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Sink or Swim

The Economic Impacts of an International Maritime Emissions System for Greenhouse Gases on the United States

Nigel Purvis and Samuel Grausz

THE AUTHORS

Nigel Purvis is a non-resident senior fellow at the Brookings Institution. He is also president and ceo of Climate Advisors.

Samuel Grausz is an associate at Climate Advisers and leads their energy, transportation and carbon markets practices.

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EXECUTIVE SUMMARY

The maritime sector, long unregulated with regards to greenhouse gas (GHG) emissions, has recently become a focus of climate change policy. Last year the International Maritime Organization (IMO), the global regulator of maritime trade, issued energy efficiency standards (which directly impact GHG emissions) for new and modified ships and is now deciding how to regulate emissions from existing ships.[1]

The European Union has also recently solicited input on how to regulate emissions from ships calling in European ports in case discussions in the IMO do not proceed. Furthermore reports issued by the World Bank and International Monetary Fund, comments by Bill Gates and language agreed to at the U.N. Climate Negotiations in 2012 all identified shipping emissions as a target for both emissions reductions and raising revenue to address climate change in developing countries.[2]

As indicated by previous climate debates, the position of the United States on these policies will likely decisively impact whether the policies succeed or fail. U.S. leaders, however, currently lack the necessary analyses on which to base their opinions as few studies have modeled the benefits and costs of these potential policies.

This study begins to fill this gap by analyzing the impacts of a global system to reduce maritime GHG emissions, such as the system being considered by the IMO, on the United States. We find that such a program could generate significant benefits for the United States and other countries. Specifically, we estimate that carbon dioxide (CO_2) emissions from global maritime sector likely cause between $18-$72 billion in social costs each year globally by contributing to the harmful effects of climate change. A global maritime GHG emissions system could potentially help avoid a large portion of this harm by reducing CO_2 emissions. The policy could also generate significant additional benefits through raising revenues to respond to climate change in developing countries and reducing non-GHG emissions.

On the cost side, we find that the policy would generate limited additional expenditures for the shipping industry, especially in comparison to other costs faced by the sector, and thus have a small impact on the U.S. economy. Specifically, the policy would likely create only a fraction of the costs caused by the increase in maritime fuel prices over the last decade, suggesting that such a policy would not significantly adversely impact shippers or U.S. consumers and businesses.

We explicitly show the limited impact of such a policy on the U.S. economy by calculating the changes in import and export prices and demand that result from the policy, as shown in Table ES1.

TABLE ES1: Changes in Import and Export Prices and Demand Resulting from a Global Emissions Regime

	Trade	Economic Impact
Carbon Tax		\$15 - \$30
Change in Prices	Imports	0.10% - 0.28%
	Exports	0.14% - 0.28%
Change in Demand	Imports	-0.61% - -1.23%
	Exports	-0.88% - -1.76%

As the table indicates, the policy would drive small increases in the price of imports (0.1-0.3 percent) and exports (0.1-0.3 percent). For comparison, the United States currently applies taxes and tariffs of 1.53 percent to each dollar of imports, significantly more than the price changes caused by the potential global maritime emissions policy. Similarly for U.S. consumers, the import price changes of the policy translate into small increases in the prices paid for imported goods, including fractions of a cent more per gallon for gasoline and $1.30 more for an average computer.

The policy would likely cause equally small impacts on import and export-dependent U.S. industries and unions by driving very small reductions in demand for U.S. imports (0.6-1.2 percent) and exports (0.9-

1.8 percent) and thus the volume of trade flowing through U.S. ports. The actual impacts could be significantly less as many studies estimate smaller elasticities of demand for U.S. imports and exports. Further, a significant portion of the lost imports would likely be replaced by additional domestic demand, offsetting the losses for U.S. industries.

INTRODUCTION

Ships are a significant and growing source of GHG emissions. They currently represent 2.7 percent of global CO_2 emissions (870 million metric tons), and the International Maritime Organization (IMO) projects the emissions will rise between 120 and 210 percent by 2050.[3] This makes current shipping emissions approximately equivalent to the emissions of Germany.[4] The GHG emissions are primarily carbon dioxide, but also include nitrous oxide (N_2O), methane (CH_4), and hydrofluorocarbons (HFCs), though in very small quantities relative to CO_2.[5]

The IMO has recently advanced towards regulating GHG emissions. In 2011, it issued standards for energy efficiency for new and modified ships, which directly impact their GHG emissions.[6] The standards mandate a 30 percent reduction in fuel consumption and thus greenhouse gas emissions by 2025, and the IMO expects this will reduce emissions from ships by 180-240 million metric tons annually by 2020.[7] IMO has also proposed voluntary measures to improve the energy efficiency of existing ships through better operations[8] and is in the process now of figuring out mandatory emissions regulations for existing ships, the status of which we review below.

In addition to the IMO, the European Union solicited input earlier this year on how to regulate emissions from all ships calling in European ports.[9] European law mandated this action as the IMO had not finished a global program by the end of 2011. The European Union proposed a number of options in the solicitation, such as the inclusion of ships in their Europe-wide cap-and-trade program for GHG emissions, the European Union Emissions Trading System (EU ETS). This follows on the EU's similar move to include aviation emissions in the EU ETS at the beginning of 2012, a decision currently opposed by many non-European airlines and other countries.

Beyond the IMO and Europe, reports issued by the World Bank and IMF, comments by Bill Gates and language agreed to at the U.N. Climate Negotiations in 2012 all identified shipping emissions as a target for both emissions reductions and raising revenue to address climate change in developing countries.[10] This is in line with the long standing desire of the climate change community to raise revenues from maritime emissions regulations and transfer those revenues to developing countries to help them reduce their emissions and prepare for accelerating climate change. These revenues would help developed countries meet the goal of mobilizing \$100 billion per year in such financing agreed to at the 2009 Conference of Parties meeting in Copenhagen. So far, the world has made relatively little progress towards meeting that goal, with only \$30 billion pledged.[11]

The position of the United States on these policies will likely decisively impact whether they succeed or fail. U.S. leaders, however, currently lack the necessary analyses on which to base their opinions. Only a few studies have attempted to model the benefits and costs of a global maritime emissions regime and none of the studies have focused on the impacts of the policy on the United States.

This study begins to fill this gap by analyzing the impacts of a global system to reduce maritime GHG emissions, such as that being considered by the IMO, on the United States. We examine the potential benefits of such a policy, including avoided climate change, economic growth, preparation for climate change impacts in developing countries and reductions to health impacts from non-GHG emissions.

We compare these benefits in general terms to the potential costs of such a policy. Specifically, we use a simple economic model to estimate the changes in prices and demand for U.S. imports and exports resulting from such a policy. These results are used to indicate the likely impacts for the U.S. economy and inform decisionmakers on whether such a policy is in the best interest of the United States.

POLICY BACKGROUND

The IMO is the global regulator of for the maritime sector. Established by the IMO Convention in 1948, the IMO has issued regulations on many aspects of maritime activity, ranging from safety to oil spills. In 2011, it issued the Energy Efficiency Design Index (EEDI) for new and modified ships.[12] These energy efficiency standards mandate a 30 percent reduction in fuel consumption and thus greenhouse gas emissions by 2025, and the IMO expects this to reduce emissions from ships by 180-240 million metric tons annually by 2020.[13]

The IMO is currently considering what approach to take in reducing emissions from existing ships and is pursuing a market-based mechanism (MBM). MBM refers to a type of regulation that creates incentives for regulated entities to increase or decrease a given behavior through changing prices. Observers often juxtapose MBMs against "command and control" regulations, which require rather than incentivize actions.

Common types of MBMs include taxes or subsidies on behaviors or programs where regulated entities may buy and sell limited permits that grant the right to do an activity (aka, a "cap-and-trade" program). MBMs to reduce environmentally harmful behavior became widespread in the 1990s with programs under the Clean Air Act to reduce sulfur dioxide (SO_2) and nitrous oxide (NO_x) emissions from power plants.[14] These programs successfully reduced these emissions at surprisingly low costs.[15]

Today, many economists and regulators prefer MBMs as they tend to reduce emissions at a lower cost than command and control regulations.[16] MBMs also appeal to many governments because they can be designed to raise revenue for various purposes, including further reducing emissions and redressing the harmful effects of the emissions.

In 2010, member countries to the IMO proposed a number of possible MBMs, described in Table 1.[17] The IMO is still in the process of analyzing these proposals, but in the most recent meeting of its Marine Environment Protection Committee (MEPC), the subsidiary body tasked with designing these regulations, set a deadline of 2015 for implementing an MBM.[18]

The proposals all take different approaches to regulating GHG emissions. Some, such as the mechanisms proposed by the United States and the World Council of Shipping, require ships to meet a certain emissions rate or efficiency standard. Others including the proposals from Norway, U.K. and France set a cap on total maritime emissions. The proposals also allow different means for ships to comply with the regulations in a manner that minimizes their costs. All of the proposals, other than the U.S. proposal, raise revenue for additional actions to address climate change.

SOCIAL BENEFITS

Regulating and reducing emissions from ships offers a number of potentially significant benefits to the United States and other countries. Most obviously the avoided GHG emissions would reduce the threat of climate change, which will likely significantly damage the U.S. and other economies in the coming years through more frequent and destructive storms, increased droughts, disruption of valuable ecosystems, and many other impacts.[19] The reduced threat of climate change might also help avoid destructive and costly future conflicts, as recently stressed by U.S. Defense Secretary Leon Panetta.[20]

To put these potentially avoidable costs in monetary terms, the U.S. government estimated in 2011 that the average cost of a ton of carbon emissions to society (the "social cost of carbon") is approximately $21 per metric ton. By this estimate, the shipping sector

TABLE 1: Proposals for a Global MBM Under IMO to Reduce Emissions From Shipping

Number	Proposal	Sponsor	Description
1	International fund for GHG emissions	Cyprus, Denmark, the Marshall Islands, Nigeria, and the International Parcel Tankers Association (IPTA)	Establishes a global reduction target for international shipping. Emissions above the target would be offset largely by purchasing approved emission reduction credits, which would be financed by a tax on marine bunker fuels.
2	Leveraged Incentive Scheme	Japan	Develops a GHG Fund from a tax on marine bunker fuels. The fund will pay ships that meet or exceed agreed efficiency benchmarks and are labeled as "good performance ships".
3	Port State Levy	Jamaica	Levies a uniform emissions charge on all vessels at each port based on the amount of fuel consumed by the respective vessel on its voyage to that port.
4	Ship Efficiency and Credit Trading	United States	Subjects all ships to mandatory energy efficiency standards that become more stringent over time. Includes trading of efficiency-credits.
5	Vessel Efficiency System (VES)	World Shipping Council	Establishes mandatory efficiency standards for new and existing ships requiring reductions relative to the average ship, differing based on vessel class and size, and becoming increasingly stringent over time. Existing ships failing to meet the standard would be subject to a fee based on their fuel consumption.
6	Emissions Trading System (ETS)	Norway	Sets up a sector-wide cap-and-trade system for emissions from international shipping. Allowances would be auctioned at a global level.
7	Emissions Trading System (ETS)	United Kingdom	Same as the Norwegian proposal except that (1) allowances would be auctioned by countries instead of globally and (2) the emissions cap would be set with a long term declining trajectory.
8	Emissions Trading System (ETS)	France	Same as the Norwegian proposal except with additional details on auction design.
9	Market-Based Instruments: A Penalty on Trade and Development	Bahamas	Not a proposal but a statement that the imposition of any costs should be proportionate to the contribution by international shipping to global CO_2 emissions.
10	Rebate Mechanism (RM): For a Market-Based Instrument	International Union for Conservation of Nature (IUCN)	Not a complete proposal but a concept for how to compensating developing countries for the financial impact of a MBM. It could be applied to any maritime MBM which generates revenue.

currently causes approximately $18 billion annually in social damage from carbon dioxide alone.[21] Other governments estimate higher social costs of carbon including the United Kingdom, which estimated an average social cost of carbon of $83 per metric ton resulting in climate change damages from the shipping sector of approximately $72 billion.[22]

Moreover, climate change creates a risk of significantly larger damages than those described above. The U.S. government estimates a range of potential social costs of carbon of $5-$65 per metric ton while the U.K. government estimates a range of $41-$124 per metric ton. Our risk adverse societies would likely prefer additional reductions to avoid significantly higher damages from climate change, making the reductions from shipping even more valuable to society.

No existing studies estimate the emissions reductions from the proposed MBMs under the IMO, so we cannot directly estimate the potential benefits of the policies. The proposed MBMs would likely significantly reduce emissions, however, and thus help avoid billions of dollars in social costs for the U.S. and other countries just by reducing maritime GHG emissions.

Many of the proposed MBMs could also drive GHG emissions reductions outside of the maritime sector by generating revenues from the MBM that could be directed to developing countries to reduce GHG emissions. These revenues could help pay for the significant potential low-cost emissions reductions across developing countries found by McKinsey in their many studies of GHG mitigation costs, further reducing the threat of climate change for the United States and other countries.[23]

The revenues could also help catalyze emissions reductions that would drive economic growth in developing countries, as detailed in the McKinsey studies mentioned above. McKinsey finds that developed and developing countries have multiple opportunities to reduce GHG emissions in a way that would actually save money and thus help the economies of those countries grow (so called "green growth"). They speculate that these countries do not take advantage of these emissions reductions due to informational, behavioral or market failures and that carbon policies and external finance might help countries overcome their barriers and take advantage of these policies. As such, the revenues from a maritime MBM could help reduce emissions in a manner than would grow developing economies.

Developing countries could also use the money to help prepare for increasingly severe climate change. These preparations would help these countries deal with increasingly erratic weather patterns, more frequent droughts and other destructive climate related events. Moreover, these countries could probably adapt more cheaply now, before the worst impacts of climate change, than in the future. Thus revenues for adaptation could again create significant economic wealth through avoided loss of crops, infrastructure and life.

The United States, the focus of this report, values helping developing countries avoid the worst impacts of climate change and grow through green growth and adaptation. More selfishly, however, the economic success of these countries also could drive more demand for U.S. exports, benefiting the U.S. economy in the long run.[24]

Outside of climate change, more efficient shipping would likely decrease emissions of non-GHG pollutants from ships, such as sulfur dioxide (SO_2), nitrous oxides (NO_X), and Volatile Organic Compounds (VOCs),[25] each of which has its own potentially significant negative health effects on the population of the United States and other countries.[26] SO_2 causes a variety of health problems for people including lung cancer and other upper respiratory ailments, and contributes to acid rain that damages ecosystems. NO_X also contributes to the acid rain, and NO_X and VOCs both drive the formation of ground-level Ozone, a pollutant which can cause severe respiratory illness.

People all over the world feel the effects of these emissions, but especially those in the vicinity of maritime ports.[27] Many U.S. ports generate many times more NO_X and PM emissions than a power plant or refinery, and a large share of the emissions from a port come from the ships. Avoiding these emissions would create significant social benefits for the United States and other countries in the form of better functioning ecosystems, more productive agriculture, less sickness and fewer avoidable deaths.

ECONOMIC IMPACTS

General

The primary economic impact on the United States by the maritime emissions regulations described above would be to generate costs for the maritime sector that would result in changes in prices and demand for imports and exports.[28] The regulations would either cause shipping companies to spend more on their fuel (as in proposals from Cyprus, Japan and Jamaica), pay for efficiency improvements (as under the United States and World Shipping Council programs), or purchase credits to cover their emissions (as under the proposals from Norway, the United Kingdom or France).[29] Regardless of the mechanism, the shippers would pass at least part of these costs through importers and wholesalers to consumers in the United States and other countries, potentially reducing demand for imports and exports.

The regulations could also potentially encourage shippers to undertake emissions reductions that actually lower their costs, leading to reductions in import and export prices. We did not attempt to model this potential effect, however, due to a lack of data on such emissions reduction measures.

Modeling Approach

The different regulatory approaches outlined above would have significantly different economic impacts due to differences in their design and structure. The incentives created to reduce emissions from GHGs, however, would drive the primary impacts of each policy and the differences between policies, although significant, pose many modeling challenges. Thus, this paper seeks to capture the primary impacts by estimating the impacts of the relatively simple-to-model carbon tax applied on maritime fuel.

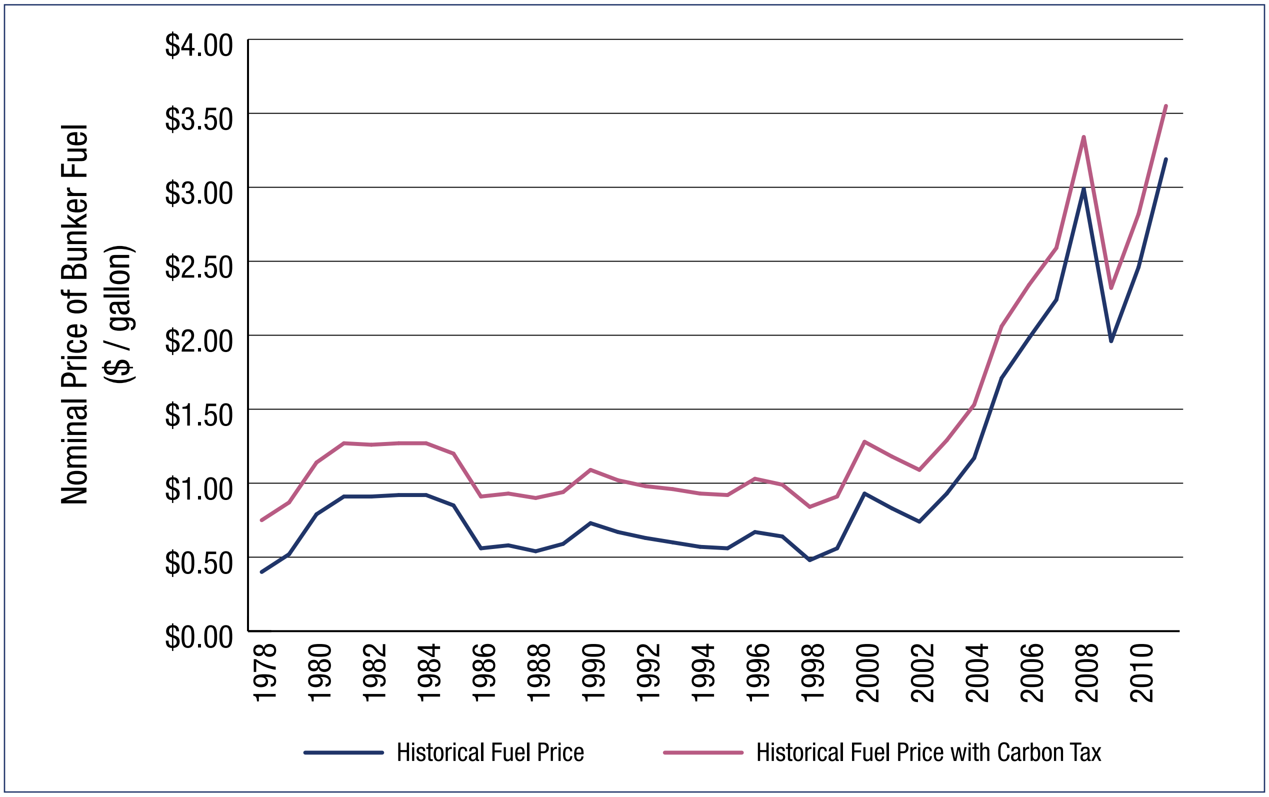
The analysis employs a simple "partial-equilibrium model", which is described in greater detail in Appendix A. The model calculates the changes in the prices of and resulting demand for U.S. imports and exports caused by a carbon tax. The model generates results for a single year, which can be taken to be any representative year in the program in the near future. It does not capture the "general equilibrium" effects, such as increases in import prices leading to reductions in disposable income or substitution from one import to another, other potential economic effects of the expenditure of the revenues collected under the carbon tax.

We use the model to analyze a range of carbon taxes, \$15-\$30 per ton, reflecting the uncertainty about the structure and stringency of the program and the price of emissions credits in other emissions and offset markets. We chose these carbon tax levels rather than the current price of carbon in many markets (\$8.25 in the case of credits in the EU ETS)[30] as we expect the price of carbon in various markets to increase as countries with new and existing cap-and-trade programs tighten their caps to increase their mitigation ambition.

We assume that shippers respond to the carbon tax by paying the tax and not reducing their own emissions as we lack data on maritime emissions reduction opportunities. Shippers likely have a number of such opportunities, including changing routes, reducing speeds, switching to more efficient ships, and retrofitting existing ships, among many others.[31] If shippers reduce their emissions using such methods at a lower cost than the carbon tax, then the actual cost and impact of the policy would be smaller. These emission reduction methods could also pose other environmental and economic impacts which we do not consider in this report.

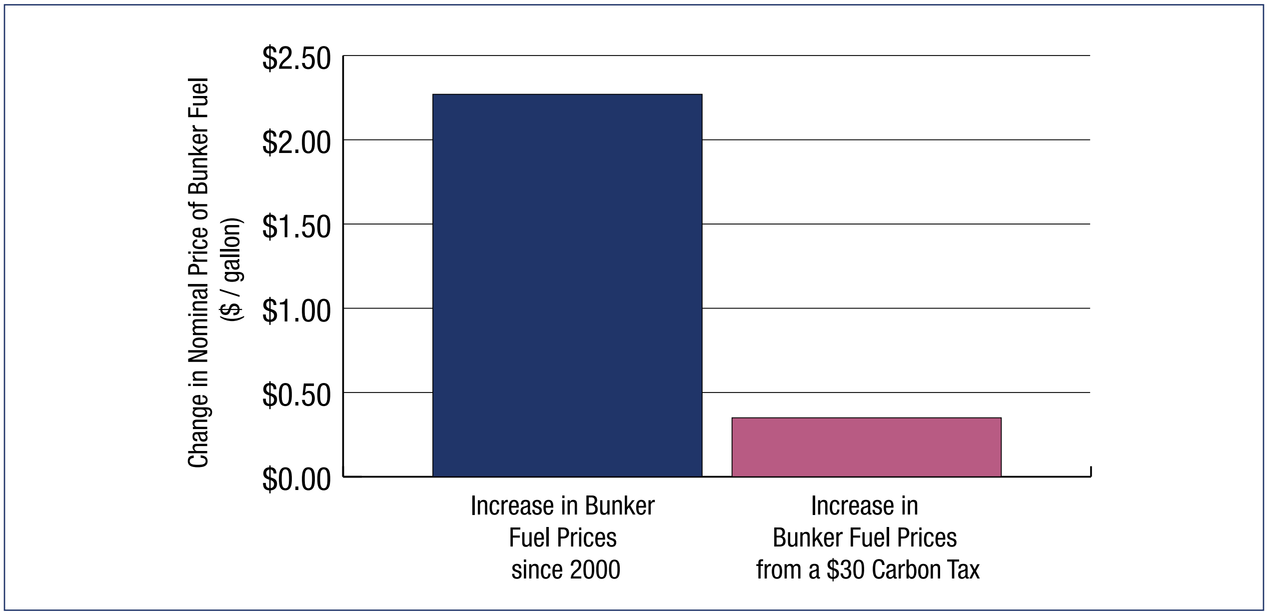
We also assume that all shippers comply with the carbon tax. Given the global nature of the policy, special attention should be given by future studies

FIGURE 1: Comparison of Historical Bunker Fuel Prices to Historical Bunker Fuel Prices with a $30 Carbon Tax



Source: Energy Information Agency (EIA) and author's calculations.[32]

FIGURE 2: Comparison of Historical Changes in Bunker Fuel Prices to Changes in Bunker Fuel Prices From a $30 Carbon Tax



Source: Energy Information Agency (EIA) and author's calculations.[33]

to the practical challenges of implementing and enforcing the policy.

Costs

The carbon tax, as described above, would increase costs for the maritime sector. Our analysis shows, however, that other cost increases recently faced by the shipping sector, most notably increases in fuel costs, significantly exceed the likely costs of the policy.

As shown in Figure 1, bunker fuel prices in the United States have skyrocketed by over 240 percent since 2000. This increase dramatically exceeds the costs imposed by the policy, which are equivalent to an increase in bunker fuel prices of 7 percent to 14 percent, as shown in Figures 1 and 2. In fact, the annual variation in fuel costs often exceeded the likely costs of this policy.

The comparisons to recent increases in fuel prices indicate that the impacts of the policy would not be unprecedented and thus could probably be managed by the shipping industry. Moreover, they suggest that the policy would not lead to unprecedented changes in import and export prices and demand, and thus would bring minimal economic harm to U.S. industries and consumers that depend on these imports and exports, as shown explicitly in the next section.

Import and Export Prices

Our analysis finds that a global emissions regime covering all shipping would have minimal impacts on the price of U.S. imports and exports. Table 2 shows the results of the analysis in terms of percent changes in the price of U.S. imports and exports for different types of commodities and goods.

TABLE 2: Impacts of a Global Emissions Regime on the Price of Imports and Exports

	Change in Prices	
	Imports	Exports
Total	0.10% - 0.28%	0.14% - 0.28%
Agriculture	0.14% - 0.29%	0.34% - 0.68%
Raw material	0.18% - 0.36%	0.23% - 0.46%
Crude Oil	0.06% - 0.13%	0.34% - 0.69%
Manufacturing	0.10% - 0.20%	0.08% - 0.16%

These price impacts are broadly in line with other studies of the impacts of global maritime policies.[34] To provide some sense of scale for these changes in prices, we compare these price changes to the taxes and tariffs normally levied against U.S. maritime imports. The United States applies multiple taxes to all maritime imports to the United States, most notably a 0.125 percent of import value Harbor Maintenance Fee and a 0.21 percent of import value Merchandise Processing Fee.[35] The United States also imposes tariffs on all imports which averaged 1.3 percent in 2010.[36] Combined together, these fees and tariffs increase the price of all maritime imports by approximately 1.54 percent, significantly more than 0.09-0.26 percent in prices caused by the policy.

Translating the percent changes in import prices into price increases for goods consumed by households, presented in Table 3, further indicates the

TABLE 3: Impacts of a Global Emissions Regime on the Prices of Common Imported Goods

		Retail Prices		
Item	Units	Reference	Percent Change	Change
Gasoline	$ / gallon	$2.84	0.06% - 0.13%	$0.0012 - $0.0023
Automobiles	$ / unit	$25,000	0.07% - 0.14%	< $34.00
Computers	$ / unit	$1,000	0.07% - 0.13%	< $1.30
Bags of Flour	$ / unit	$4	0.20% - 0.40%	< $0.02

Note: We calculate price changes for automobiles, computers, and flour as maximum values due to data limitations.[37] Price changes do not take into account the general equilibrium effects of the emissions regime on the costs of other goods and services in the economy.

size of the impact of the policy on U.S. households. The import price changes would likely result in small increases in the prices paid by households for imported goods, including fractions of a cent more for gasoline and up to $1.30 more for an average computer. This further indicates that U.S. consumers will not face significant economic impacts from the policy.

Import and Export Demand

The increase in import and export prices from a global maritime emissions regime, as described above, would likely cause some decrease in the demand for imports and exports. We estimate that the small increase in prices, however, would likely drive small decreases in demand, as shown in Table 4.

TABLE 4: The Impact of a Global Emissions Regime on the Demand for Imports and Exports

	Change in Demand	
	Imports	Exports
Total	-0.61% - -1.23%	-0.88% - -1.76%
Agriculture	-0.93% - -1.86%	NA
Raw material	-1.15% - -2.30%	NA
Crude oil	-0.35% - -0.71%	NA
Manufacturing	-0.64% - 1.28%	NA

Note: We do not estimate changes in export demand for specific product groups as we do not have enough data on the elasticity of demand for exports. See Appendix A for more details.

These decreases in imports and exports pale in comparison to the increases in imports (approximately 95 percent) and exports (approximately 110 percent) over the last decade.[38] The relative size of the reductions in demand can also be shown by translating these percent reductions into reductions in import and export traffic at major U.S. ports, as shown in Table 5.[39]

The small reductions in the volume of maritime imports and exports means that few exporters, shippers, ports, longshoremen and other industries and workers who depend on imports and exports would suffer significant loses. Moreover, a significant portion of the imports lost would likely be replaced by domestic production, creating additional demand for U.S. products and jobs in the United States.

TABLE 5: The Impact of a Global Emissions Regime on Traffic at Major U.S. Ports

		Volume of Maritime Trade (million of kilograms)	
Trade	Ports	Reference	Change
Imports	Houston-Galveston, TX	161,253	-990 - -1,979
	New Orleans, LA	136,272	-835 - -1,670
	Los Angeles, CA	76,977	-472 - -943
	New York City, NY	61,594	-377 - -755
	Philadelphia, PA	50,225	-308 - -616
Exports	New Orleans, LA	121,168	-1,068 - -2,135
	Houston-Galveston, TX	100,641	-887 - -1,774
	Los Angeles, CA	48,890	-431 - -862
	Norfolk, VA	47,940	-422 - -845
	Columbia-Snake, OR	34,106	-301 - -601

Source: U.S. Census Bureau.[40]
Note: The changes in the volume of maritime trade reflect national average reductions in demand being applied to each port and do not reflect the specific products traveling through each port.

CONCLUSION

The proposed global system to reduce maritime GHG emissions under the IMO is an important policy that is quickly approaching a critical moment. The U.S. government in particular must weigh its decision carefully. As previous debates on international emissions policies indicate, most recently the continuing conflict over European aviation regulations, the response of the United States will significantly impact the success or failure of the policy.

This study finds that such an IMO program could generate significant benefits for the United States and other countries. Specifically, we estimate that carbon dioxide emissions from global maritime sector likely currently cause between $18-$72 billion in social costs each year globally by contributing to the harmful effects of climate change. A global maritime GHG emissions system could potentially help avoid a large portion of this harm by reducing CO_2 emissions. The policy could also generate significant additional benefits through raising revenues to respond to climate change in developing countries and reducing non-GHG emissions.

On the cost side, we find that the policy would generate limited additional expenditures for the shipping industry especially in comparison to other costs faced by the sector, and thus will have limited impacts on the U.S. economy. Specifically, the policy would likely create for shippers a fraction of the costs caused by the increase in maritime fuel prices over the last decade, suggesting that such a policy would not significantly adversely impact shippers or U.S. consumers and businesses.

The policy would also cause relatively small impacts on the U.S. economy, including small increases in the price of imports (0.1-0.3 percent) and exports (0.1-0.3 percent). For comparison, the United States currently applies taxes and tariffs of 1.53 percent to each dollar of imports, significantly more than the price changes caused by the potential global maritime emissions policy. Similarly for U.S. consumers, the import price changes of the policy translate into small increases in the prices paid for imported goods, including fractions of a cent more per gallon for gasoline and $1.30 more for an average computer.

The policy would likely cause equally small impacts on import and export-dependent U.S. industries and unions. The policy would drive very small reductions in demand for U.S. imports (0.6-1.2 percent) and exports (0.9-1.8 percent) and thus the volume of trade flowing through U.S. ports. The actual impacts could be significantly smaller, as many studies estimate the elasticity of demand for U.S. imports and exports to be significantly smaller. Furthermore, a significant portion of the lost imports would likely be replaced by additional domestic demand, offsetting the losses for industries.

Future studies should seek to further inform this decision by directly estimating the social benefits and costs of the proposed IMO policies. To do so, they would need to consider how much ships would reduce their emissions of GHG and non-GHG pollutants in response to the regulations and determine the social benefits associated with these emissions reductions. These estimates should include all of the benefits of pathways identified earlier in this report. The studies could then compare these benefits to the economic costs associated with policy. Future studies should also compare the different proposals to determine which proposals generate the greatest benefits at the lowest costs.

APPENDIX A: MODELING METHODOLOGY

For the analyses described in the paper, we employ a simple model of the impact of an upstream global carbon tax on U.S. imports and exports. The model translates assumed carbon taxes into price changes for bunker fuels. It then uses disaggregated data on shipping costs for imports and exports of different goods to calculate the increase in goods prices that would result from the change in bunker fuel prices. Finally, the model applies price elasticities of demand from the economics literature to translate the changes in goods prices into reductions in demand for imports and exports.

The model is a partial equilibrium model and thus does not incorporate general equilibrium effects. The most important excluded general equilibrium effects impacts of changes in import and export prices on disposable income, substitution between imports, changes in shipping behavior and changes in the labor market. The model also does not address the potential effects of the expenditure of the revenues collected under the carbon tax.

The first calculation, translating carbon taxes into price changes for bunker fuels, uses the following equation.

$\Delta p_{bf} = t_c{}^*c_{bf}{}^*r_{bf}$

p_{bf} = price of bunker fuels

t_c = carbon tax

c_{bf} = carbon content of bunker fuel

r_{bf} = pass-through rate of carbon taxes into bunker fuel prices

We model two possible carbon taxes, $15 and $30, to reflect the uncertainty in the structure and stringency of the policy and in the price of emissions credits in other markets (which the maritime mechanism might be linked to) and offset credits (which might be available as an alternative compliance mechanism within the maritime policy). We assume the carbon content of bunker fuel to be 0.0118 mt CO_2e / gallon of bunker fuel following EPA[41] and translate the change in price into a percent change in price using a baseline bunker fuel price of $2.40 / gallon taken from the Energy Information Administration.[42]

The model assumes a 100 percent pass-through rate of carbon taxes into bunker fuels (how much of the carbon tax that refiners can pass through). We base this estimate on a study of carbon price pass-through by European refiners under the EU ETS.[43]

The second calculation, estimating the increases in goods prices, follows the following formula.

$\Delta p_{g,i,j} = (\Delta p_{bf} / p_{bf})^* e_{fl\text{-}fr,j}{}^* s_{t,i,j}{}^* r_{fr}$

$e_{fl\text{-}fr,j}$ = elasticity of the price of fuel to the price of bunker fuel for transportation mode j

$s_{t,i,j}$ = transportation share of value-added of imported or exported goods for good i and transportation mode j

r_{fr} = pass-through rate of changes in transportation costs into changes in costs of imports or exports

The model takes the percent changes in bunker fuel prices from the previous calculation and uses different elasticities of the price of transportation from price of fuel depending on the transportation mode.[44] The model assumes a 100 precent pass-through rate of changes in transportation costs to changes in the cost of imports and exports following other similar analyses.[45]

We take the transportation share of value-added of U.S. imports and exports from the Organization for Economic Co-operation and Development (OECD) database of Maritime Transportation Costs. The shares vary by trading partners, goods, and transportation modes.[46] We estimate the shares for imports based on data from the nine largest trading partners to the United States available in the dataset, namely Canada, Japan, Mexico, the European Union, Brazil, China, India, Singapore and

Venezuela. These countries represent 73 percent of U.S. imports by value and thus we take them to be representative of transportation costs in general.[47] We estimate the shares for exports based on data from the same countries, except without Canada and with South Korea and Saudi Arabia because of data availability. These countries represent 54 percent of U.S. exports by value. [48]

The third calculation, calculating changes in import demand resulting from the changes in prices, uses the following equation.

$$\Delta p_{g,i,j} / q_{g,i,j} = (\Delta p_{g,i,j} / p_{g,i,j})^{*} e_{q\text{-}p,j}$$

$q_{g,i,j}$ = imports or exports of good i by transportation mode j

$e_{q\text{-}p,j}$ = price elasticity of imports or exports for the good i

We derive the price elasticities of imports from the literature, using the price elasticities shown in Table A1.

Due to data limitations, as shown in the table, we could not match an elasticity to each goods category. Instead, we match a unique elasticity to each of the top ten goods in terms of value of imports, which represent over 72 percent of the value of all imported goods to the U.S., and assign the an import-weighted average elasticity to all other goods. Our assigned elasticities are at the higher end of those found by other studies with some studies finding price elasticities that are smaller by an order of magnitude. This suggests that if anything our study overestimates the negative impact of the potential policy on the U.S. demand for imports.[49]

We use the same price elasticities for exports that we use for imports as we could not find similarly detailed data for price elasticities of U.S. exports. This if anything means that our study overestimates the impact of the policy on the demand for U.S. exports as most studies find that the elasticities of U.S. imports exceed the elasticities for U.S. exports.[50]

TABLE A1: Assumed Price Elasticities of Demand

Goods Category	Share of Value of Imports	Elasticity
Crude oil and other fuels	18.10%	-5.61
Automobiles and other non-rail vehicles	15.43%	-7.11
Heavy Industrial Machinery	13.95%	-7.87
Electronics	8.44%	-6.98
Toys, game and sporting equipment	3.92%	-4.88
Furniture, lighting, and other household items	3.80%	-4.64
Iron and steel products	2.75%	-4.85
Footwear	2.28%	-7.22
Plastics and plastic products	2.19%	-5.58
Apparel	1.91%	-5.61
All other imports	27.24%	-6.45

Source: Hummels 1999. [51]

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at the time of import and then applying the mark-up from imported crude to retail motor gasoline. The price change is applied to crude oil and not imported gasoline as the vast majority (> 99%) of gasoline is produced domestically. This does not attempt to account for the significant imports of motor gasoline blend components (which are drive approximately 6% of total U.S. gasoline supply). We do not expect this to have a significant impact on the results. Energy Information Administration, "Petroleum & Other Liquids: Supply and Disposition", n.d., http://205.254.135.7/dnav/pet/pet_sum_snd_d_nus_mbbl_m_cur.htm; Energy Information Administration, "Petroleum & Other Liquids: Spot Prices", May 8, 2012, http://205.254.135.7/dnav/pet/pet_pri_spt_s1_a.htm.

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