0.4$ and 0.8.

Table 1. Summary of Estimated Price Responsiveness of International Air Travel by Trip Type

Type of trip	Median price-elasticity estimate	Range
Long-haul international business	-0.27	-0.48 to -0.20
Long-haul international lesiure	-1.00	-1.70 to -0.56
Long-haul domestic business	-1.15	-1.43 to -0.84
Long-haul domestic leisure	-1.10	-1.23 to -0.79
Short-haul business	-0.70	-0.78 to -0.60
Short-haul leisure	-1.52	-1.74 to -1.29
Simple average	-0.96	

Source. Various studies summarized in Gillen, Morrison, and Stewart (2002).

Revenue

We consider only direct revenue from fuel charge, given by $t_F F$ (so ignoring possible indirect effects on other revenue sources).

[34] Here we assume that the number of flights changes in proportion with passenger demand, so travel demand and fuel economy are both defined either with respect to vehicle miles or, equivalently, passenger miles.

Welfare effects

These are derived, in Appendix A, from a model in which the tax system of a representative country is consolidated into a tax on labor income (or equivalently, general consumption) and a (tax-) subsidy for aviation (capturing zero-rating under the VAT). Preferences are assumed to be such that, externalities aside, an efficient tax system would tax the final consumption of leisure-related air travel at the same rate as other consumer goods (and would not tax business use at all). If anything, as noted above, one might expect leisure-related travel to be a relatively strong complement for leisure, which in optimal tax terms would point to taxing air travel at a higher rate than the generality of commodities. To focus on essentials, however, we leave this possibility aside. We assume revenue from fuel charges to be used to lower (distortionary) domestic taxes; the analysis would be unaffected if this revenue financed (domestic or international) spending that yielding gains comparable, at the margin, to those from reducing distortionary taxes.

The marginal welfare gain from an increase in the aviation fuel charge t_F in this setting is shown in the Appendix to be given by:

$$dW = (\hat{t}_F - MCPF \cdot t_F)\left(-\frac{dF}{dp_F}\right) + MCPF \cdot s_A \cdot p_A \cdot \left(-\frac{dA}{dp_F}\right) \qquad (3)$$

Several critical quantities are introduced here. *MCPF* is the ‘marginal cost of public funds’ for the broad labor tax, that is, one, plus the efficiency cost from raising an extra dollar of revenue through this tax (which is essentially a transform of the elasticity of taxable income). This varies across countries due to differences in their tax rates and labor supply responses: for illustration, we consider a plausible—but, if anything, probably conservative—range for it of 1.1 to 1.3, with a benchmark value of 1.2.[35] The term $\hat{t}_F$ is the corrective (‘Pigovian’) fuel charge to reflect the external harm its use creates at the margin, effectively *e* times marginal damages per ton of emissions. For this (see above) we use illustrative values of $25 per ton, a higher value of $80 per ton (based on some results in Judd et al. 2012) and a lower value of $15 per ton. These damages imply corrective fuel charges of 3.8, 6.3, and 20.2 cents per liter. Finally, s_A is the effective rate of tax subsidy for aviation (due to zero-rating under the VAT), expressed as a fraction of aviation ticket prices. Implicitly it is the product of three components. One is the standard VAT rate, which we assume is 0.2. Another is the share of value-added in the value of ticket prices, which we take to be 0.5.[36] The third is the

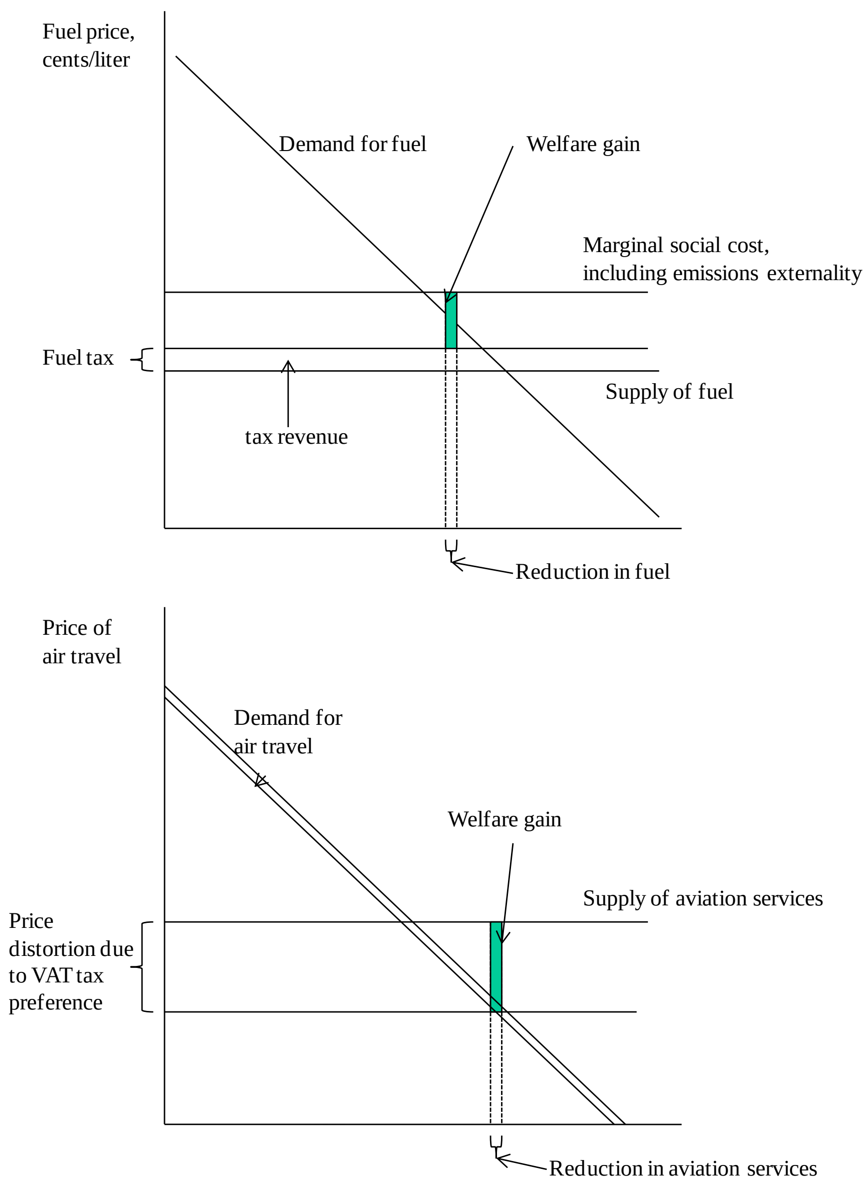
[35] There is much controversy (see Keane and Rogerson, 2012) about whether the behavioral responses to labor income taxes are fairly modest (as generally suggested by empirical micro studies in the labor literature and assumed here) or much larger (as generally suggested by the macroeconomics literature). Recent literature also indicates that the MCPF can be substantially higher in countries—like the United States—where there are large tax preferences (for employer medical insurance, homeownership, etc.) that introduce large distortions in the pattern of spending (e.g., Saez et al. 2012).

[36] The choice of illustrative VAT rate is from an internal IMF database of rates among different countries. The VAT share is based on an assumption that labor accounts for 70 percent of non-fuel aviation supply costs, which is about the economy-wide average for many countries. In turn, non-fuel aviation costs account for about

(continued)

portion of air travel that is leisure-related, as opposed to business-related—any VAT on the latter would in principle be rebated, as discussed above; we take this fraction to be 0.7 (from Figure 1). Overall therefore, s_A = 0.07. For sensitivity we also consider the cases in which s_A = 0.02 and 0.12.

Figure 2. Marginal Welfare Effects of a Fuel Charge



70 percent of total production costs (see above), hence value added (payments to labor) is about 50 percent of total costs.

The marginal welfare gain in (3) consists of two (straightforward) components. The first is the reduction in fuel use times the gap between environmental benefits per liter reduction and the welfare cost of the tax increase itself. Ignoring, for a moment, the value of public funds, the latter is the fuel tax (the wedge between consumer and producer surplus in the fuel market). The top panel of Figure 2, which shows the derived demand for and (perfectly elastic) supply o of fuel illustrates, with this first component of welfare gain corresponding to the shaded rectangle. Accounting for the value of tax revenues however, implies an additional cost of $(MCPF - 1) \cdot t_F$, because a liter reduction in fuel use implies that other distortionary taxes must be increased to maintain the government's budget, and each dollar of revenue from broader taxes causes a deadweight loss of *MCPF*-1.

The second component of the welfare gain in (3), again ignoring the value of public funds, is the reduction in air travel (as higher fuel taxes are passed forward into higher fares) times $s_A \cdot p_A$, which is the wedge between the marginal costs of supplying a unit of air travel and marginal consumer benefits (and positive because of the tax-subsidy). This corresponds to the shaded rectangle in the lower panel of Figure 2, the demand curve there being that for leisure air travel. There is a further gain, however, because reducing air travel reduces the base of the subsidy, implying that (marginally) less revenue needs to be collected from broader distortionary taxes to finance the government's budget.

From (3), the optimal fuel charge is given by

$$t_F^* = \frac{\hat{t}_F}{MCPF} + \frac{s_A \cdot \sigma \cdot p_F}{\beta} \quad (4)$$

This optimal charge can principle be either above or below the Pigovian charge $\hat{t}_F$. If there were no tax-subsidy (s_A = 0) it would simply be the Pigovian charge divided by the *MCPF*—a familiar result from the environmental tax literature (Bovenberg and de Mooij 1994).[37] However, a higher tax than that is warranted (on second-best grounds) to the extent it offsets the distortionary tax-subsidy for aviation from the broader fiscal system. This upward adjustment to the emissions tax is larger the greater are the tax-subsidy and the fraction of the fuel reduction that comes from reduced travel (because the former implies a taller rectangle in the lower panel of Figure 2, and the latter a wider base) and the less important are fuel in total costs (since then a larger fuel charge is needed to dampen the subsidy-induced expansion of demand).

For the simulations, we compute the (total) welfare gain from the fuel charge by numerically integrating (6), after expressing it as a portion of the initial fuel cost.

Air travel taxes

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[37] For this case, the optimal tax is (moderately) below the Pigovian tax because raising the tax (to reduce the externality) erodes its base (implying efficiency losses from higher distortionary taxes elsewhere).

Experience with the ATPL mentioned earlier suggests that imposing taxes on air tickets may be more practicable, at least for the short term than applying VAT to the sector (the difference between them being that the VAT, but not the ticket tax, would in principle exclude business use) [38]—indeed may be more immediately practicable than a fuel charge.

Such a ticket tax, which reduces travel demand (in the same way that a fuel tax does) but (unlike a fuel tax) has no effect on fuel economy, is also considered in Appendix A, where expressions analogous to those above are derived. Two main differences emerge. First, for the ticket tax (translated, using the fact that fuel use per unit output will be unaffected, into a 'virtual' tax on fuel), fuel demand is less price-responsive than in (1), as the relevant elasticity ($\sigma\eta_{FF}$) reflects only the impact on reducing travel demand. Second, the welfare gain per (tax-induced) liter reduction in fuel use is larger than before: each liter reduction still produces the same welfare gain in the fuel market (reflecting the gap between environmental benefits and the tax rate, adjusted for the *MCPF*), but there is a larger welfare gain from the reduction in air travel, because all (rather than a fraction) of the reduction in fuel use is due to reduced travel.

The optimal virtual fuel tax is larger than in equation (7) for the same reason—it generates a larger welfare gain from reduced travel, per liter reduction in fuel use (the corrective component of the optimal tax is the same in both cases however, as this is the same, regardless of the responsiveness of fuel demand to the tax). On the other hand, welfare effects are integrated over a smaller reduction in fuel use, given the absence of the fuel economy response. Therefore, theory is ambiguous on whether fuel taxes or ticket taxes yield higher welfare gains—it depends on parameter values.

Quantifying effect on emissions, revenue, and welfare

Using the equations and parameter assumptions above and in Appendix A, Table 2 summarizes (for both taxes) the effects on emissions, (global) revenue, and welfare, along with sensitivity analysis on optimal taxes.

The results in the first row show that if taxes are set at their corrective level—\$25 per ton of CO_2 or, equivalently, 6.3 cents per liter—the reduction in emissions is relatively modest: about 3 percent for the fuel tax and 2 percent for the fuel tax equivalent of the ticket tax. Revenue raised is correspondingly sizable, at about \$12 billion. Welfare gains are similar in either case, at roughly 0.5 percent of initial fuel costs. Although the behavioral response to

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[38] The air passenger duty in the U.K. is broadly of this form, being chargeable on individual air departures in an amount that varies by distance and travel class. It varies from £13 for flight distances of 0–2000 miles up to £92 for flight distances above 6000 miles in economy class, and twice these rates in premium classes. No other country currently has similar charges, although many countries have individual rates that do not vary with flight distance, and are lower; see 2005 figures in Keen and Strand (2007), Table 4.

Table 2. Aviation: Impacts on Emissions, Revenue, and Welfare from Alternative Tax and Parameter Scenarios

	fuel tax				ticket tax or virtual fuel tax with fuel economy fixed			
parameter scenarios	tax rate, cents per liter	emissions reduction, percent	revenue, $billion	welfare gain, percent of intial fuel cost	tax rate (fuel tax equivalent), cents per liter	emissions reduction, percent	revenue, $billion	welfare gain, percent of intial fuel cost
taxes set at corrective levels								
benchmark	6.3	3.3	12.2	0.54	6.3	2.0	12.3	0.51
taxes set at optimal levels								
benchmark	17.8	8.6	32.5	0.85	26.2	7.4	48.5	1.07
higher environmental damages	29.3	13.1	50.8	2.14	37.7	10.0	67.8	2.08
lower environmental damages	15.8	7.8	29.1	0.68	24.2	6.9	45.0	0.92
higher tax-subsidy	26.8	12.2	47.1	1.82	41.2	10.7	73.6	2.45
lower tax-subsidy	8.8	4.6	16.8	0.22	11.2	3.5	21.6	0.22
higher portion of response from travel	22.0	10.4	39.5	1.27	26.2	9.7	47.3	1.41
lower portion of response from travel	13.6	6.8	25.4	0.51	26.2	5.0	49.8	0.73
higher fuel price elasticity	17.8	12.7	31.1	1.25	26.2	10.9	46.7	1.58
lower fuel price elasticity	17.8	4.4	34.0	0.44	26.2	3.8	50.4	0.55
higher MCPF	17.4	8.5	31.9	0.82	25.8	7.3	47.9	1.04
lower MCPF	18.3	8.8	33.3	0.90	26.7	7.5	49.4	1.11

Source: See the text and Appendix for the equations and parameter values underlying these calculations.

the ticket tax is more muted (implying smaller welfare gains), it directly targets the subsidy distortion which is larger than the environmental distortion (implying larger welfare gains)

From the second row, under benchmark parameters) the optimal fuel charge is much higher (almost three times as high) than the corrective charge, at 17.8 cents per liter. The optimal (fuel tax equivalent) of the ticket tax is even higher, at 26.2 cents per liter. The reason for these results is that the tax-subsidy distortion is much larger (about 3.5 times as large) than the environmental distortion: as noted above, the tax-subsidy is 7 percent of the total costs of air travel while the CO_2 externality is about 7 percent of fuel costs, or about 2 percent of the costs of air travel. Implementing the optimal (rather than just the Pigovian) fuel charges has a more sizable effect on emissions (which fall by 7.4 to 8.6 percent), and revenue (which is then $32.5–48.5 billion), and generates welfare gains that are around twice as large).[39]

From the third set of rows, the optimal ticket tax equivalent is somewhat larger than the optimal fuel tax, even if CO_2 damages are $80 per ton, because the subsidy equivalent distortion is still a little larger than (even this high) environmental damage.

Incidence and compensation

Low-income countries

The distributional impact of charges on aviation can be expected to be broadly progressive. Clearly, they would have some impact on travel costs of poorer groups in lower income countries (such as migrant workers), but most of the burden of higher air travel prices is likely to fall on travelers from higher income countries and relatively well-off domestic travelers. Indeed, in fact, as noted above, a number of lower income countries have imposed solidarity levies, suggesting few reservations on this account.

Nonetheless, the impact on low income countries has been a primary concern in discussions of charging international transportation fuels. The principle of "common but differentiated responsibility" in addressing climate problems is taken as implying that lower income countries should not suffer from measures of collective mitigation. Combined with the principles of equal treatment central to both the ICAO and IMO, it points to essentially global application of the charges combined with some allocation of at least part of proceeds to protect the most venereal countries.

Two possibilities for allocating revenue to address this concern come to mind. One is for lower income countries, somehow defined, to simply keep for their own use receipts from charges on fuel disbursements within their country for international flights. With a globally applied charge, and hence no distortion of decisions as to where to take up fuel, these

[39] Although the two taxes are only considered in isolation here, it is straightforward to show that the optimal fuel tax declines with the introduction of a ticket tax, and conversely, the optimal ticket tax is reduced to the extent a fuel tax internalizes the environmental externality.

disbursements would amount to about half of the total fuel consumed for a flight to and from another country. Another possibility might be to collect all revenue centrally, then rebate developing countries some revenue in line with inward passenger kilometers to that country as a share of global passenger kilometers traveled (or rebates might instead be based on passenger, freight, and mail combined, in ton- km). Either approach causes distortions. Under the first, developing countries have an additional incentive to establish themselves as hubs (to expand their revenue base), while under the second they have an incentive to encourage more passengers. Any compensation scheme linked to future outcomes will create distortions, however, and these do not seem unmanageable.

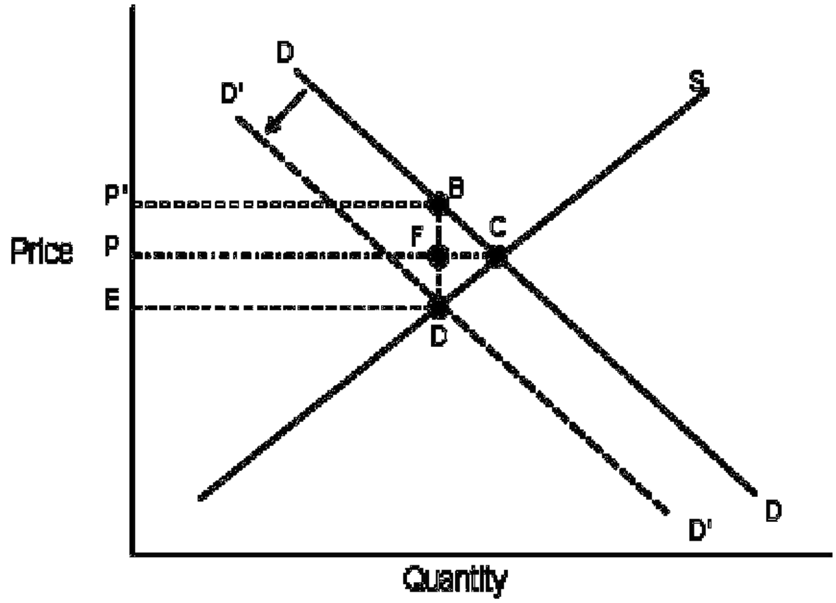
The first of these schemes is in some respects the more appealing. It is simpler, less demanding in its information requirements—and it seems likely to provide adequate compensation for the country as a whole. To see this, consider Figure 3, showing the domestic supply of tourism services for the developing country and the demand for these services taken (for simplicity) to come entirely from residents of developed countries. Charges on fuel used in flights into and out of the tourist country cause the tourism demand curve to shift down from *DD* to *D′D′*, by an amount that (assuming full pass through to the price of tourism services) reflects the underlying charge. The demand price rises to *P′* while the supply price falls to *P″* causing the usual losses in consumer and producer surplus, trapezoids *PP′BC* and *PCDP″*, respectively. Approximately half of the tax revenue, rectangle *P′BDP″*, will be collected by governments in other countries where flight legs *to* the tourist destination originate and the remainder by the tourist destination for flight legs *from* that country. It is straightforward to show that this (latter) revenue will provide adequate, or more than adequate, compensation for the loss of domestic producer surplus, for the modest price changes at issue here, so long as the price elasticity of demand for tourism is less (in absolute value) than the supply elasticity for tourism services. Estimates of the former vary widely (Lim, 2006) but the elasticity is likely (well) below unity so long as travel costs increase for all tourist destinations (as they would for a globally applied charge). Where tourism capacity is fairly easily varied, it is a reasonably plausible starting point to suppose that developing country tourist destinations will gain on net from the charge and compensation scheme.

Impact on the aviation industry

A uniform, globally applied, charge on international aviation fuel would not, to an approximation, impact competitiveness within the sector, since all airlines face the same fuel price increase.[40] Although airline prices would rise—by around 2–3 percent for levels of fuel taxation in the first row of Table 2, higher at the fully optimal levels—this would largely alleviate (rather than introduce) competitive distortions.

[40] There could still be some impact on their competitive positions relative to one another: ‘no frills’ airlines, for instance, for whom fuel costs tend to be a disproportionately larger portion of the ticket price (as per passenger fuel consumption is more difficult to manipulate by airlines than other variable costs) will lose some edge. But none is privileged by facing different input prices.

Figure 3. Tourism and the Incidence of an Aviation Fuel Charge



The industry itself has suggested that revenue collected from aviation fuel charges be largely retained in the sector, particularly to fund technology programs. Such earmarking runs counter to standard public finance principles: it either leads to an inefficient composition of public spending (there being no inherent relation between the efficient level of tax to correct for an externality and the efficient level of any spending program related to mitigating it) or to non-transparency if it does not. Earmarking does seem, nonetheless, to be more common in relation to environmental charges than to others, perhaps as a means of compensating the losers from the charge, perhaps to provide some assurance, given that the motive of such tax is commonly not primarily revenue-raising, to provide some protection against diversion of the proceeds to inappropriate use. In the present context, if there is some inefficiency in R&D in international aviation, the case for intervention to address this does not seem to hinge on whether a carbon charge is in place (if anything, is probably weaker if it is). If a case is to be made, it would perhaps be done most convincingly as a way to ease sectoral adjustment to a permanently higher fuel prices.

IV. Policies for International Maritime Emissions

This section provides a similarly-structured analysis of the international maritime sector. Again, the assumption is that the charge is globally applied—reflecting not least the extraordinary high mobility of the tax base.

More analytics

The formulae in Section 3 can also be used to compute the impacts on fuel use or emissions, and revenue, from charges on international maritime fuels—but of course with potentially different parameters.

For this case, the emissions coefficient (e) is 0.003 tons per liter; about 20 percent higher than for aviation fuels, reflecting the greater weight and carbon content of maritime fuels (EIA, 2011a). Baseline CO_2 emissions in 2020 are taken to be 1,050 tons,[41] implying initial fuel use of 350 billion liters. The initial fuel price is taken to be 67 cents per liter, based on 2011 prices.[42]

The own-price elasticity for maritime fuel can be decomposed as in (1). There are, however, now far fewer prior studies to draw on than was the case for aviation. Fuel costs are assumed to 30 percent of the cost of shipping freight (UNCTAD, 2011), so that β = 0.3. The price elasticity η_{AA} in (3) is now that of maritime services. For landed imports as a whole, it seems reasonable to assume an own-price elasticity of unity, given that that imported products are a mixture of necessities and luxuries. We scale this back by 90 percent, given that shipping costs are commonly around 10 percent of the value of landed imports (see Table 4 below) thus $\beta\eta_{AA}$= 0.03. The fuel economy elasticity η_{FE} is given, on the basis of judgment (again), a baseline value of 0.3, implying that now η_{FF} = -0.33: one might expect fuel economy to be somewhat more elastic than for aviation, because, for example, margins for economizing fuel use that are not available for aviation (such as reducing the use of fuel as ballast). For sensitivity analysis, we use elasticities of -0.2 and -0.7. We discuss the analog to σ below.

By the same token, the optimal charge formula for maritime fuels has the same structure as in (4), but with two differences (besides the differing parameter values already discussed). First, the denominator of the second term is now the ratio of (pre-tax) fuel costs to the value of capital (rather than the value of output) in shipping—as this parameter is picking up the size of the market with the tax subsidy relative to the fuel market. We assume that capital costs are 30 percent of total shipping costs (fuel costs are 30 percent, as mentioned above, and labor costs the remaining 40 percent): thus, fuel to capital costs are unity.[43] Second, in the numerator of the second term, σ represents the fraction of the fuel reduction that is due to capital shifting away from shipping. We assume that capital falls in proportion to the reduction in shipping output, and so, from the discussion above, now take σ = 0.09.

Results for the two taxes are summarized in Table 3 (with the same baseline for the MCPF as before).

As before, the first row looks at corrective charges. Per liter of fuel, these are moderately higher than for aviation (7.5 cents per liter compared with 6.3) due to the higher carbon coefficient for maritime fuel. Emissions fall in about the same proportion (3.3. percent) as for

[41] This is based on IMO (2009), after making a modest adjustment for enhanced technical and operational improvements in fuel economy.

[42] See Platts, August 29, 2011, see http://www.platts.com/Shipping/BunkerFuel/?WT.srch=1&gclid=CP_0hLHT9KoCFeMD5QodLkuIOw.)

[43] It is shipping costs that matter here, not the value of landed imports, since the tax subsidy only applies to capital used in maritime (and not to the capital used to produce products for shipping).

aviation—although the assumed price elasticity for maritime fuels is smaller, the proportionate increase in maritime fuel prices is larger because prior fuel prices are lower (67 cents per liter for maritime compared with 90 cents per liter for aviation).

On the other hand, increasing the tonnage tax has a far smaller proportionate impact on emissions compared with the corrective aviation ticket tax (emissions fall by just 0.3 percent here, compared with 2.0 percent in Table 2)—this is because fuel economy is relatively more responsive to maritime fuel prices (the fuel economy response accounts for an assumed 91 percent of the fuel price elasticity for maritime, compared with 40 percent for the aviation fuel price elasticity) so failing to exploit this response implies an (even more) limited emissions impact for maritime fuels.

Revenues raised from these corrective taxes are more than twice as high for maritime charges as for aviation charges. For instance, the corrective fuel tax raises $25.3 billion compared with $12.2 billion for the corrective aviation fuel charge. This essentially reflects the higher baseline fuel use for maritime.

The results in the second row show that the difference between the optimal and corrective fuel charge is much less pronounced—and in the opposite direction—for maritime—7.1 cents per liter (optimal) versus 7.5 cents per liter (corrective) for maritime, compared with 17.8 cents per liter (optimal) versus 6.3 cents per liter (corrective) for aviation. The main reason for this is that for maritime, the fuel tax has a much weaker impact on alleviating the broader tax-subsidy because nearly all of its effect is to increase fuel economy rather than reduce output and capital. In contrast, in the case of aviation, the downward adjustment to the optimal tax in equation (4), from dividing the first term by the MCPF, dominates the upward adjustment from the second term (due to offsetting the tax subsidy).

As for the tonnage tax/virtual fuel tax equivalent the optimal charge is 15.6 cents per liter, again much higher than for the fuel tax as it directly affects the largest distortion (the tax-subsidy). This charge is well below the virtual fuel tax equivalent of the optimal aviation ticket tax (26.2 cents per liter), mostly because the tax-subsidy is smaller (4 percent of shipping output compared with 7 percent for aviation).

The implications for optimal taxes of varying parameters are broadly to those already described for aviation taxes.

Just as the welfare analysis of an aviation fuel charge needs to recognize the pre-existing distortion of preferential tax treatment of leisure air travel, so that of maritime fuels needs to recognize the preferential treatment of shipping under the corporate tax. Appendix B sets out a framework allowing this. Since the pre-existing distortion is in each case a subsidy to the emitting sector, there emerges a strong analytical analogy between the two cases. Indeed it is shown in the appendix that the marginal welfare gain from a maritime fuel charge has the same structure as equation (6) above, and so, appropriately reinterpreted, applies here too.

The first component of the marginal gain from a maritime charge is exactly analogous to that in (3) above. Now, however, corrective fuel charge is moderately higher (given the lager carbon coefficient for maritime fuel) at 4.6, 7.6, and 24.2 cents per liter for the \$15, \$25, and \$80 damages per ton of CO_2 respectively. In the second component, the price coefficient is now the induced change in capital in the maritime sector, times the subsidy for capital (expressed as a fraction of the price of capital) times the price of capital. This is because the tax system distorts (subsidizes) the quantity of capital input into shipping, rather than distorting (as in the case of aviation) the output market—hence, efficiency is affected to the extent that capital inputs (rather than output) change. Calibrating the implicit subsidy to capital in shipping is not straightforward, since the bases of the tonnage tax and standard corporate tax are inherently different. Elschner (2013) cites evidence for German shipping firms that the tonnage tax is equivalent to roughly ten percent of the regular corporate tax. Assuming an effective tax rate under the regular corporate tax of 14 percent, this implies a benchmark value of the tax subsidy of 0.14.

By the same token, the optimal charge formula for maritime fuels has the same structure as in (4), but with two differences (beside the differing parameter values already discussed). First, the denominator of the second term is now the ratio of (pre-tax) fuel costs to the value of capital (rather than the value of output) in shipping—as this parameter is picking up the size of the market with the tax subsidy relative to the fuel market. We assume that fuel costs are 20 percent of total shipping costs, capital costs are 30 percent (and labor costs accounts for the remaining 50 percent). Thus, fuel to capital costs are 0.67.[44] Second, in the numerator of the second term, σ represents the fraction of the fuel reduction that is due to capital shifting away from shipping. We assume that capital falls in proportion to the fall in shipping output, and so, the discussion above, now take $\sigma = 0.2$.

Analogous to the ticket tax in the case of aviation, we also consider an increase in shipping tonnage taxes, which directly reduces the distortion from the tax preference. As before, we express this as its virtual fuel tax equivalent to facilitate comparison with the fuel tax. In doing so, we make the assumption that the amount of freight shipped falls in proportion to shipping capital so that (as with aviation) the tax differs from the fuel tax as it fails to exploit the fuel economy margin.

Quantification

Results for the two taxes are summarized in Table 3 (with the same baseline for the MCPF as before).

As before, the first row looks at corrective charges. Per liter of fuel, these are moderately higher than for aviation (7.5 cents per liter compared with 6.3) due to the higher carbon

[44] It is shipping costs that matter here, not the value of landed imports, since the tax subsidy only applies to capital used in maritime (and not to the capital used to produce products for shipping).

coefficient for maritime fuel. And fuel is more responsive to an (absolute) increase in the fuel tax because prior fuel prices are lower (67 cents per liter compared with 90 cents per liter for aviation). Consequently emissions fall by somewhat more (5.2 percent compared with 3.3 percent) in response to the corrective maritime fuel charge.

On the other hand, increasing the tonnage tax has a smaller proportionate impact on emissions compared with the corrective aviation ticket tax (emissions fall by just 1.1 percent here, compared with 2 percent in Table 2)—this is because fuel economy is relatively more responsive to maritime fuel prices (the fuel economy response accounts for 80 percent of the fuel price elasticity for maritime, compared with 40 percent for the aviation fuel price elasticity) so failing to exploit this response implies an (even more) limited emissions impact for maritime fuels.

Revenues raised from these corrective taxes are more than twice as high for maritime charges as for aviation charges. For instance, the corrective fuel tax raises $24.9 billion compared with $12.2 billion for the corrective aviation fuel charge. This essentially reflects the higher baseline fuel use for maritime.

The results in the second row show that the difference between the optimal and corrective fuel charge is much less pronounced for maritime—9.1 cents per liter versus 7.5 cents per liter (maritime), compared with 17.8 cents per liter versus 6.3 cents per liter (aviation). The main reason for this is that for maritime the fuel tax has a much weaker impact on alleviating the broader tax-subsidy because most of its effect is to increase fuel economy rather than reduce output and capital. Indeed reflecting this, revenue raised from the optimal maritime fuel charge is slightly lower than for the optimal aviation fuel charge ($29.7 billion versus $32.5 billion).

As for the tonnage tax/virtual fuel tax equivalent the optimal charge is 20.3 cents per liter, again a lot higher than for the fuel tax as it directly the biggest distortion (the tax-subsidy). This charge is somewhat smaller than the virtual fuel tax equivalent of the optimal aviation ticket tax (26.2 cents per liter), mostly because the tax-subsidy is a smaller (5 percent of shipping output compared with 7 percent for aviation).

The implications for optimal taxes of varying parameters are broadly to those already described for aviation taxes.

Incidence and compensation

Low-income countries

Likely impacts on landed import prices vary, but are in most cases small. Estimates reported in AGF (2010b; p. 38) suggest an impact from a charge of $25 per tonne of CO_2 of less than 1 percent for most items, though up to 2–3 percent for some commodities. For food, a particularly sensitive item, calculations in Table 4 (from Stochniol, 2011a) suggest modest

Table 3. Maritime: Impacts on Emissions, Revenue, and Welfare from Alternative Tax and Parameter Scenarios

	fuel tax				capital tax or virtual fuel tax with fuel economy fixed			
parameter scenarios	tax rate, cents per liter	emissions reduction, percent	revenue, $billion	welfare gain, percent of intial fuel cost	tax rate (fuel tax equivalent), cents per liter	emissions reduction, percent	revenue, $billion	welfare gain, percent of intial fuel cost
taxes set at corrective levels								
benchmark	7.5	3.4	25.3	0.17	7.5	0.3	26.2	0.06
taxes set at optimal levels								
benchmark	7.1	3.3	24.0	0.17	15.6	0.6	54.4	0.07
higher environmental damages	20.8	8.6	66.7	1.33	29.4	1.1	101.7	0.24
lower environmental damages	4.6	2.2	15.7	0.07	13.1	0.5	45.7	0.05
higher tax-subsidy	7.5	3.4	25.4	0.19	20.3	0.8	70.6	0.12
lower tax-subsidy	6.7	3.1	22.6	0.15	10.9	0.4	38.1	0.04
higher portion of response from output	25.0	9.9	78.8	1.85	15.6	12.9	47.6	1.51
lower portion of response from output	6.6	3.1	22.5	0.15	15.6	0.3	54.6	0.03
higher fuel price elasticity	7.1	6.8	23.1	0.36	15.6	1.3	54.0	0.15
lower fuel price elasticity	7.1	2.0	24.3	0.11	15.6	0.4	54.5	0.04
higher MCPF	6.6	3.1	22.4	0.15	15.1	0.6	52.7	0.07
lower MCPF	7.7	3.5	25.9	0.20	16.2	0.6	56.3	0.08

Source. See the text and Appendix B for the equations and parameter values underlying these calculations.

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Table 4. Maritime Transport Costs by Product Category and Ship Segment

Food category	AV (percent)	Unit cost $/Tonne	Price increase (percent)	Shipping mode
Live animals	19	821	0.79	Container
Meat	5	168	0.21	Container
Fish	4	172	0.17	Container
Dairy products, birds eggs, honey	3	110	0.13	Container
Live trees, plants, bulbs, cut flowers	8	250	0.34	Container
Vegetables	22	154	0.92	Container
Fruit & nuts	13	123	0.55	Container
Coffee, tea, mate & spices	4	103	0.17	Container
Cereals	21	58	0.88	Clean Bulk
Milling products, malt, starch	11	70	0.44	Container
Oil seeds and oleaginous fruits	16	68	0.67	Clean Bulk
Vegetable plaiting materials	10	65	0.42	Container
Animal or vegetable fats, oils	5	62	0.21	Tanker
Sugars and sugar confectionary	9	52	0.38	Container
Beverages, spirits and vinegar	5	95	0.21	Container
Food industry residues & waste	25	124	1.05	Container
Tobacco	3	193	0.13	Container

Source: Stochniol (2011a), which builds on UNCTAD (2010) and Vivid Economics (2010).
Notes: AV = average transport cost share of total import value; Unit cost = Average absolute transport cost per tonne of transported goods.

effects, ranging from about 0.2 to 1.0 percent for a $25 per tonne CO_2 price. For fuel, another particular concern, the effect also seems modest: an increase in oil prices of about 0.33 percent in importing countries.[45] These are tiny amounts relative to the swings in food and fuel prices commonly observed.[46]

These small numbers might suggest that compensation issues hardly require much attention. But there are possible exceptional cases, and, moreover, the political sensitivity of the issue is such that without some form of compensation it may be difficult to achieve the close to universal participation, given the high mobility of the tax base, that is needed to make charging maritime fuel feasible.

[45] IMO (2009) reports that the fuel consumption of tankers in international oil transport was approximately 60 million tonnes of oil in 2009. The volume of oil exported in 2009 was approximately 1900 million tonnes. Bunker fuel prices are about 90 percent of average crude (non-refined) oil product prices. This implies that fuel transport costs correspond to about 2.7 percent of exported oil values on the average. This means that a US$25 per tonne CO_2 charge (fully passed forward) would raise the fuel price by 12 percent, giving an impact on the final import price of oil will rise of about 0.33 percent in importing countries (again assuming no back-shifting of a fuel charge on the crude price).

[46] See UNCTAD (2010) for further discussion.

The scheme envisaged earlier for aviation—having developing countries retain the receipts on fuel taken up in their jurisdiction—would not work for maritime. Due to the far greater mismatch between where ships re-fuel and where they offload goods, this would often provide too much, but more often too little, compensation. Landlocked (developing) countries, for example, would receive no compensation but may still suffer from higher import prices (to the extent they import goods by road or rail that were previously shipped to neighboring countries). Countries with hub ports on the other hand, would likely be over-compensated, as they collect revenues from ships whose final port of call is elsewhere.

An alternative, it might seem, would to levy a charge on freight arrival (or departure), varied by weight and distance travelled. This would have the merit that collection of the levy would be closely tied to the benefit enjoyed from the underlying fuel use: trade to countries that it is desired to shield from damage from the charge could simply be exempted or refunded a corresponding amount on fuel use. But this approach is problematic in several respects. It would take no account of vessels' differing fuel efficiencies. Even more importantly, since such a charge is not directly related to vessels' fuel consumption, it would tend to reward speedier service, which is particularly fuel intensive and is widely used by vessels carrying high-valued cargo. Not the least difficulty, however, is the sheer administrative burden of tracking the origin (let alone the route taken and other pieces of information in principle related to embedded fuel use) of each item arriving at customs: a single container can bring dozens of items of differ origin; and a ship thousands of such items.

In general, the welfare loss suffered by a country from a (small) charge-induced increase in transportation cost is given by the consequent increase in the value of its net exports, imports being measured at c.i.f. prices and exports at f.o.b. (these being the prices affecting domestic consumers and firms). Solving to the implied change in these prices, it is shown IMF-World Bank (2011) that this is given by:

$$C = (\tau_X V_X + \tau_M V_M)\left(\frac{\eta_X^{ROW}}{\eta_X^{ROW} + E_M}\right) \tag{5}$$

where X and M refer respectively to imports and exports, τ_i is the charge–induced increase in transport costs for as a proportion of border prices, the V_i are import and export values, η_X^{ROW} is the elasticity of export supply in the rest of the worlds and E_M is the (absolute value of the) elasticity of domestic import demand.

An immediate implication is that, even with full pass-through of fuel charges into transportation costs, so long as domestic import demand is not entirely inelastic, full return of all charges on the transportation of all charges bearing on both imports and exports would be over-compensation. The presumption is thus that simply returning the revenue from charges corresponding to all maritime transport to and from lower income countries would thus appear more than adequate.

Table 5 reports on a mechanical application of (5) to a large sample of countries, both in summary and with selected examples. These figures, it should be stressed, are no more than illustrative: the application is to all trade, for instance, not just seaborne (and in that respect will tend to overstate welfare losses), and the elasticity of foreign supply is assumed to be the same for all. The results are suggestive, nonetheless. For a charge that creates a 0.5 percent wedge between the prices of goods on departure and arrival—which the evidence cited above suggest as broadly plausible order of magnitude for the average impact of a charge of $25 per tonne of CO_2— the impact is modest, though perhaps not entirely negligible: on average, a little over one-tenth of one percent of GDP. Even for twice as large an impact, the average effect remains well under 0.5 percent of GDP.[47] The welfare cost is noticeably, and significantly, higher in small island developing countries; this does not directly reflect their physical character but rather their higher openness, which is the main drive of these welfare impacts. Simple regressions also show that the welfare impact is negatively related to per capita income, but not significantly so. The results also point, however, to some potential outliers: for (only) Malta, for instance, where openness commonly exceeds 100 percent of GDP, the welfare cost exceeds 0.5 percent of GDP even for the 0.5 percent price wedge.

Table 5. Estimated Welfare Impacts of a Charge-Induced Increase in International Trade Costs (in percent of GDP)

	Number of countries	Mean	maximum	Minimum
All countries	135	0.13	0.59	0.04
Small island developing states	18	0.21	0.59	0.08
		Selected country effects		
Australia	0.06		Mali	0.08
Bolivia	0.12		Malta	0.59
Brazil	0.04		Peru	0.09
Ethiopia	0.08		South Africa	0.09
Haiti	0.13		Sri Lanka	0.09
Italy	0.08		Uganda	0.08
Lebanon	0.13		United Kingdom	0.08

Note: Calculated as C/GDP from (5), assuming $\tau_X = \tau_M = 0.05$,using 2011 data on import and export values in percent of GDP from the *World Economic Outlook* database, country-specific estimates of import demand elasticities (short run) from Tokarick (2010) (deleting cases in which is this negative) and taking η_X^{ROW} to be 0.93 for all countries (the short run value for OEC Economies in Tokarick (2010).

While equation (5) and its application gives a sense of the likely magnitude, drivers, and patterns of the welfare impact of a charge-induced increase in transport costs results, the dependence on inherently uncertain demand elasticities makes it an unlikely practical candidate. For that, some more pragmatic approach is likely to be needed. One such proposal that has attracted attention is a rebate mechanism based on shares of global import value,

[47] These estimates are proportional to the assumed increase in the price wedge, so doubling these simply doubles all numbers in the table.

proposed most prominently by Stochniol (2001b).[48] This rests on the view that import value is a good predictor of overall fuel cost involved in imports[49]—better than (another candidate sometimes suggested) distance traveled. Even supposing that to be so, an evident conceptual weakness of this approach is that it implicitly assumes that the burden of any increase in transport costs to be entirely on the importer. So, for instance, the implicit assumption is that a fuel charge on exports from developing to developed countries is borne entirely by the latter (and vice versa for exports from developed to developing countries). To the extent that this is not the case—and in the strict logic of simple trade models, it cannot possibly be the case for all countries—the scheme will not provide an exact level of compensation (though whether too little or too much is ambiguous). The formula in (6) suggests that reimbursement of the charge embodied in the freight costs of imports alone provides exact compensation, for a small charge, if and only if it so happens the elasticity of import demand in the country to be compensated is equal to the elasticity of export supply from the rest of the world. Detailed calculations in IMO (2011) suggest the further that the structure of maritime freight costs is such that exporters may be affected significantly, in particular, if their main customers are far away and they export high density, low value commodities. This could have a substantial impact on the numbers at stake, potentially in the order of doubling the compensation required.

Clearly these are issues capable of almost endless refinement. What emerges clearly from this discussion, however, is that perfect calibration of compensation to each country's circumstances will not be possible—and searching for it risks proving a distraction. Since most price effects seem likely to be small, it is reasonable to look for simpler approaches based on one or two indicators (based on import and/or export values or volumes and trade-weighted distance) that are scaled to build in adequate assurance—perhaps with a guarantee

[48] See also World Wildlife Fund, 2012; IMO, 2010b; Stochniol, 2011b. More precisely, Stochniol (2011a, c) envisages allocating the revenue raised by some maritime charge to countries according to their share in the value of world imports, these values being adjusted (1) by including only imports from non-adjacent countries (most of which—in the absence of data on import values by mode of transport—is presumed to be by other modes); (2) to reflect the extensive trade between close but non-adjacent countries in Europe, as most of this is presumed to be road- and rail-based. Non-annex I countries would be entitled to a transfer equal to their share of receipts thus calculated, though provision would be made for them to waive this. Annex I countries would treat their allocated receipts as a contribution to climate finance.

Stochniol (2011a, c) provides a full set of country-specific weights had such a scheme been in effect in 2007. These imply that in 2007 about 40 percent of proceeds would have been allocated to non-Annex I countries. Ethiopia for instance, would have had a weight of around 0.06 percent, so would have received around $16 million if total receipts were $26 billion.

[49] Stochniol (2011c) argues that average fuel consumption per value unit of imports varies little between different types of vessels even though the value of shipped goods per tonne may vary substantially. This is because low-value (bulk) goods tend to be shipped in vessels (bulk vessels and tankers) that are both fuel efficient relative to their weight loads, and run much slower than (container) ships transporting higher-valued, manufactured goods; so that fuel consumption per tonne of freight tends to be proportional to value per tonne. This is however not to deny that, for given bulkiness of imports, countries with longer average import routes will tend to have greater fuel costs per value unit associated with imports.

of some minimum monetary amount for the most vulnerable—while providing some allowance for truly exceptional cases.

Impact on the maritime industry

The low elasticity of demand for freight services suggests a high degree of pass-through to purchasers of freight services—and little impact on profitability. The impacts of higher bunker fuels prices on freight rates will vary with economic structure of the importing and exporting country; the trade route; ship size; and the supply and demand, not only for the product, but also for cargo space on the ship.[50]

V. IMPLEMENTATION

The analysis above has made, in our view at least, a compelling case for the introduction of some form of charge on fuels used in international aviation and maritime transport. This section focuses on practical questions of how this might be done.

One issue that becomes more determinative in this context than above is the question of who gets the money—of whether, in particular, it would be retained by national governments or passed on to provide some form of global climate finance. Both possibilities are in mind below. We also make the working assumption that there will be no more general and near-global carbon pricing scheme into which the treatment of these sectors can be embedded,

A. Taxes, Trading Schemes, and Offsets

One high level choice to be made is that between taxation and trading schemes. There is a large literature on the economics of this choice, and the arguments--which apply in essentially the same form to international transportation fuels—need not be repeated here.[51] In short, both instruments, applied to the same base, equivalently scaled, and leaving aside uncertainty,[52] have about the same effect on fuel prices, emissions, and—critically, so long as emissions allowances are auctioned—revenue. It is these equivalences that have allowed the previous analysis to encompass either instrument.

[50] For further discussion, see IMO (2011 and UNCTAD (2010).

[51] See for example Goulder and Parry (2008), Hepburn (2006), and Jones, Keen, and Strand (2012).

[52] Emissions price volatility is inherent in a pure ETS. This is problematic, as it causes an uneven pattern of discounted marginal abatement costs at different points in time (undermining cost effectiveness from a dynamic perspective) and an uncertain environment for investment. The problem could be partially addressed through price stability provisions. In particular, allowing firms to bank and borrow allowances over time smoothes out expected fluctuations in emissions prices. Alternatively, the cap can be combined with a price collar, with allowances bought out of the system as needed by the authorities at a fixed price to keep a floor under the price, and sold to the system as needed to maintain a price ceiling.

One aspect of the debate worth particular note in the present context is the potential role of offset provisions, which have attracted particular attention in proposals that have circulated in both the ICAO and IMO. These would allow allowing covered sources to pay for emissions reductions in other countries, for example through the Clean Development Mechanism, or acquiring permits from another trading system (most obviously the EU ETS), in lieu of needing permits from within their own system to cover all of their emissions. Offsetting does not lead to any further emission reductions, but simply re-allocates reductions across sources in a way that lowers overall abatement costs (by exploiting opportunities presented by differences in marginal abatement costs across sources). The appeal in the ETS context is that they provide an 'escape valve' against high permit prices. Though not so often considered, offsetting Offsets, it is important to note, could also be incorporated into tax schemes, through rebates or credits. In this case, however, the offsets in principle *increase* overall emissions reductions (since it remains privately optimal to abate wherever the marginal cost of doing so is lower than the tax).

Offsetting has, however, two troubling weaknesses. First, the conceptual and practical difficulties of verifying that offsets actually do reduce emissions are considerable: How can one be sure, for instance, that the offset projects would not have gone ahead anyway? Absent such an assurance, the risk is that allowing offsetting (under an ETS) will actually increase emissions. The second, is that offsetting provisions reduce the potential fiscal dividend—either through lowering the price of (auctioned) allowances or narrowing the base on which the tax is collected. Given the pressing fiscal needs in many countries, and the problems of verification, offsetting seems best used with considerable caution.

Political economy considerations also have a role in instrument choice. Some argue that an ETS has the advantage that firms will have an interest in preserving the program, if they have accumulated a substantial stock of allowances or have previously purchased allowances that can only be used in future periods. But such effects can cut both ways: an ETS could create greater space for influential firms to lobby for free allowances, and taxes can also build up a strong lobby of support in governments who become loath to forego the revenue.

Other political consideration may be more telling in the present context. One is the potentially greater capacity of tax schemes to encompass differentiation across countries. Such measures of coordination as have been adopted in other contexts—such as on VAT and excises in the EU and other regional blocs—have taken the form of agreement on minimum rates. Agreeing a common price floor may be easier than agreeing over a completely uniform price, especially amongst so heterogeneous a group of countries as would likely need to be involved in coordinating aviation or, especially, maritime charges; it would accommodate countries that might wish, perhaps for administrative reasons, to apply the same tax to domestic and international fuel use. Though such differentiation undermines efficiency, in acknowledging equity concerns across countries aiming for a common minimum charge may facilitate a reasonable compromise.

Whichever instrument is adopted, it would ideally embrace both sectors: with the marginal abatement costs in each sector then equated to a common price, they would be equated to each other and so ensure that emissions reductions are efficient not only within sectors but between them too. If technological progress were to make mitigation cheaper in one sector than the other, for instance, then a combined scheme would enable the aggregate emission target to be met more cheaply.[53] A common scheme would also ensure that the competitive positions of the two sectors reflected their relative climate impacts. Substitution between the two forms of transport does not seem so great, however, as to make a common scheme essential, at least initially.[54]

B. Administration

Fuel taxes

Taxes on domestic fuel use are a staple source of revenue in many countries—and have proved among the easiest of taxes to administer. They are much simpler, for instance, than a VAT or a corporate tax on telecom companies—tasks that they are expected to undertake even in low income countries Taxing fuels used in international aviation and maritime, accordingly, should not be an especially great challenge. Relatively few new issues would be raised by extending a tax on fuel to international aviation and maritime use—indeed this could in some respects be a simplification.

There are three main options for the point at which fuel taxes might be imposed: on fuel refiners (and importers), on fuel distributors, or on operators. In principle, where the tax is levied has little relevance (if perfectly enforced) for the environmental, fiscal, or real incidence impacts of the tax. From an administrative point of view, it can matter a great deal. Ideally the tax should be levied where the number of collection points is smallest to minimize enforcement problems and compliance costs. But again, there is little at stake here—in all the cases, the taxpayers are easily identifiable and relatively small in number; even in the U.S., for instance, there are only about 150 refineries.[55]

A possible drawback of taxing at the refinery level is that administration will be complicated (through the need for some form of subsequent crediting arrangements) if the tax needs to be differentiated according to how or where fuels will be used later, for example if differential taxes are needed for domestic and international flights. But this is not an issue if the sole

[53] For discussion of the related advantages and implementation difficulties, see Haites (2009).

[54] A caveat here is that some high value freight might shift between sectors if only one were taxed; since emissions per ton carried are higher for aviation, this might be a concern if a change were levied only on maritime.

[55] Another difference, potentially, is the set of participating countries. Upstream producing countries could, in principle, levy the tax on sales to others even if the latter did not formally participate in any scheme.

purpose of taxes is to address the carbon externality, since that is the same for both domestic and international use. Indeed establishing more uniform treatment of fuels used domestically and internationally is likely to be, if anything, an administrative simplification. A further set of control problems arises when the fuels used in the activity it is intended to tax differentially have an alternative use. Jet fuel, for instance, can also be used as kerosene for heating, while the heavy fuel oil used by international maritime may be further refined into higher quality products or used by industry and power stations.[56] But these are the kinds of problems tax administration cope with every day.

Failing application at refinery level, there is considerable experience in levying fuel taxes at import or further down the chain: they can be collected, if not at refinery, then at bulk storage points or the depots that are standard at airports and major ports (with withholding and crediting/refund procedures being used to preserve revenue through the distribution chain).

Collection could thus reasonably be left to national tax administrations. The possibility of allocating some of the proceeds to climate finance or compensation of more vulnerable countries—should that be the chosen policy—also seems fairly straightforward to handle, by allowing countries to retain some fraction of proceeds. There are several precedents of such arrangements, perhaps the most directly comparable being that customs revenue within the EU is passed to the central bodies of the union but member states retain 10 percent of the amounts they collect. That this works well doubtless reflects a sense that these revenues properly belong to all Member States, not just those at which entry happens to occur. A similar sense may come to be held in relation to taxes in international transport, reflecting as they do the exploitation of the common property—belonging to no nation in particular but to all in general—of the international seas and skies. Any requirement to pass on some of the revenue collected would likely apply, in any event, only to more developed administrations: many lower income countries would likely retain all of the revenue they collected, whether as full compensation (as suggested above for aviation) or as in effect a down payment of a somewhat more complex compensation arrangements (perhaps for maritime).

A quite different approach, if all the proceeds of the charge were to be allocated to such common purposes, would be for operators to remit tax directly to a central body without intervention of the tax administration.

In maritime, the IOPC Funds[57] are often cited as something of a precedent, while the implementation and enforcement regime would follow the well established regulatory IMO framework for safety and environment standards in shipping through flag and port State controls. The very high concentration of emissions from a limited number of ships, combined

[56] Coastal and domestic shipping largely uses diesel.

[57] IPOC Funds, established under the Civil Liability Convention of IMO, are financed by contributions paid by any entity receiving more than 150,000 tons of crude oil or heavy fuel oil a year (net of sea transport) and the contributions are channeled directly to the Funds. Member States implement the needed legal regime and ensure compliance by entities within their territories.

with current enforcement mechanisms (flag and port state controls), could be helpful for implementing either form of carbon charge. Around 80 percent of emissions from international shipping are produced by only around 17, 300 vessels (Table 5). And both actual and potential monitoring are extensive.[58] Under a tax-based approach, levying the charge only on fuel used by ships over some threshold tonnage would thus capture the bulk of environmental. The gain in pure administrative terms relative to relying on national tax administrations, with their powers reinforced if need by international agreement, is unclear.[59] While there could be se risk of distorting ship size, this would likely be modest if the threshold were set at a reasonable level.

Table 5. Ship Sizes, Numbers, and Associated Emissions

Ship size threshold (GT)	No. of ships	No. of ships as percent of ships ≥ 400 GT	Emissions (as percent of emissions from ships ≥ 400 GT)
≥ 400	42,697	100	100
≥ 500	39,180	92	99
≥ 1,000	34,866	82	98
≥ 2,000	30,138	71	96
≥ 4,000	24,267	57	91
≥ 5,000	22,311	52	89
≥ 10,000	17,346	41	81

Source: IMO (2011).

Quite what would be achieved by simply side-stepping national tax administrations well-used to implementing taxes of this kind, however, is far from clear. This approach would also raise significant obstacles from concerns of national sovereignty: both the United States and China, in particular, have made it clear that they would not accept any form of compulsory payment directly to some funding body.

[58]Continuous monitoring could be mandated using utilizing IMO’s Long Range Identification and Tracking system to transmit the ship data. All merchant ships above 300 GT are mandated under IMO’s SOLAS Convention to provide their position and other information at regular intervals through IMO’s Long Range Identification and Tracking system. And all ships above 400 GT are under IMO’s MARPOL Convention mandated to keep record of their fuel in the Oil Record Book and to obtain a Bunker Delivery Note for each bunkering which has to be kept onboard for 12 months after the fuel is consumed. This data could be held against the ship’s electronic account in the central register and would give reliable check against reported fuel use at ports where charges might be administered.

[59] Countries concerned to assure themselves that tax has been collected elsewhere could expand their port entry requirements to include the provision of acceptable documentation, backed if need be by satellite monitoring of ships’ prior movements—but again at an additional cost in administrative burden.

Emissions Trading Schemes

As with fuel taxes, the question arises as to where in the chain the policy would be imposed: meaning here who—refiners, airlines, shipping operators or actors in between—would be required to hold permits. In this case, the balance of considerations points towards a reasonably large number of players, not as few as possible, so as to ensure competitive auction markets. Even with an upstream requirement, however, this seems unlikely to be a major difficulty, especially if allowances are traded internationally. The more significant concern is the need to create a new institutional framework to administer the auctioning of rights, implying higher costs of administration and compliance (at least over some set-up period). There is some comfort, however, in evidence that the 'transactions costs' associated with market trading are usually small relative to the overall costs of the program (Stavins, 1995)—though this does not reflect the deeper governance issues referred to above.

For aviation, plans for inclusion in the EU-ETS are already in place. Should these ultimately proceed, it seems likely that any scheme for international aviation—whether tax or ETS—would need to be coordinated with the EU-ETS. It would not make sense to tax airlines whose emissions are already priced under the ETS or, conversely, to include airlines in the ETS that have already paid a comparable fuel tax. The EU-ETS plans do indeed include provisions to avoid this possibility of double charging. One concern with the EU ETS plans, however, is that the vast majority of allowances will be given away for free. This could lead to windfall profits to the extent that airlines pass forward emissions prices into higher ticket prices, just as power companies received large windfall profits from free allowance allocations in the initial stages of the EU-ETS. Enhancing the profitability of airlines in this way could increase resistance in other countries to revenue-raising charges on their airlines. For maritime, the high concentration of emission and close control of shipping, could be advantageous if the ETS route is taken, since that would in any event require creating a whole set of new governance arrangements, The former would reduces transactions costs by limiting the number of bidders but without creating an unduly thin market, and latter, especially if supported by the powerful device of denying port entry to non-compliant businesses, can provide an effective route for implementation.

C. Governance Arrangements

The greatest challenges to be faced in implementing charges on international aviation and maritime fuels are not the technical one just discussed—those, as just seen, are really fairly straightforward—but, ultimately, political. Deep issues of governance and institutional design arise. Even if revenue is simply to be retained where it is collected, mechanisms will be needed to determine applicable rates (or caps). And if some of the revenue is to allocated away from the point of collection (whether to climate finance or compensation schemes) further issues arise concerning the use of the funds so raised. The two sets of concerns are to some degree linked, so that the choice made on one may influence the proper chose on the other: scheme for collecting taxes on aviation fuel in ways that bypass national administrations likely makes little sense, for example, if revenues are to be allocated according to where fuel is taken up. Nonetheless, the two issues are to quite a large degree separable; and here we focus on the collection side, there being considerable experience in the monitoring of spending financed collectively (within the UN and other international organizations, for instance—and with the ATPL noted earlier a smaller example directly relevant to these sectors).

Some issues that arise in the implementation of internationally coordinated charges, while largely novel, are essentially mechanical. Since, for instance, the appropriate emissions tax is in specific form (a fixed amount per unit of fuel), not ad valorem (proportional to the price), it would need to be specified in terms of some basket of currencies. Many such problems are clearly manageable—as the EU has done, for instance, in specifying minimum excises common to both euro zone and non-euro zone members. .

Other issues are more profound. Some process would be needed, for instance, to agree on and revise the level of such charges, and provide for the automatic ramping up that Pigovian considerations imply is needed in taxing a stock externality of this kind. Previous efforts at international tax coordination are not entirely encouraging. But nor should they be underestimated. The agreement of minimum rates of excise taxation—which is essentially all a carbon charge would be—is a now a commonplace of regional trading bloc, not only the EU but, for example, in sub-Saharan Africa. Moreover, countries routinely enter into double tax treaties with one another that restrict their ability to vary a number of the tax rates they set. The difficulties are less, of course, the narrower the set of participating countries. For aviation, universal participation is not a prerequisite. More limited participation could also be envisaged for maritime–for instance, with only advanced economies imposing (and implementing through port controls) payment of a fuel charge—but the greater mobility of the base makes this more problematic. The alternative is agreement on emissions limits for these sectors. That would be more in line with the traditional and continuing focus of climate negotiations, though this process has, as yet, achieved little real progress.

Issues of verification will also be critical—indeed these may be the most difficult of all. Countries participating in a tax or ETS scheme will naturally want assurance that others are honoring their commitments But such issues arise with any form of internationally coordinated carbon pricing, and indeed if anything should be less in these sectors than others: the close monitoring to which international movements of planes and ships are subject, combined with nations’ rights to deny entry or exits, provide key elements need to verify and enforce fuel charges.

While the governance issues are daunting, they are not insuperable. In international aviation, there are specific legal issues, with differing views on their real force but, in any event, substantial international momentum towards finding a way to overcome them. There seem to be no such obstacles to imposing charges on international maritime fuels. And for all the key elements of the governance arrangements needed—such as international agreement on minimum levels (or, more generally, constraints on) tax rates, monitoring the use of funds allocated to some common purpose, incentivizing collection—there are already working precedents. Such problems as remain are not unique to these sectors, but apply—in some respects, indeed, with even more force—to any collective action on climate challenges.

VI. Conclusion

The exclusion from any kind of charge on fuels used in international aviation and maritime is highly anomalous, and interacts with other unique and extraordinarily favorable tax provisions for these sectors to generate significant costs in terms of the environment, government revenue and welfare more broadly defined. The basic case for such charges, it should be stressed, is independent of the use to which the consequent revenue is put (assuming this not to be too foolish). For national governments in straitened fiscal circumstances, they should appeal as a source of revenue likely more efficient than almost any other option available to them. Though the case for this was not explored here, they are also among the more appealing of the specific instruments that have been suggested as a source of climate finance. While the use to be made of the revenue may affect issues of administration and governance, it does not affect the core economic case for these charges.

While it is the damage done to prospects for meaningful mitigation of carbon emissions that is most obvious, the analysis here has shown that amplification of pre-existing distortions in commodity and profit taxes levied on these sectors—a concern almost absent from the debate—can be quantitatively significant. Indeed most likely, the proportionate emissions reductions from reasonably-scaled charges (of say \$25 per ton of CO_2) would be modest for the foreseeable future, so that the narrowly fiscal case for these instruments can be more important than the environmental. In the aviation sector in particular, it has been seen that substantial fuel charges would be warranted event in the absence of climate concerns, as an imperfect correction for failure to levy VAT or other sales tax on international leisure travel. In maritime, the implication for optimal fuel taxation of the pre-existing tax distortion—a preferentially favorable corporate tax regime)—are less pronounced, reflecting, for example, a lesser impact of fuel prices on the price of final products. The revenue at stake is also sizable: even with developing country compensation (which on some estimates might absorb around 40 percent of potential revenues), charges could raise (from both industries combined) revenues of around \$22 billion a year in 2020—going a long way to meet advanced countries' climate finance commitments.

The technical obstacles to achieving these considerable gains from charging these fuels, we hope also to have shown here, are very modest. Certainly there are difficulties, but the familiarity of almost all national tax administrations with the implementation of fuel taxes (one of the very simplest they have to deal with), the close monitoring to which international aviation and shipping are in any event subject, features of the industrial organization of these sectors (including the high concentration of emission among what is little more than an handful of ships), and the existence of international bodies charged with their oversight and development in the common interest should all mean that the technical issues are if anything easier to handle than in many other sectors.

There is no great difficulty in envisaging how such charges might be applied. Indeed there are several ways in which this could be done, with the best choice depending to a large degree on the simple question: Who gets the money? If simply retained where collected, then administration through national tax administrations (or pre-existing trading schemes, as in the EU) is the obvious choice. If, on the other hand, the revenue is to be allocated entirely to climate finance, then a centrally organized cap and trade scheme becomes more attractive.

To the extent that compensation schemes are needed to induce wide enough participation for the schemes to be workable—a particular concern in maritime—these too seem to pose no insuperable obstacles. The price effects are likely to be fairly minor: the impact of aviation ticket prices would be in the order of 2–4 percent and on landed import prices mostly well below 1 percent. Compensation may well be politically necessary for the participation of developing countries, and if so seems perfectly feasible: the incidence analysis here suggests that in aviation, retaining proceeds on fuel taken up will often be adequate, while in maritime there is a case for more formulaic-based approaches based on import and export values. Doubtless these approaches will require closer study and fine-tuning—but there is little doubt that conceptually coherent and practically implementable schemes can be designed.

The obstacles lie elsewhere. They are to some degree different in the two sectors: in aviation, progress has been allowed to be held up by a mass of outdated legal provisions; in maritime, securing near universal participation is made necessary by the extraordinary flexibility that large ships have on where they take up fuel. This likely means that progress will need to take different forms in the two sectors: gradualism in terms of breadth of country participation, for instance, seems much more feasible in aviation.

But some obstacles—and opportunities—are common to both. The case for charges of the kind considered here is to a large degree independent of the use to which the proceeds are to be used (though there are, as sketched above, potential implications for implementation). It might be that allocating the proceeds to climate finance would cut through at least one practical and political problem: that of allocating emissions from international transportation, and the proceeds from taxing them, to specific. Perhaps the most fundamental difficulty, however, is that it has been left to the sectors themselves to come up with charging schemes. One consequence has been the emergence of principles of doubtful merit: quite why a tax-based approach should be ruled out in aviation, for instance, is entirely unclear, and the general emphasis on earmarking proceeds to the benefit of the industry itself is no less questionable. The more profound consequence, however, of simply leaving the matter to the industry itself is that nothing approaching agreement has yet emerged. The costs of this unnecessary failure are large, and will grow.

Appendix A. Aviation—Derivations for Section III

Model Assumptions. Consider a static model where the representative agent has the following utility function:

(A1) $u = u(C, A, L) - \alpha E$

where C is a general consumption good, A is (international) aviation trips, L is labor supply, and E is aviation fuel emissions. $u(.)$ is continuous, quasi-concave, and increasing in its first two arguments and declining in the third. Parameter α is environmental damages per unit of emissions.

Households are subject to the budget constraint:

(A2) $(1 - t_L)L + G = C + p_A A$

where the gross wage and the price of the general consumption good are normalized to unity. t_L is the tax rate on labor supply, which implicitly combines general consumption taxes (VAT) with personal and payroll taxes. G is a fixed lump-sum transfer payment from the government (simply to reflect the return of tax revenues). p_A is the consumer price of international air tickets (inclusive of any taxes and tax preferences).

The price of aviation services is given by:

(A3) $p_A = c(f) + \left(t_E e + p_f\right)f + \bar{p}_A(1 - \bar{s}_A) + t_A$

where f is fuel use per unit of air travel, e is emissions per unit of fuel, t_E is an emissions charge and p_f is the (fixed) pre-tax fuel price. $c(.)$ is a unit cost function to capture the costs of lowering fuel intensity (e.g., costs of installing more efficient engine technologies or use of lighter but more expensive body materials). $\bar{p}_A$ is labor and other unit production costs (taken as given). $\bar{s}_A$ reflects a tax-subsidy due to the failure to include international air travel under the VAT.[60] Finally t_A is a ticket tax, set to zero initially.

Firms will reduce fuel intensity until:

(A4) $-c'(f) = t_E e_f + p_f \rightarrow f = f(t_E)$

that is, fuel intensity is reduced until the marginal cost equals the fuel price, inclusive of the emissions charge. Emissions of fuel intensity will therefore fall with higher taxes.

Total emissions are

(A5) $E = e_f f A$

[60] Since fuel costs and the costs of fuel-saving technologies are not value added, they are not subsidized through the VAT exemption.

The indirect utility function *V*(.), defined as a function of (endogenous) travel prices, the labor tax, and environmental damages, is obtained from the household optimization problem as follows:

$$\text{(A6)} \quad V(p_A, t_L, E) = \underbrace{Max}_{C,A,L} \; u(C, A, L) - \alpha E + \lambda\{(1 - t_L)L + G - C - p_A A\}$$

where the Lagrange multiplier λ is the marginal utility of income. From the resulting first order conditions, we obtain the demand functions:

$$\text{(A7)} \quad C = C(p_A, t_L), \qquad A = A(p_A, t_L), \qquad L = L(p_A, t_L)$$

Furthermore, from (A5) and (A7), emissions can be expressed

$$\text{(A8)} \quad E = E(t_E, p_A, t_L)$$

Partially differentiating *V*(.) gives:

$$\text{(A9)} \quad \frac{\partial V}{\partial p_A} = -\lambda A, \quad \frac{\partial V}{\partial t_L} = -\lambda L, \quad \frac{\partial V}{\partial E} = -\alpha$$

The government budget constraint, equating revenues from taxes (net of the tax-subsidy) is given by:

$$\text{(A10)} \quad G = t_L L + t_E E + (t_A - \bar{s}_A \bar{p}_A)A$$

Any revenues from emissions or aviation charges are used to lower the labor tax (holding *G* and $\bar{s}_A$ constant).

Marginal welfare effect from the emissions tax

The welfare effect of an incremental increase in the emissions tax can be obtained by totally differentiating the indirect utility function with respect to the emissions tax, taking into account changes in the labor tax (via the government budget constraint), the price of air travel, and emissions.

To start with, we totally differentiate *V*(.) in equation (A6) with respect to t_E to give:

$$\text{(A11)} \quad \frac{dV}{dt_E} = \frac{\partial V}{\partial p_A}\frac{dp_A}{dt_E} + \frac{\partial V}{\partial t_L}\frac{dt_L}{dt_E} + \frac{\partial V}{\partial E}\frac{dE}{dt_E}$$

Next, we express this in monetary units and substitute using (A9) to give:

$$\text{(A12)} \quad \frac{1}{\lambda}\frac{dV}{dt_E} = -A\frac{dp_A}{dt_E} - L\frac{dt_L}{dt_E} - \hat{t}_E\frac{dE}{dt_E}$$

where $\hat{t}_E = \alpha/\lambda$ denotes (monetized) environmental damages per ton of emissions, or the corrective emissions charge.

To obtain the impact on air travel prices, differentiate (A3) with respect to t_E and then substitute from (A4). This gives:

(A13) $\frac{dp_A}{dt_E} = e_f f$

Obtaining an expression for dt_L/dt_E is a bit more involved. We start by totally differentiating the government budget constraint (A10), holding *G* fixed and with t_A set to zero. In doing so (to facilitate analytical derivation) we express the incremental effects on emissions and aviation as total differentials while we decompose the effects on labor supply into those from higher emissions taxes and lower labor taxes. This gives:

(A14) $0 = E + t_E \frac{dE}{dt_E} - \bar{s}_A \bar{p}_A \frac{dA}{dt_E} + t_L \frac{\partial L}{\partial p_A} \frac{dp_A}{dt_E} + \left\{ L + t_L \frac{\partial L}{\partial t_L} \right\} \frac{dt_L}{dt_E}$

Next, we define the marginal cost of public funds (*MCPF*), which is one, plus the efficiency loss from an incremental increase in labor tax,$-t_L \partial L/\partial t_L$, where the latter is expressed per dollar of extra revenue, that is divided by $L + t_L \partial L/\partial t_L$. Thus:

(A15) $MCPF = \frac{L}{L + t_L \frac{\partial L}{\partial t_L}}$

Re-arranging (A14) in terms of dt_L/dt_E, and substituting (A15), gives:

(A16) $\frac{dt_L}{dt_E} = -\frac{MCPF}{L} \left\{ E + t_E \frac{dE}{dt_E} - \bar{s}_A \bar{p}_A \frac{dA}{dt_E} + t_L \frac{\partial L}{\partial p_A} \frac{dp_A}{dt_E} \right\}$

Using the Slutsky equation for $\partial L/\partial p_A$, and assuming air travel is an average substitute for leisure for compensated price effects—in which case $\partial \tilde{L}/\partial p_A = (\partial \tilde{L}/\partial t_L) A/L$, where ~ denotes a compensated coefficient[61]—then

(A17) $\frac{\partial L}{\partial p_A} = \left(\frac{\partial \tilde{L}}{\partial t_L} - \frac{\partial L}{\partial I} L \right) = \frac{A}{L} \frac{\partial L}{\partial t_L}$

($\partial L/\partial I$ is the partial derivative with respect to income).

Substituting (A17) in (A16), and the result into (A12), and using (A15), (A13), and (A5) gives, after some manipulation:

(A18) $\frac{1}{\lambda} \frac{dV}{dt_E} = (MCPF \cdot t_E - \hat{t}_E) \frac{dE}{dt_E} - MCPF \cdot \bar{s}_A \cdot \bar{p}_A \cdot \frac{dA}{dt_E}$

Finally, dividing through by $-dE/dt_E$, and defining $s_A = \bar{s}_A \cdot \bar{p}_A$ as the tax-subsidy expressed per unit of air travel, gives the welfare cost per ton of emissions reduced, indicated

[61] In other words, an increase in the price of air travel has the same effect on labor supply as an increase in the labor tax (or, equivalently, an increase in the price of all consumer goods), scaled by the base of the air travel tax relative to that of the labor tax.

in equation (6) in the text. In that expression, we define the portion of emissions reductions coming from reduced demand for air travel as:

(A19) $\sigma = \frac{e_f \cdot f \cdot dA/dt_E}{dE/dt_E}$

To obtain the optimal tax equation (7), we first divide equation (6) in the text by $-dF/dt_F$. Using notation defined above, gives the welfare benefit per liter reduction in fuel use:

(A20) $(\hat{t}_F - MCPF \cdot t_F) + \frac{MCPF \cdot s_A \cdot \sigma \cdot p_F}{\beta}$

Setting this expression to zero, we can easily obtain (7).

Computing welfare effects

To compute welfare effects, we express the incremental welfare change in (6) as a proportion of the initial fuel cost, that is, we divide by $p_F^0 F^0$. This gives (using (1)):

(A21) $-(\hat{t}_F - MCPF \cdot t_F)\left(\frac{\eta_{FF} F}{F^0 \cdot p_F^0 \cdot p_F}\right) + MCPF \cdot \frac{s_A \cdot \sigma \cdot \beta \cdot \eta_{FF} \cdot F}{p_F^0 F^0}$

This expression can be numerically integrated in a spreadsheet using the parameter values described in the text.

Ticket tax, expressed as the virtual fuel tax equivalent

For this case the analogous expressions for equations (1), (6), (7), and (A20) are: <to be derived>

(1´) $F = F^0 \left(\frac{p_F^0 + \tau_F}{p_F^0}\right)^{\sigma \eta_{FF}}$

(6´) $(\hat{t}_F - MCPF \cdot \tau_F) + \frac{MCPF \cdot s_A \cdot p_F}{\beta}$

(7´) $\tau_F^* = \frac{\hat{t}_F}{MCPF} + \frac{s_A \cdot p_F}{\beta}$

(A20´) $-(\hat{t}_F - MCPF \cdot \tau_F)\left(\frac{\sigma \eta_{FF} F}{F^0 \cdot p_F^0 \cdot p_F}\right) + MCPF \cdot \frac{s_A \cdot \sigma \cdot \beta \cdot \eta_{FF} \cdot F}{p_F^0 F^0}$

Appendix B: Maritime—Derivations for Section IV

To capture the intersectoral distortion associated with differential corporate tax treatment, the framework is one in which a fixed amount of capital *k* must be allocated between two sectors, shipping (*s*) and not shipping (*n*), so that $k = k_s + k_n$. The use of capital in sector *i* is taxed at the rate t_i; that on shipping, t_s, corresponds fairly directly to a tonnage tax, being based directly on productive capacity; that on other sectors, t_n, is best thought of as corresponding to a marginal effective rate of corporate tax. (METR).[62] The presumption is that $t_s < t_n$. Shipping generates emissions of $E = ek_s$, sectoral profits being reduced by abatement costs $c(e)k$, with $c' < 0 < c''$ Emissions are taxed at the rate t_e, and output in sector *i* is $f_i(k_i)$, each f_i being increasing and strictly concave.

In competitive equilibrium the allocation of capital and emissions intensity maximize aggregate net profit

$$\Pi \equiv f_s(k_s) + f_n(k - k_s) - (\rho + t_s)k_s - (\rho + t_n)(k - k_s) - c(e)k_s - t_e e k_s\,. \qquad \text{(B2.1)}$$

where ρ is the after-tax return required by capital owners. Assuming that firms take this cost of capital as given, the necessary condition on k_s is that

$$f_n'(k - k_s) - t_n = f_s'(k_s) - t_s - c(e) - t_e e\,, \qquad \text{(B2.2)}$$

so that net rates of return are equated across the two sectors, that in shipping being net of the abatement costs and emissions tax associated with an expansion of capital employed; the necessary condition on *e* is simply that

$$-c'(e) = t_e\,, \qquad \text{(B2.3)}$$

so that marginal abatement costs are equated to the emissions tax. This latter defines $e(t_e)$, with $e'(t_e) < 0$; using this in (B2.2) then gives $k_s(t_s - t_n, t_e)$, with

$$\frac{\partial k_s}{\partial t_s} = -\frac{\partial k_s}{\partial t_n} = \frac{1}{f_s'' + f_n''} = \left(\frac{1}{e}\right)\frac{\partial k_s}{\partial t_e} < 0 \qquad \text{(B2.4)}$$

Preferences are assumed to be of the form $U(X, G) - \alpha E$, where private consumption is $X = \Pi + \rho k$ and *G* denotes the tax-financed public spending of

$$G = t_s k_s + t_n(k - k_s) - t_e e k_s\,. \qquad \text{(B2.5)}$$

Taking the effective tax rates t_s and t_n as given, the necessary condition for the welfare maximizing emission tax t_e can then be written, using (B2.1) and (B2.2), as

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[62] Broadly speaking, the METR is the difference between the pre- and post-tax rate of return on an investment that just yields investors' required net return. It thus reflects not only statutory rates of tax but also depreciation, financing and other tax deductions.

$$t_e = \frac{\alpha}{U_G} + \left((t_n - t_s) \frac{\partial k_s}{\partial t_e} + (\lambda - 1) e k_s \right) \left(\frac{\partial (e k_s)}{\partial t_e} \right)^{-1} \tag{B2.6}$$

where $U_y \equiv \partial U / \partial y$ and $\lambda \equiv U_C / U_G$. Beyond the Pigovian term, the optimal emissions tax thus reflects two additional effects. The first is to partly correct the misallocation of capital implied by the intersectoral difference in corporate tax rates: to the extent that shipping is more lightly taxed, the tax on its emission should on this account be higher than would otherwise be the case. The second is simply as a revenue source: to the extent that $\lambda < 1$, as one would expect to be the case given the inability to deploy lump sum taxes, the emissions tax would on this account again be higher than otherwise.

Ignoring the last, revenue-raising component—analogous to the assumption of average complementarity in the aviation case, removing a potential argument for differential taxation for reasons unrelated to emissions or the pre-existing subsidy—rearranging (B2.6) gives (4), reinterpreted as described in the text.

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