A Carbon Levy for International Maritime Fuels

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Introduction

The central objective of the 2015 Paris Agreement is to hold future global warming to 1.5°C–2°C above preindustrial levels. Global carbon dioxide (CO_2) emissions, along with other greenhouse gases (GHGs), must be cut by 30–60 percent below projected baseline levels in 2030 to stay on track with these climate stabilization targets, followed by progressively deeper reductions thereafter (CAT 2021; Parry, Black, and Roaf 2021).

International maritime emissions from bunker fuel (the residual fuel oil loaded into bunker tanks) accounted for about 2 percent of global industrial CO_2 emissions in 2016, which exceeds the CO_2 emissions generated by all but five individual countries.[1] As we will discuss, in the absence of mitigation measures, maritime emissions are projected to expand steadily as the global economy grows in the long term. The UN body that oversees the maritime industry—the International Maritime Organization (IMO)—is responsible for developing a strategy for reducing international maritime emissions because (as with international aviation) maritime emissions are generated outside national borders.[2] In April 2018, the IMO announced a pledge to cut emissions from the sector by at least 50 percent by 2050 relative to the 2008 level of 1.1 billion tons and, ultimately, to phase out emissions entirely, following a pathway that is consistent with meeting the Paris Agreement's climate targets (IMO 2018). The IMO has been considering specific strategies for achieving this objective.

Although there is some scope for lowering the fuel consumption rate of the existing oil-based shipping fleet, in the long term, zero-emission vessels (ZEVs) that use fuels such as hydrogen and ammonia will be needed. Indeed, the recently formed Getting to Zero Coalition seeks to implement an R & D and investment program to rapidly develop ZEVs and the supporting fuel infrastructure and to demonstrate the viability and safety of these technologies

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[1]See figure A1.
[2]Under the Paris Agreement, countries are responsible for emissions released within their own borders. Moreover, it may be contentious to assign international maritime emissions to different countries given that ships may be registered in one country, be operated by crews from another country, and pick up/dispense cargo from multiple other countries.

Electronically published January 7, 2022

Review of Environmental Economics and Policy, volume 16, number 1, winter 2022.
 Published by The University of Chicago Press for AERE. https://doi.org/10.1086/717961

at scale.[3] However, promoting the eventual deployment of ZEVs will require pricing incentives for closing the gap between their (life cycle) cost and the cost of oil-based vessels; upfront funding sources will also be needed for the R & D and infrastructure investment.

This article examines the rationale for an international maritime carbon levy, key design and implementation issues, and the environmental and economic impacts of such a carbon levy (the term “levy” is used to indicate that at least some of the revenues will likely stay within the sector). It is particularly timely to consider a carbon levy on bunker fuel as the centerpiece of a policy strategy aimed at progressively decarbonizing the maritime sector. This levy could provide both the critical price signal needed to promote short- and long-term mitigation responses in the sector and a funding stream to support the development of ZEVs.

The remainder of the article is organized as follows. First, we provide background on carbon pricing for the international maritime sector, including highlighting key features that distinguish the application of carbon pricing for this sector from the application of carbon pricing for domestic fossil fuels. Then we discuss the rationale for an international maritime carbon levy. This is followed by a discussion of various design issues that need to be considered and a comparison of a carbon levy with other mitigation instruments. In the penultimate section, we present a modeling framework that illustrates how the IMO’s mitigation pledge could be achieved through a carbon levy and ZEV deployment. The final section presents a summary and conclusions.

Background on Carbon Pricing for the International Maritime Sector

The international maritime sector is subject to unusually favorable tax treatment, which strengthens the economic efficiency argument for a carbon levy. Maritime bunker fuel is undercharged from an environmental perspective because (unlike domestic transportation fuels) maritime fuel is not subject to excise taxes. This tax exemption appears to reflect both longstanding practice and (especially) the extreme mobility of the tax base (see below). The international maritime sector is also subject to a business tax regime that effectively subsidizes it relative to other industries. In fact, shipping is subject to tonnage taxes that amount to only about 10 percent of normal corporate income taxes (Elschner 2013; Keen, Parry, and Strand 2013).

Responsibility for developing environmental strategies for the international maritime sector lies with the IMO. For example, a recent IMO initiative requires that from 2020 onward, the sulfur content of fuel oil be no more than 0.5 percent. Although at earlier IMO meetings there was some discussion of using market-based mechanisms to reduce carbon emissions (IMO 2010; Lamotte 2011), these discussions were suspended in 2013 because of a lack of agreement on how to move forward. The European Union’s announcement that it will extend its Emissions Trading System (ETS) to cover shipping starting in 2023 if the IMO fails to make progress on mitigation and the IMO’s announcement of an emissions target have reinvigorated interest in carbon pricing policies for the international maritime sector.[4] However, mitigation

[3]See http://www.globalmaritimeforum.org/getting-to-zero-coalition.
[4]See http://www.reuters.com/article/eu-carbontrading-shipping-idUSL3N2OC302.

measures seem unlikely to attract widespread support among the 171 IMO member states unless such measures address the principle of common but differentiated responsibilities (IMO 2018).[5]

To date, the IMO has been focusing on other environmental initiatives rather than carbon pricing. Through its Energy Efficiency Design Index, the IMO has been promoting energy efficiency improvements for the new shipping fleet since 2013, with standards tightened every 5 years.[6] And in 2019, the IMO established a data collection system for the fuel consumption, tons of cargo capacity, and miles traveled associated with individual shipping voyages for ships of at least 5,000 gross tonnage. These ships account for about half of the operational fleet of 50,000 vessels but almost 90 percent of its CO_2 emissions (IMO 2016).

The international maritime sector has a couple of features that distinguish the application of carbon pricing for this sector from domestic carbon pricing. First, the tax base for international maritime fuel is extremely mobile. Large ships can undertake very long voyages on a single bunkering of fuel, which enables them to retank at ports (or from tankers and platforms on the high seas) that have lower fuel prices without significantly adding to their operational costs. This provides a rationale for an international levy because unilateral fuel taxes would likely result in severe emissions leakage. Second, a truly global carbon levy is uniquely feasible for the maritime sector. Given the IMO's oversight of the global shipping fleet, global application of a levy would largely eliminate one of the key design challenges for domestic carbon pricing, namely, addressing concerns about the international competitiveness impacts on energy-intensive, trade-exposed industries.

Rationale for an International Maritime Carbon Levy

Besides its administrative simplicity, there are two main economic rationales for a carbon levy on international maritime fuel (see Kachi, Mooldijk, and Warnecke 2019). First, it can cost-effectively promote short- and long-term carbon mitigation responses by the maritime sector. Second, it mobilizes revenue that could be used to fund R & D and infrastructure investment for ZEVs.[7]

Promotion of Mitigation Responses

As the carbon levy is passed through into higher prices for fuel and shipped products,[8] it would promote a range of shorter-term mitigation responses (see, e.g., ICCT 2011; Calleya,

[5]This is the principle (United Nations 1992, Article 3.1) that countries have a differentiated responsibility for their contributions toward GHG mitigation that recognizes their economic status and respective capabilities.
[6]This index requires a minimum energy efficiency level per ton-mile for different ship type and size segments. This tightening is consistent with the requirement to improve energy efficiency by 10 percent for ships built between 2015 and 2020, by 20 percent for ships built between 2020 and 2025, and by 30 percent for ships built after 2025. Ship operators must also have a plan for improving their operational efficiency, although improvements are not mandatory.
[7]The levy would also help to address local air pollution and ecological damages from bunker fuels (e.g., Eide et al. 2013).
[8]Simulations by IMF and WBG (2011) suggest that 95 percent or more of maritime fuel charges would be passed through into higher fuel prices.

Pawling, and Greig 2015; Smith et al. 2016; OECD and ITF 2018). These responses include (1) efficiency improvements of new vessels (e.g., increased engine/propulsion efficiency and use of lower-carbon fuels, like liquefied natural gas), (2) efficiency improvements of used vessels (e.g., through better maintenance or retrofitting of engines, propellers, and hulls), (3) improvements in operational efficiency (e.g., optimizing vessel speeds, route lengths, and port dwell time), (4) shifting to larger (more fuel-efficient) ships and increasing load factors, and (5) shifting consumer demand away from heavy/long-distance products to light/short-distance products (e.g., high-value electronics) and nonshipped goods.

Over the medium to longer term, the levy can promote the deployment of ZEVs by closing the cost differential between them and conventional fuel vessels. Potential fuels for ZEVs include hydrogen and ammonia, which are produced through electrolysis.[9] Near-term challenges for ZEV deployment include developing lower-cost and safe technologies for electrolysis, onboard fuel storage, and fuel cells for converting fuel to propulsion, as well as obtaining the necessary investments for pipeline and port distribution infrastructure.[10]

Revenue Mobilization

There is currently no international source of funding for an R & D and investment program for ZEVs, and a carbon levy could provide a sustainable funding source. In fact, a levy that is effective from an environmental perspective would raise tens of billions of dollars in revenue a year (see below); this is more than could be efficiently absorbed by the industry for clean fuel R & D and investment. For example, UMAS and ETC (2020) estimate the total investment needs for ZEV development at around \$50–\$70 billion a year for 20 years (with 90 percent for land-based infrastructure and fuel production), but much of this investment would be private, mobilized by the carbon price signal.

Using some of the excess revenues for climate finance (i.e., meeting the Paris Agreement goal of mobilizing \$100 billion a year for mitigation/adaptation projects in developing countries) has some appeal given that the fuel is combusted in international waters (see AGF 2010; IMF and WBG 2011; UNCTAD 2016; ICS 2017; ITF 2017). In fact, a bunker fuel levy of \$25 per ton of CO_2 in 2016 would have filled the estimated \$25 billion shortfall in climate finance in 2016 (see figure 1). However, the IMO's developing country member states may oppose this approach because under the Paris Agreement, advanced countries are responsible for the full \$100 billion commitment.

Alternatively, revenues might be fully retained within the shipping industry. However, there would likely be little economic rationale for compensating ship operators if the burden of the levy would largely be passed on to consumers through higher import prices. Moreover, as is

[9]Electrolysis uses electricity to split water into hydrogen (which can be reacted with nitrogen to form ammonia) and oxygen, preferably with additional electricity generated through renewables (e.g., Glenk and Reichelstein 2019). Hydrogen could also be produced from natural gas with carbon capture and storage. In principle, all countries could produce hydrogen, implying a potentially diversified international market.

[10]Zero-carbon fuels have lower energy density than conventional maritime fuel, and thus they require larger onboard storage and propulsion technologies. Biofuels or biomethane, which can burn on existing combustion engines, might be transitional rather than longer-term options, given that biomass may compete with land use (for food production or forest carbon storage).

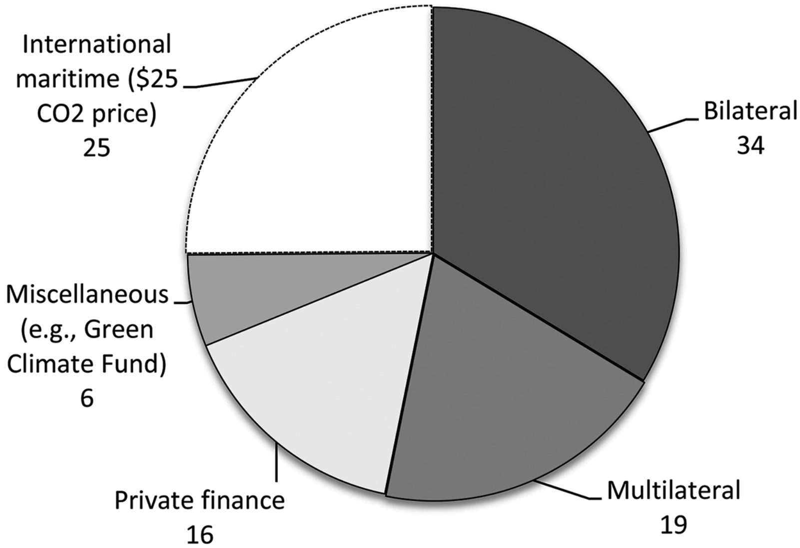

Figure 1 Actual and potential sources of climate finance in billions of dollars, 2016. These estimates are controversial (e.g., bilateral sources might reflect some relabeling of funding that would otherwise have gone to overseas development assistance). Sources: Parry et al. (2018); UNFCCC (2018). A color version of this figure is available online.

well established in the environmental economics literature, returning revenues in lump-sum transfers (to ship operators) rather than using them to increase economic efficiency severely undermines the cost-effectiveness of carbon taxation (e.g., Parry 2003; Goulder and Parry 2008; Parry and Williams 2012).

Another option would be to use a variant of a carbon levy—known as a feebate—that decouples the amount of revenue raised from the emissions price.[11] Applied to the maritime sector, such a feebate would impose a charge on operators that is equal to the difference between their emission rate (i.e., tons of CO_2 emitted per ton-mile of freight) and a benchmark emission rate, which is then multiplied by their output (ton-miles) and a CO_2 price. For a given CO_2 price, benchmark emission rates (which might differ across broad categories, such as bulk and container shipping) could then be set such that the total expected revenue from the feebate scheme equals a target amount. Another possibility would be to use excess carbon levy revenues to fund a deployment subsidy for ZEVs, which in turn would reduce the size of the carbon levy required. However, this approach would also result in a mismatch between revenue collection and disbursement until the start of ZEV deployment.

The Design of an International Maritime Carbon Levy

To maximize effectiveness, the carbon levy would need to be applied globally, which would also be consistent with the IMO's guiding principle of nondiscriminatory treatment for all

[11]See IMF (2019) annexes 1.4 and 1.5 for a general discussion of feebates.

ships. If global action is not taken, regional-level schemes may emerge,[12] but these are likely to be much less effective than a uniformly applied global levy. Even with a global levy, there is some risk of emissions leakage because of freight being diverted from shipping to rail, trucking, or air. However, in practice, the substitution possibilities for this are generally very limited (see, e.g., Psaraftis 2016). In the remainder of this section, we discuss levy collection and enforcement, levy formulas, CO_2 price trajectories, and compensation mechanisms.

Levy Collection and Enforcement

In principle, international maritime carbon levies could be collected from shipping fuel suppliers at the refinery gate (there are about 700 refineries worldwide) or at the point of distribution to ships in ports, as an extension of routine national fuel tax collection. However, given that the IMO has no mandate to take enforcement action against fuel suppliers, this approach would likely be challenging because policy coordination would be required across national governments.

In practice, international carbon levies would need to be collected directly from ship operators, through a new fund that would be overseen by the IMO (the IMO itself cannot raise funds). The costs of administering such a fund would likely be small, despite the greater number of taxpayers involved (initially about 25,000 vessels) relative to collection at the national level. There is a precedent for such a fund (albeit on a much smaller scale): the International Oil Pollution Compensation (IOPC) Funds. The IMO supervises the collection of IOPC Funds from oil-receiving entities in ports and disburses them as compensation for oil spill damages.[13]

Operators could remit the carbon levy on an individual route or annual basis using fuel data from the data collection system. As long as all major port states were party to the scheme, it could be comprehensively enforced through the denial of port access to any operator unable to provide invoices verifying payment of the levy; this would be the case even if some flag states (i.e., where ships are registered) were not party to the scheme.[14]

Levy Formulas

We next consider potential formulas for an international maritime carbon levy. Under a pure carbon levy, the formula for a ship operator's liability would be the price per ton of CO_2 emissions times the operator's CO_2 emissions, with the latter being equal to the ship's fuel use multiplied by a CO_2 emissions factor (3.15 tons of CO_2 per ton of bunker shipping fuel; IMO 2014).

[12]For example, Dominioni, Heine, and Martinez Romera (2018) compare the relative performance of various regional carbon pricing options and conclude that a well-designed cargo-based measure covering emissions released during shipping trips is most appealing on legal and effectiveness grounds.

[13]Contributions are channeled directly to the IOPC Funds, which had cash assets of $100 million in 2017. See http://www.iopcfunds.org.

[14]The UN Convention on the Law of the Sea allows port states to take actions against ships violating international rules, and many environmental and safety measures are enforced in this way (GEF et al. 2018). When a state becomes a party to an IMO convention, it agrees to make the convention part of its national law and to enforce it.

Under the feebate variant, a ship operator's payments would be the price per ton of CO_2 emissions multiplied by the operator's ton-miles, which is then multiplied by the difference between the operator's emission rate per ton-mile and an exogenous benchmark emission rate that is assigned to the operator. This means that under a feebate approach, whether ship operators pay taxes or receive subsidies depends on whether their emissions are above or below the benchmark for their ship classification (e.g., ships might be classified as container or as wet/dry bulk, where the latter might include oil products, steel, iron ore, coal, and grain). If the benchmark emission rate is set to zero, the feebate converges to the pure carbon levy; if the benchmark is set to equal the industry average emission rate, then the feebate is revenue neutral.

The feebate provides the same incentives as the pure carbon levy (for a given CO_2 price) for all the short- and long-term behavioral responses mentioned above, except for response 5—that is, shifting consumer demand away from heavy/long-distance products to light/short-distance products and nonshipped goods. The feebate will effectively tax ship operators less than the pure levy, which means that the prices of imported goods will rise less under the feebate than under the pure levy.

Setting the CO_2 Price Trajectory

Next, a trajectory for the CO_2 price needs to be specified. In principle, the trajectory could be based on projections of the following.

1. Emissions prices implied by countries' Paris Agreement mitigation pledges, although these vary considerably across countries, depending on the stringency of their emissions commitments and the price responsiveness of emissions (e.g., Aldy et al. 2016; IMF 2019; Liu et al. 2019).

2. Prices in other carbon pricing schemes, which currently range from around \$5 to \$50 per ton in most cases (WBG 2020),[15] although prices will rise as countries increase decarbonization over time.

3. Global CO_2 prices that are consistent with temperature goals, which, for 1.5°C–2°C, need to rapidly reach around at least \$75 per ton by 2030 (CPLC 2017; Parry, Black, and Roaf 2021)—this is far from the current global average price of about \$3 per ton (based on WBG 2020).

4. Prices that would ultimately be required to ensure the adoption of ZEVs into the maritime fleet.

The last option appears to be the most appropriate in the case of an international maritime carbon levy because this would be consistent with the IMO's mitigation pledge. This means that at the present time, very high carbon prices would be needed to equalize the life cycle costs of ZEVs and oil-based vessels. For example, in the case of ammonia vessels, an estimated price of \$277 per ton of CO_2 would be required to account for the higher fuel costs and a further price of \$21 per ton to account for the higher capital costs of new ships or \$81 per ton for retrofitting existing ships (Smith et al. 2016; BHP et al. 2019). However, the cost differential between ZEVs and oil-based vessels is expected to decline rapidly, perhaps to around \$75 per ton by 2030, if there is an aggressive R & D program (Lloyd's Register and UMAS 2017).

[15] Throughout the discussion that follows, monetary values are expressed (approximately) in real 2018 US dollars.

Compensation Mechanisms

We next discuss the issue of compensation mechanisms for vulnerable states. In principle, broad compensation could be provided to all developing countries for the incidence of the maritime levy, although this would be complex to administer and would absorb about 40 percent of the revenue (IMF and WBG 2011). Moreover, the rationale for compensating middle- and high-income developing countries is questionable, given the relatively small impact of a maritime carbon levy on import prices (see below); thus, the concern about differentiated responsibilities has focused on low-income countries and (remote) small island developing states, where imports and shipping costs are disproportionately high relative to GDP (UNCTAD 2014).

There are several options for compensation, although no one single mechanism may be entirely satisfactory. For example, reimbursing vulnerable countries for levies assessed on their maritime fuel sales would overcompensate some countries (e.g., hubs where ships frequently refuel prior to off-loading cargo in other countries) but undercompensate others (e.g., small islands where ships off-load cargo without refueling). Another possibility is to base compensation on countries' shares of global import values (Stochniol 2011). However, import value is not always a reliable predictor of CO_2 (e.g., light electronic equipment has a low ratio of CO_2 to import value), and this approach may also disadvantage the poorest countries. Alternatively, compensation could also be based on cross-country incidence studies by external experts.

Some form of compensation should be feasible, especially because the incidence of a maritime carbon levy would generally be modest. For example, a $75 per ton of CO_2 levy would increase bunker fuel prices (relative to 2019 levels) by about 50 percent, which means that maritime transport costs would increase by 25 percent, assuming that fuel costs are 50 percent of operating costs (e.g., Keen, Parry, and Strand 2013, table 4; ITF 2017). In turn, this would increase landed import prices by only about 2.5 percent (if ship operating costs are 10 percent of landed import prices).[16] Potential price increases could be approximately twice as high for low-income countries and small island developing states because maritime transport costs are roughly 20 percent of landed import prices for this group (UNCTAD 2017), but the price increases would still be modest.

Alternative Mitigation Instruments

This section considers alternatives to a carbon levy, including an ETS, energy efficiency standards, and carbon offsets.

ETS

Under an ETS, ship operators would need to acquire allowances (from a body overseen by the IMO) for the CO_2 emissions associated with each trip. Total allowances, and hence emissions,

[16] On average, the share of maritime transport costs in landed import prices is 5 percent for manufactured products, 11 percent for agricultural products, and 24 percent for industrial raw materials (OECD 2011). A review by Halim, Smith, and Englert (2019) suggests that a carbon levy of $10–$50 per ton would increase maritime transport costs by 0.4–16 percent and, in most cases, increase the price of landed imports by less than 1 percent.

would be capped, with trading among ship operators establishing an allowance price. In principle, this approach would promote the same near- and medium-term mitigation responses as the levy, while auctioning of the allowances could generate similar revenues.

An ETS has the advantage of providing greater certainty about future emissions in a particular year. However, this has limited relevance because the IMO's emissions target is three decades in the future, and the development and deployment of ZEVs in the shipping fleet is a more urgent priority. Given the long-lived nature of the investment in ZEVs (the average ship life is about 35 years), a levy (with a clearly specified price trajectory) seems better suited to promoting this deployment because such a levy provides certainty about the future emissions price and hence about lifetime fuel costs. Price certainty also provides more certainty about the revenues that might be raised for R & D and investment into ZEVs.

An ETS would also involve higher transaction costs than a levy. Large shipping companies, like Maersk and MSC, already have trading departments that could buy, sell, and hedge emission allowances at minimal additional cost. However, a large share of the global fleet is operated by small companies that use only a few ships with limited capacity; involvement in trading markets for allowances could significantly increase the overhead costs for these companies. The issue of allowance market manipulation could also arise given the significant concentration in the sector (Pirrong 2009), with eight companies accounting for about 60 percent of shipping capacity (UNCTAD 2016). Finally, an ETS is potentially less cost-effective than a carbon levy in a short-run dynamic sense; this depends on the extent to which year-to-year volatility in emissions prices around a long-term trend causes significant differences in (discounted) incremental mitigation abatement costs at different points in time (Fell, MacKenzie, and Pizer 2012).

Energy Efficiency Standards

Energy efficiency standards for new ships have three disadvantages relative to a carbon levy. First, they do not raise revenue. Second, they do not provide the robust price signal to close the gap between the cost of ZEVs and the cost of conventional vessels (because they do not charge ship operators for their fuel use). Third, they do not promote all the near-term mitigation responses discussed above. For example, energy efficiency standards do not promote improvements in operational efficiency or the efficiency of used ships. Moreover, standards do not provide an automatic mechanism for equating the incremental costs of CO_2 reductions across different ship builders, which undermines their cost-effectiveness.

However, energy efficiency regulations could be used to address a market failure that might arise because ship owners, who bear the costs of energy efficiency investment, are often not the ship operators, who benefit from the fuel savings from improved energy efficiency. This might lead to some underinvestment in energy efficiency, although the importance of the market failure is not entirely clear (Rehmatulla, Smith, and Stulgis 2017).

Carbon Offsets

The centerpiece of the International Civil Aviation Organization's strategy to stabilize the aviation sector's emissions is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Under this scheme, which will become mandatory in 2026, flight operators are required to purchase international offsets for any emissions above 2019 levels.[17] In contrast to the aviation sector, under the IMO's strategy for the maritime sector, international emission offsets cannot be used in lieu of reducing within-sector emissions (IMO 2018). However, even if the IMO strategy were replaced with a CORSIA-type scheme, with operators required to purchase offsets for any CO_2 emissions above a benchmark level, this would not raise revenue. In addition, at least at the present time, it would have minimal impact on within-sector emissions because of the low offset price.[18]

A Road Map for Implementing a Carbon Levy to Achieve Mitigation Goals

On the basis of a simplified modeling framework,[19] this section presents a road map for using a carbon levy to implement the IMO's mitigation pledge under plausible scenarios for turnover of the shipping fleet and the price signal needed to replace retiring ships with ZEVs. We first describe the methodology and then discuss the impacts of the carbon levy and alternative mitigation policies.

Methodology

We project fuel use by wet/dry bulk and container shipping under a business as usual (BAU) scenario that is based on global GDP trends (assumed to expand by 20 percent between 2017 and 2023 and to grow by 2.9 percent a year thereafter)[20] and income elasticities of 0.5 and 0.8 for bulk and container products, respectively.[21] The BAU does not consider new mitigation measures, including tightening of the existing IMO efficiency standard. We assume that the energy intensity of shipping declines autonomously at 0.5 percent annually (e.g., because of turnover of older, less fuel-efficient ships) and that international crude oil prices remain constant in real terms at $475 per ton ($65 per barrel). However, there is a (permanent) one-time price increase of $150 per ton ($20 per barrel) from 2020 onward because of the new IMO requirement that the sulfur content of fuel oil not exceed 0.5 percent. We parameterize the near-term behavioral responses for reducing emissions (discussed above) to imply an overall bunker fuel price elasticity of –0.45 (based on McCollum, Gould, and Greene 2009; Smith et al. 2016). Beyond 2030, we assume that 3 percent of the fleet is retired each year (because the average ship life is 35 years) and that once the carbon price reaches $75 per ton, all new ship replacements will be ZEVs.

[17] See ICAO (2013) and http://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx.

[18] Recent offset prices have been around $3–$5 per ton, although they may increase significantly over the next decade (Trove Research 2021).

[19] This framework is based on the working paper version of this article (see Parry et al. 2018), with a modification to allow ZEV penetration and reliance on updated GDP forecasts.

[20] Fuel use was 334 million tons in 2016 (equivalent to 1,051 million tons of CO_2), 55 percent of which was allocated to bulk and the rest to container shipping.

[21] This below-unitary income elasticity for container shipping reflects the larger budget shares of services and higher-quality products among higher-income households. Estimated income elasticities for crude oil (a major component of bulk shipping) are around 0.5 to 1.0 (e.g., Gately and Huntington 2001; Xiong and Wu 2009; Huntington, Barrios, and Arora 2017), although the lower bound in this range seems to more accurately account for future efforts to curb fossil fuel use.

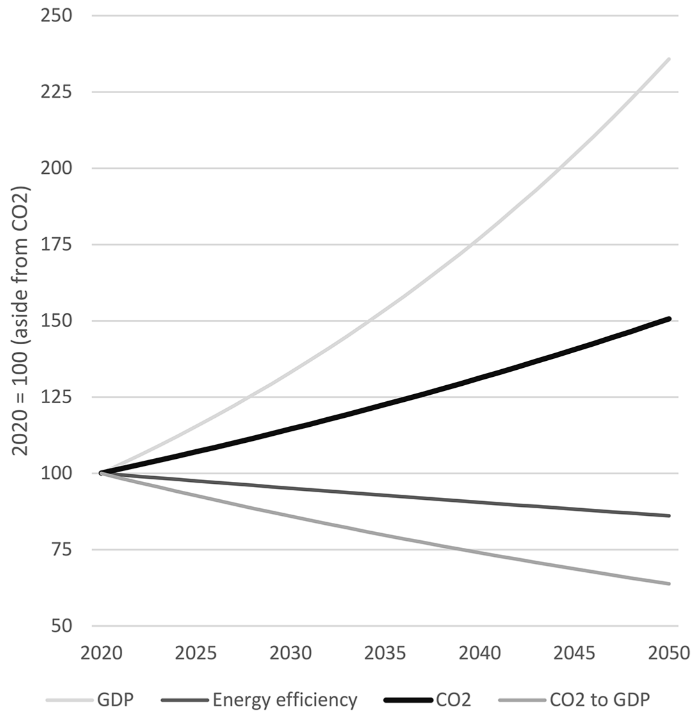

Figure 2 BAU GDP, energy efficiency, and CO_2 emission trends. Variables are expressed relative to 2020 levels. Source: Updated from Parry et al. (2018). A color version of this figure is available online.

As shown in figure 2, under the BAU scenario, bunker fuel use and CO_2 emissions rise by 15 percent by 2030 and 50 percent by 2050, respectively, relative to 2020 levels. This is much lower than the growth in GDP because of a decline in the ratio of maritime emissions relative to world GDP (14 percent and 36 percent by 2030 and 2050, respectively), which reflects the below-unitary income elasticities and improvements in energy efficiency.[22]

Impacts of a Carbon Levy and Alternative Mitigation Policies

Figure 3*a* illustrates the effects of various mitigation policies on emissions. Tightening energy efficiency for new ships (in line with IMO efficiency standards) lowers fuel use relative to the BAU, but it is still 15 percent above 2008 levels in 2050.

A pure carbon levy (combined with the energy efficiency standard) that rises annually at $7.5 per ton of CO_2 from 2021 onward, reaching $75 per ton by 2030 and held constant in real terms thereafter, is considered. From 2030 onward, this levy raises bunker fuel prices 40 percent above BAU levels and—if there are no prospects for deploying ZEVs—reduces annual CO_2 emissions 14 percent below BAU levels in 2030; however, thereafter, emissions continue

[22]Some studies have suggested higher BAU emissions growth. For example, in Smith et al. (2016), BAU emissions grow by about 50 percent between 2016 and 2030, which primarily reflects higher GDP growth and income elasticity assumptions. The IMO (2014) projects baseline emissions growth of 50–250 percent by midcentury, depending on the scenario for international trade, while Hoen, Faber, and Lee (2017) predict emissions growth of 20–120 percent by 2050.

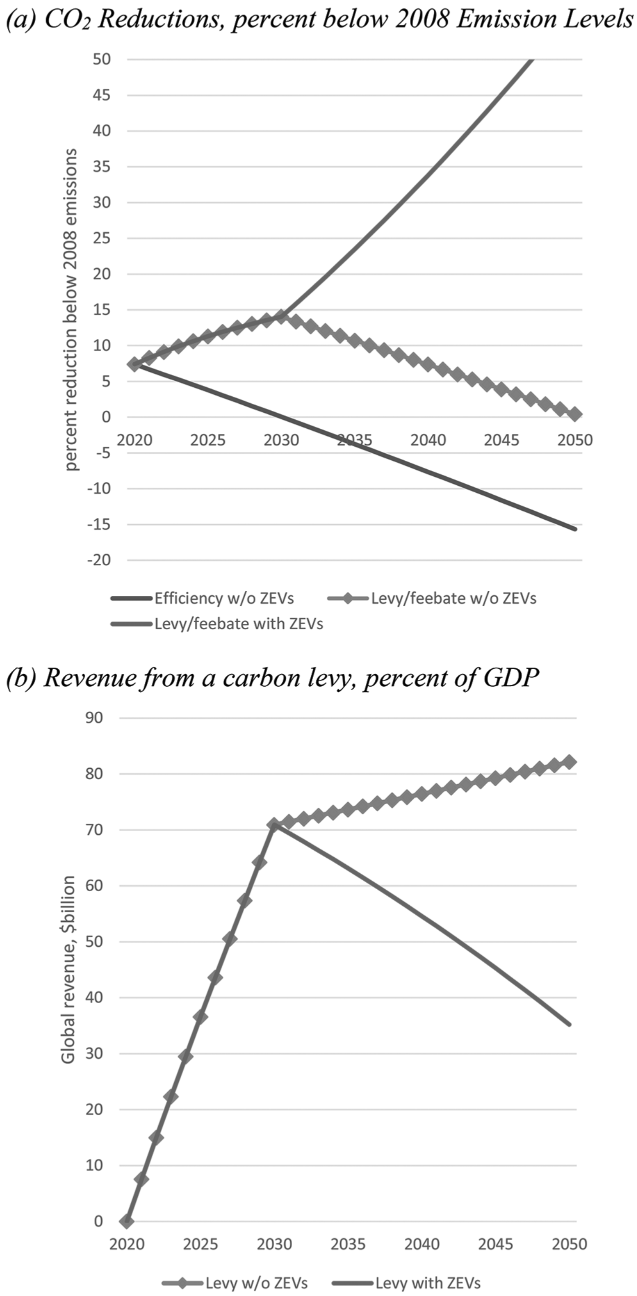

Figure 3 Impacts of carbon mitigation policies on the international maritime sector. The upward-sloping solid line in *a* indicates a levy/feebate with ZEVs, and the downward-sloping solid line indicates efficiency without ZEVs. Feebate policies are revenue neutral. Source: Updated from Parry et al. (2018). A color version of this figure is available online.

to grow in absolute terms (they are back to 2008 levels by 2050). This result underscores the inadequacy of policy scenarios that do not involve the deployment of ZEVs. However, if ZEVs are available to replace ships that are being retired from 2030 onward, emissions reductions (below 2008 levels) increase steadily over time to meet the IMO's 50 percent reduction pledge just before 2050.

Feebates have essentially the same impacts on fuel use and emissions as the levy, in scenarios with and without the availability of ZEVs. This is because (for the same implicit carbon price) the only difference between the pure levy and the feebate is that the former reduces emissions by reducing ton-miles (as levy revenues are passed forward in higher shipping costs), while the latter does not. However, given the small projected increases in the price of shipped products (see above), this response is very small and is thus ignored in the modeling.

Once fully phased in, the pure carbon levy raises about \$75 billion a year in revenues, although they decline progressively (to \$38 billion by 2050) with ZEV penetration (see figure 3*b*). A feebate variant with the same carbon price could be set to raise anywhere between zero and the amount of revenue raised under the pure carbon levy through the choice of the benchmark emission rates. In short, these scenarios illustrate the feasibility of achieving long-term mitigation goals for the maritime sector through an appropriately scaled carbon levy.

Summary and Conclusions

This article has demonstrated that a carbon levy should be a key component of any long-term policy to decarbonize the international maritime sector. Indeed, it would be straightforward for an IMO-supervised fund to apply and monitor the carbon levy at global scale. The levy would need to mobilize sufficient funding for ZEV development in the near term while providing a price signal that closes the cost gap between conventional vessels and ZEVs when the latter are ready for deployment. A CO_2 price on the order of \$75 per ton by 2030 appears consistent with long-term emission reduction commitments for the sector.

Extensive consultation with key stakeholders, particularly shipping interests and IMO member states, will be needed to establish a broad coalition of support for the levy. This coalition building will require awareness about the lack of other policy options for achieving the sector's emissions goals (aside from outright bans on conventional vessels) and the role of compensation schemes for vulnerable small islands and low-income countries. Agreement will also need to be reached on the procedures for allocating levy revenues across potential R & D and investment projects on ZEVs in different countries, as well as on how other revenues (beyond those for compensation schemes) will be used. The IMO and other stakeholders could also consider feebates as an alternative to a pure carbon levy, whereby revenues would be set independently (for a given carbon price) through the adjustment of benchmark emission rates.

Finally, a well-designed maritime carbon levy may also have some spillover benefits for other sectors. First, it could provide a prototype for pricing reform in the international aviation sector. Pressure for robust aviation price reform may increase as a maritime carbon levy ramps up over time, especially if the price of offsets under the CORSIA remains depressed. Second, promoting hydrogen fuel supply chains could trigger the development of this fuel for other sectors, such as land-based transportation and residential heating systems.

Appendix

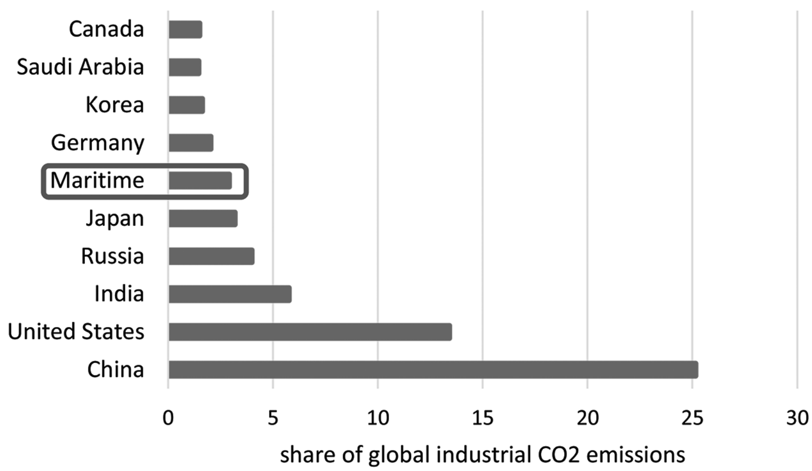

Figure A1 Major sources of global CO_2 emissions, 2016. Sources: IEA (2018); Parry et al. (2018). A color version of this figure is available online.

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