

# **CO<sub>2</sub> Marginal Abatement Cost and Its Impacts on Emissions per Import Value from Containerships in the United States**

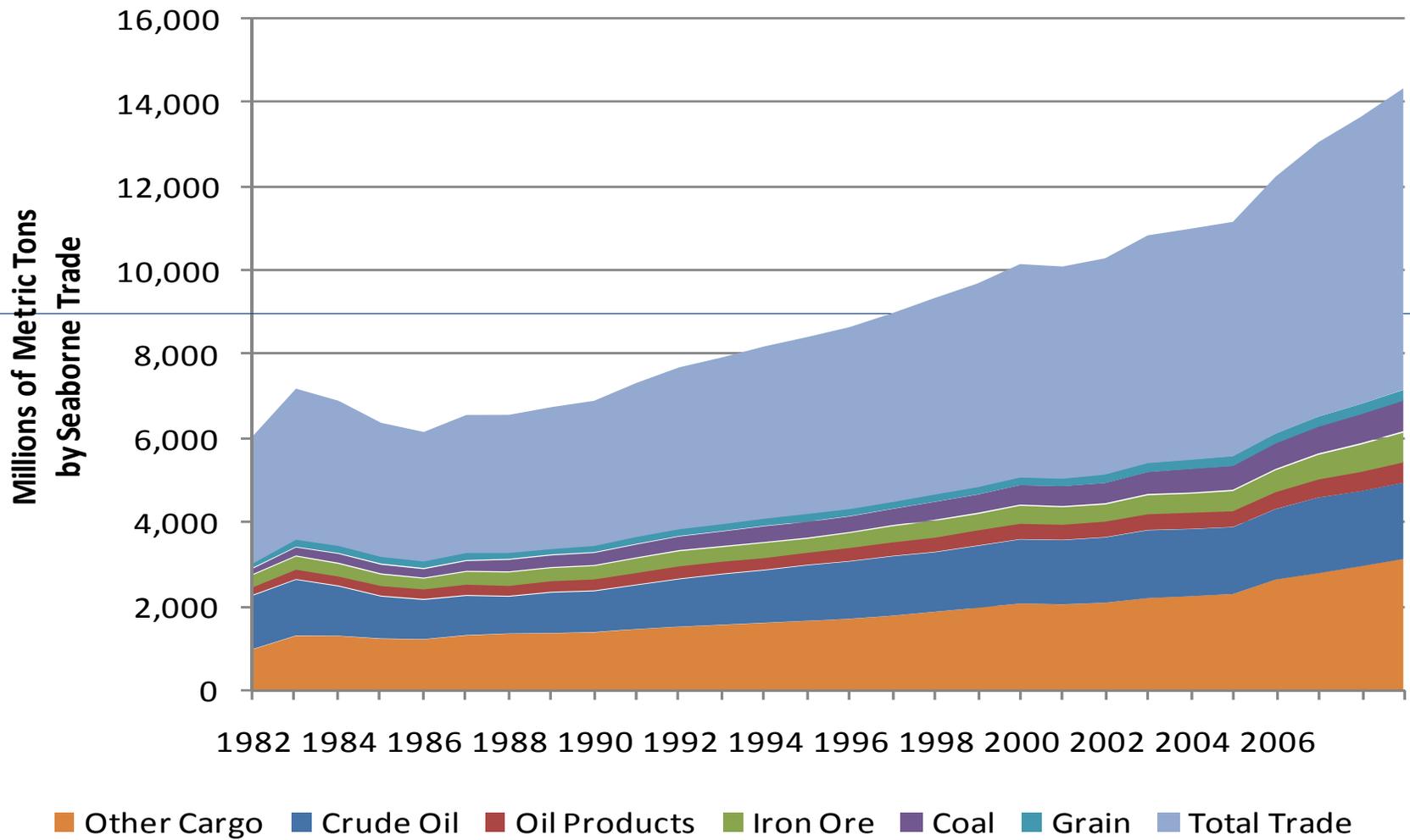
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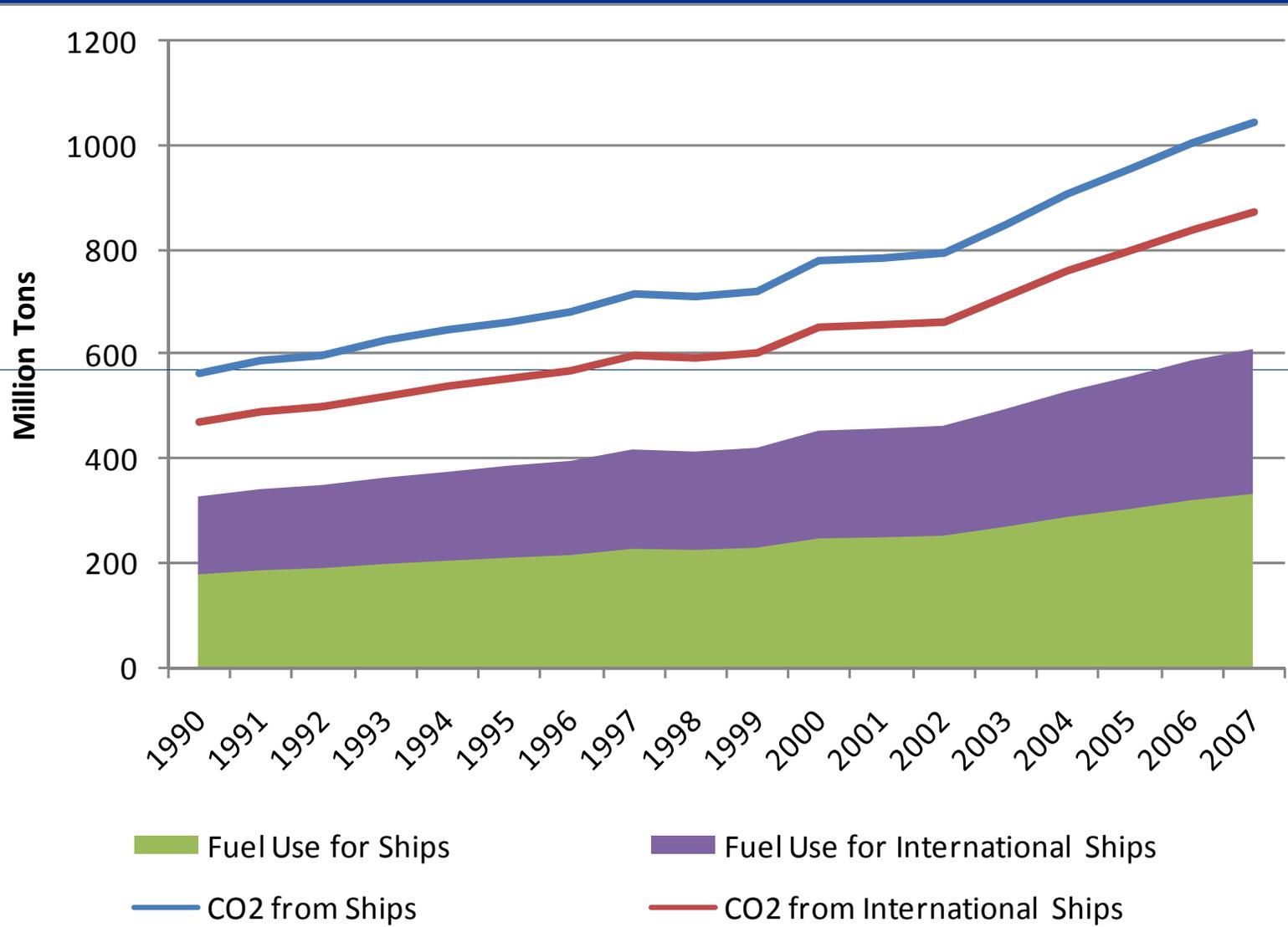
## Outline of Analysis

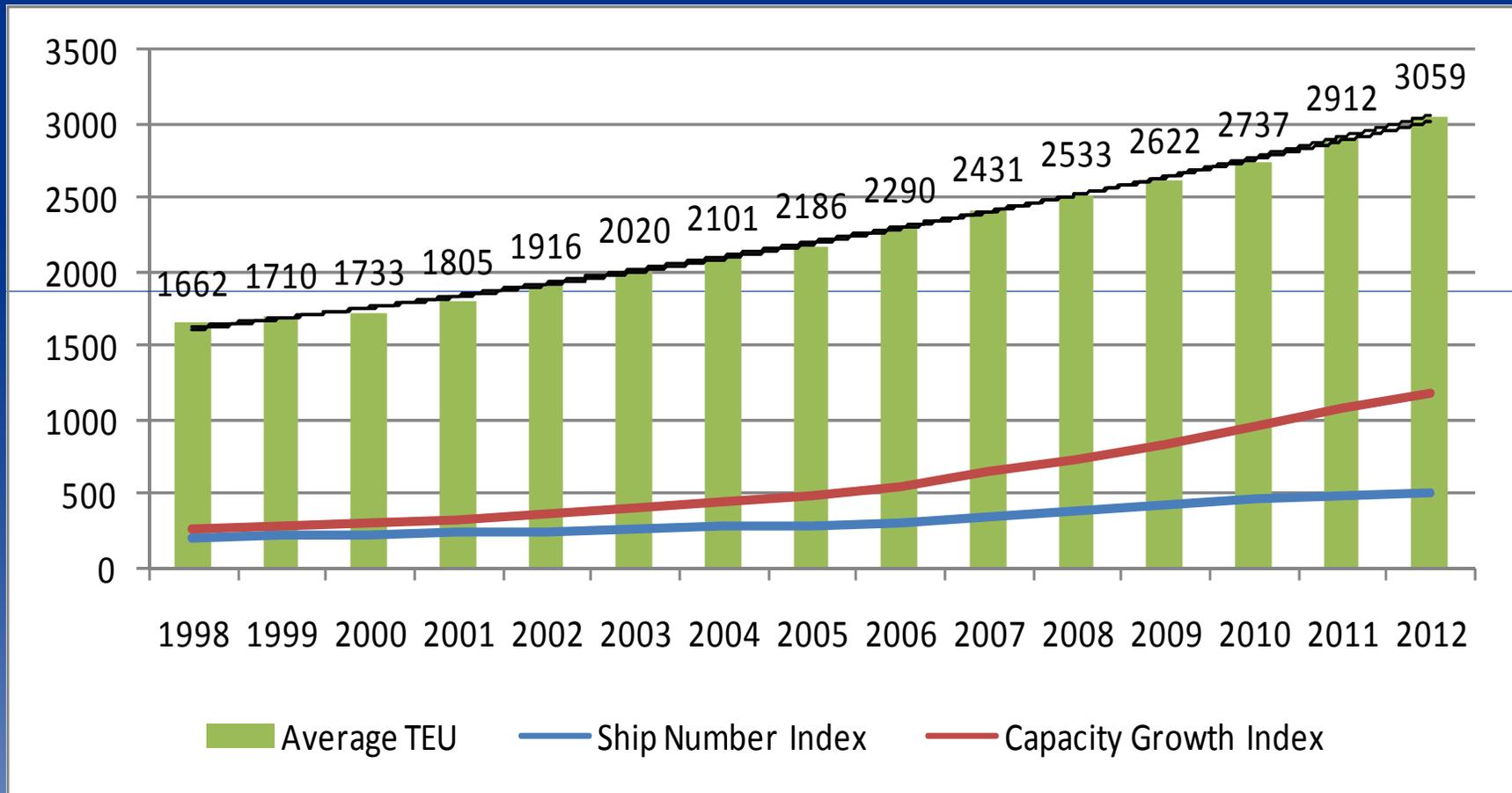
- Impacts of emission levy on countries and commodity types
  - Prepare basic inventories and trade weight
  - Combine CO<sub>2</sub> inventory and trade
  - Analyze the price increase due to levy by countries and by commodity groups
- Impacts of speed reduction on CO<sub>2</sub> reduction
  - CO<sub>2</sub> reduction rate from cutting fleets' speeds
  - Marginal abatement cost (MAC) of reducing CO<sub>2</sub> emissions
  - Compare MAC with cap-and-trade prices in other markets

## Background

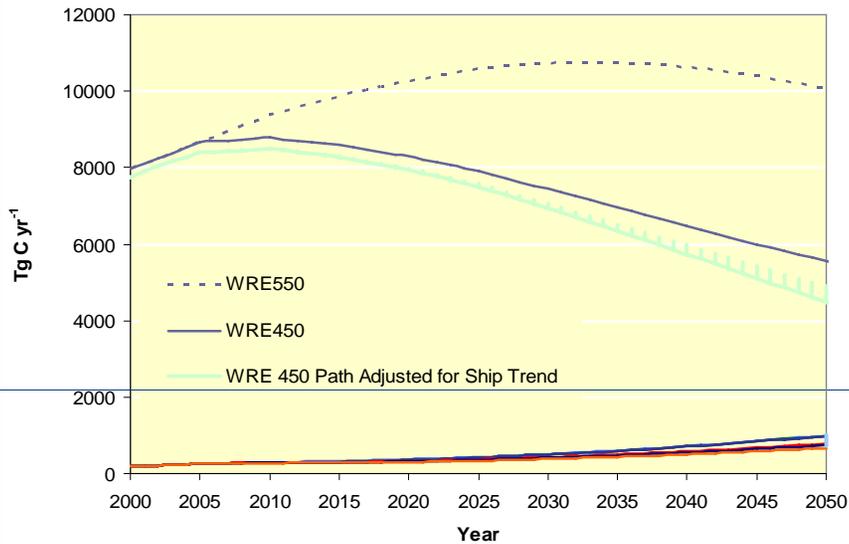
- International trade is increasing in the recent decade before the recession
  - Average above 3%
- More than 80% trade in volume was carried by ships
- Ship is one of the major sources of several pollutants
  - 1.2-1.6 million metric tons of particulate matter
  - 4.7-6.5 metric tons of sulfur oxides
  - 5.0-6.9 metric tons of nitrogen oxides
- Increasing attention is paid to GHG, especially CO<sub>2</sub>
  - 1019 million tons of CO<sub>2</sub>
  - 3.3% of world CO<sub>2</sub> emissions
  - 90% is from international shipping



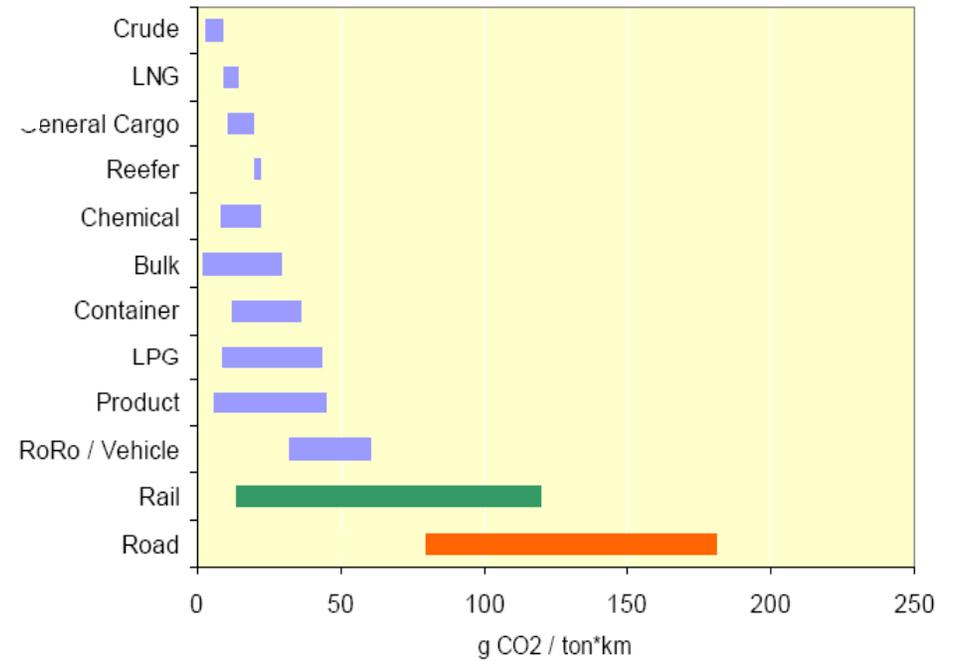




Potential impact of shipping on WRE 450 / 550 emissions stabilization



Range of typical CO2 efficiencies for various cargo carriers



Buhaug, Ø.; Corbett, J. J.; Endresen, Ø.; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D. S.; Lee, D.; Lindstad, H.; Mjelde, A.; Pålsson, C.; Wanqing, W.; Winebrake, J. J.; Yoshida, K. *Updated Study on Greenhouse Gas Emissions from Ships: Phase I Report; International Maritime Organization (IMO) London, UK, 1 September, 2008*

## Regulator Responses to CO<sub>2</sub>

- IMO Policy Instrument to reduce CO<sub>2</sub>
  - Market-based instrument
  - Ship operational index
  - Ship design index
    - Main Engine retrofit
    - Retrofit hull improvement
- Europe Union
  - With Japan, they are pushing to give IMO authority to audit the flag states
  - They plan to regulator GHG within EU if IMO does not take enough action

## Efficiency of scale

< 4%



A larger ship will in most cases offer greater transport efficiency – “Efficiency of Scale” effect. A larger ship can transport more cargo at the same speed with less power per cargo unit. Limitations may be met in port handling.

Regression analysis of recently built ships show that a 10% larger ship will give about 4-5% higher transport efficiency.



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From Wartsila

## Wind power – sails and kites

< 20%



Wing shaped sails installed on the deck or a kite attached to the bow of the ship uses the wind energy for added forward thrust. Both static wings with composite material and fabric material are possible.

Fuel consumption savings:

Tanker	~ 21%
PCTC	~20%
Ferry	~8,5%



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## Questions

- What is the effect of CO<sub>2</sub> reduction cost on trade
  - Its impacts on countries and commodities
- What is the effect of speed reduction
  - No technology bottleneck
  - Easy to enforce and monitor
- What is the economy behind
  - Higher cost on trade
  - Marginal abatement cost of slowing vessels

## Data Source

- US Army Corps of Engineers
  - Clearance and Entrance (2002) dataset
  - More than 7,000 routes identified and analyzed
  - More than 10,000 international ship calls to the United States
- Ship Traffic Energy and Environmental Model (STEEM)
  - Port to Port distances
- Department of Commerce
  - U.S. Import and Export Dataset
  - Trade data by commodity groups and by countries

## Inventory Estimate

- Bottom-up approach
  - Estimate CO<sub>2</sub> emissions from each ship that called the U.S. ports in 2002
  - Add up emissions from each ship
- Parameter assumption
  - SFOC: 206 g/kwh
  - Average main engine load factor: 0.8
  - Average auxiliary engine load factor: 0.5

# Inventory Estimation

Fuel usage estimate

$$Fuel_{i,j,k} = \sum_{i,j} (MEfuel_k \times \left(\frac{s_1}{s_0}\right)^3 + AEfuel_k) \times \frac{d_{i,j}}{24 \times s_1}$$

CO<sub>2</sub> Emission

$$CO_2 = 3.17 \times \sum_{i,j,k} \left\{ \left[ MF_k \times \left(\frac{s_{1k}}{s_{0k}}\right)^3 + AF_k \right] \times \frac{d_{ij}}{24 \times s_{1k}} \right\}$$

Total CO<sub>2</sub> emissions: ~22 million tons

## Basic Facts

- Total CO<sub>2</sub> emissions from International Shipping that call the United States: ~22 million tons
- 13.6 billion kg commodities were imported to the United States
- 2 ton CO<sub>2</sub> emission for every one ton of commodity
- Unit emission: Emission/weight of imported commodity

## Top Emitters of CO<sub>2</sub> in Trade with the United States

Country	Emission (ton)	Annex I
Japan	19,365,000	Yes
South Korea	7,366,000	No
China Taiwan	5,267,000	No
China Mainland	5,229,000	No
Mexico	4,841,000	No
Canada	4,451,000	Yes
Venezuela	3,027,000	No
Spain	3,001,000	Yes
United Kingdom	2,777,000	Yes

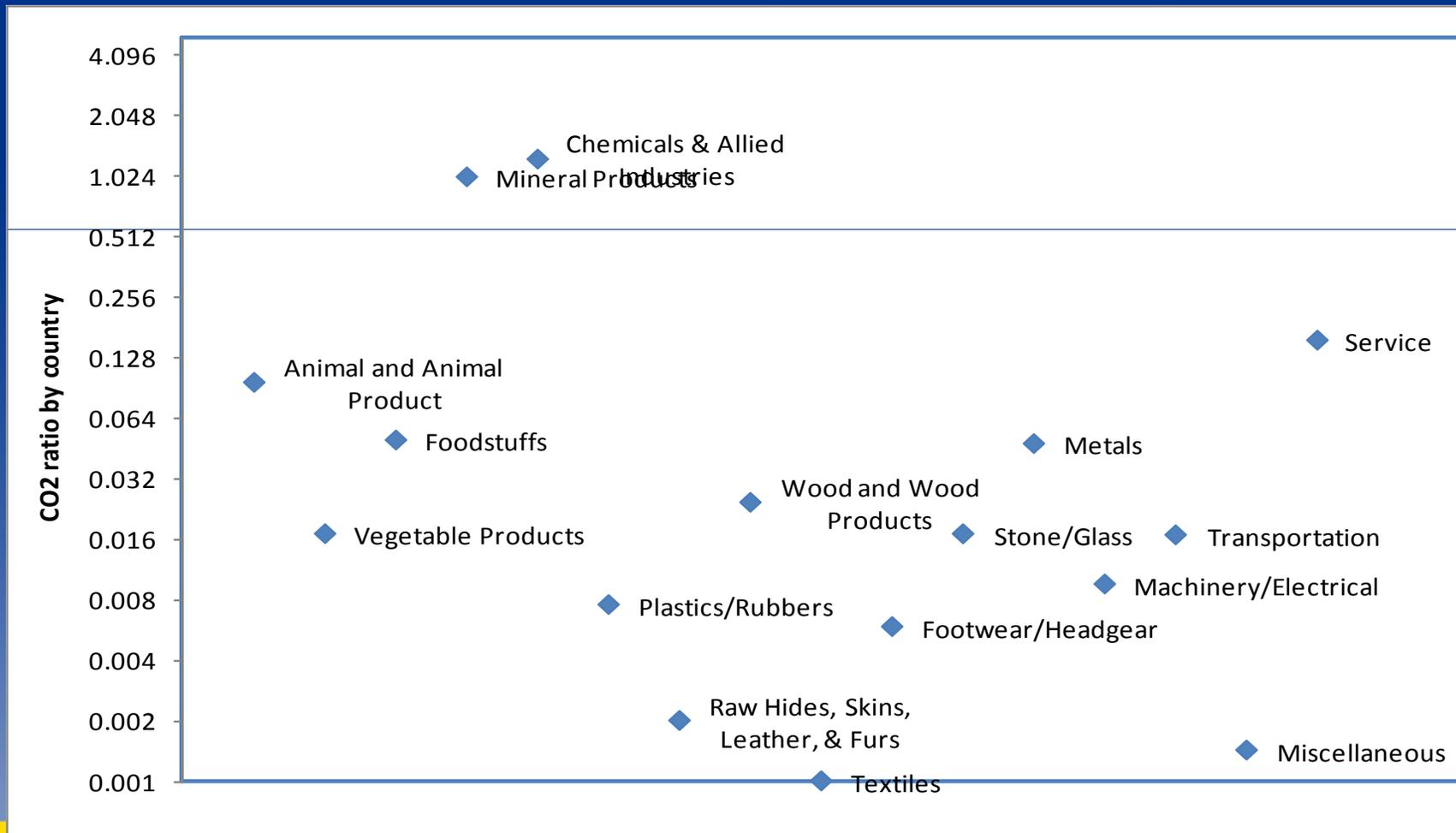
## Top Unit Emitters of CO<sub>2</sub> in Trade with the United States

Country	CO <sub>2</sub>	Annex I
American Samoa	1.05	No
Pacific Islands N.E.C.	0.75	No
St. Helena	0.58	No
Western Sahara	0.31	No
Eritrea	0.26	No
South Pacific Islands	0.18	No
Gambia	0.16	No
Kiribati	0.12	No
Cuba	0.08	No
Guam	0.04	No

## Emission/Import Ratio by Commodity

- Trade data classified by 2 digit Harmonized System (HS2)
- One underpinning assumption: CO<sub>2</sub> emissions from containerships are proportional to trade weight.
  - In practice commodities are packed in containers in one ship and transported
  - Calculate CO<sub>2</sub> emission and total weight
  - Assign CO<sub>2</sub> emissions to different commodity types according to their weight ratio

# Unit Emission by Commodity



# Price Increase due to CO<sub>2</sub> levy

Assume a \$ 50 per ton CO<sub>2</sub> levy is imposed to commodities that are transported by international shipping

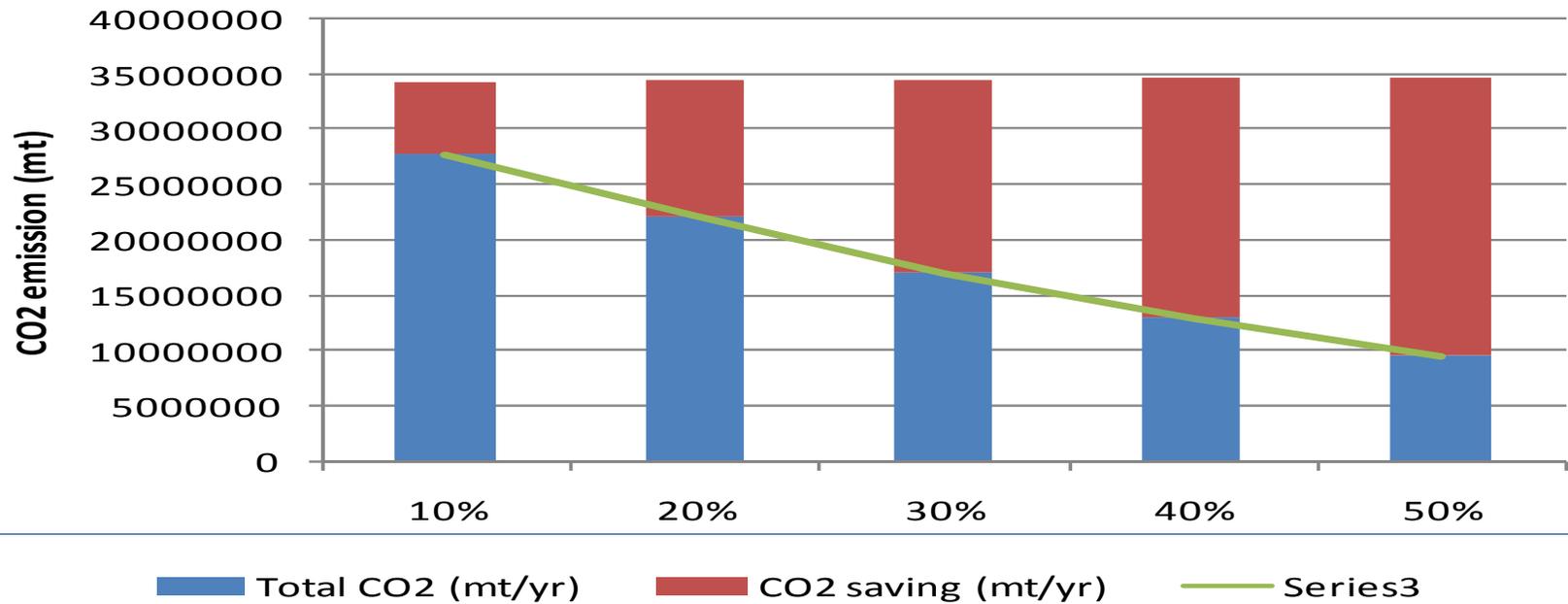
HS19: Food		HS72: Steal		HS61: Textile	
Guam	370%	Guadeloupe	2770%	Guam	70%
Pacific Islands N.E.C.	370%	Belize	790%	Dominican Republic	40%
Kiribati	360%	Bahamas	540%	Sao Tome and Principe	3%
Fiji	15%	New Zealand	530%	Kiribati	2%
Georgia	4%	Panama	530%	Ivory Coast	1%
Panama	4%	Portugal	490%	Fiji	0.5%
French Guiana	3%	Ukraine	430%	New Zealand	0.4%
Albania	3%	France	410%	Greenland	0.3%
Cayman Isl	2%	Denmark	370%	Namibia	0.3%
Ivory Coast	2%	Korea	350%	Haiti	0.3%
Average	5%		3%		0.5%

# Speed Reduction and CO<sub>2</sub> Mitigation

Re-visit equation 2, the CO<sub>2</sub> is directly related to the relationship between operational speed and designed speed

$$CO_2 = 3.17 \times \sum_{i,j,k} \left\{ \left[ MF_k \times \left( \frac{s_{1k}}{s_{0k}} \right)^3 + AF_k \right] \times \frac{d_{ij}}{24 \times s_{1k}} \right\}$$

Reducing speed can reduce CO<sub>2</sub> emission



Percent Reduction in Speed	CO2 saving (mt/yr)	Fuel usage (mt/yr)	CO2 saving % change
10%	6,520,000	9,210,000	19%
20%	12,290,000	7,390,000	35%
30%	17,340,000	5,800,000	50%
40%	21,640,000	4,440,000	62%
50%	25,180,000	3,330,000	72%

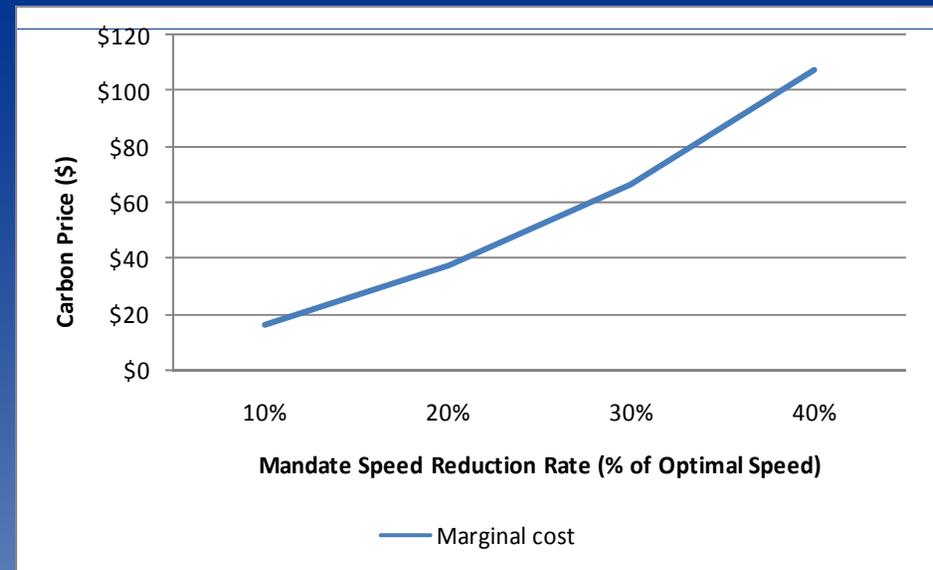
Assume no extra ship is added into the lineup to cover the already published schedule

## Marginal Abatement Cost of CO<sub>2</sub>

- Marginal abatement cost = extra reduction of CO<sub>2</sub>/extra cost of reducing CO<sub>2</sub>
- Marginal abatement cost = CO<sub>2</sub> price
- Calculation
  - Assume ships operate at their optimal speed which is defined as the speed that shipping companies produce maximum profit
  - When regulators mandate speed reduction from optimal speed, there is cost (opportunity cost)

- IMO is looking at the possibility of 10% speed reduction
  - Marginal cost is around \$20 per ton
- Haven't considered extra ships that maintain the frequency
  - Otherwise, the CO<sub>2</sub> reduction rate will be discounted
  - Marginal cost will be much higher

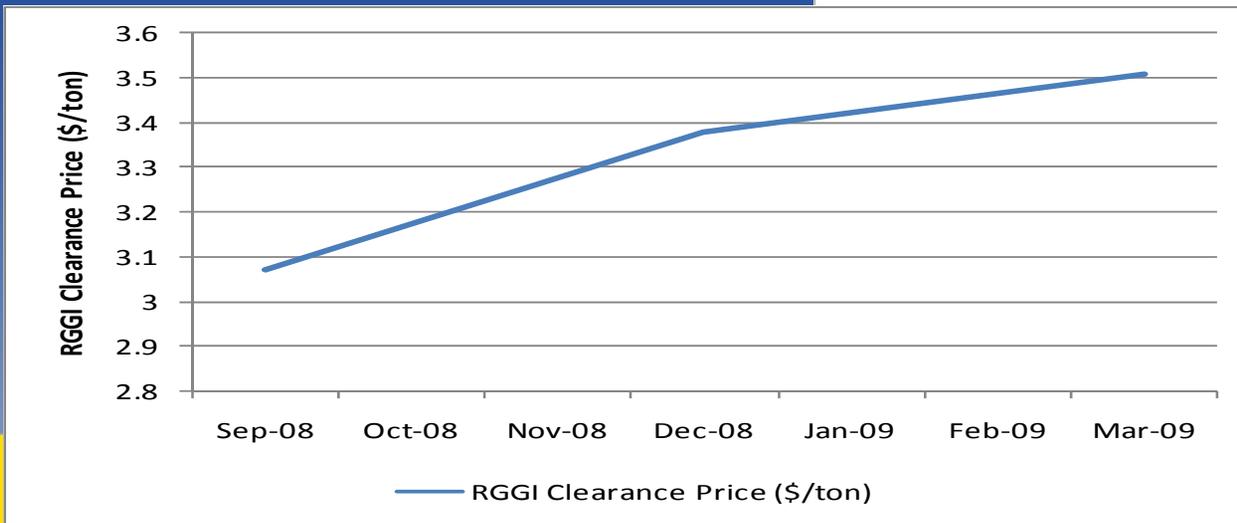
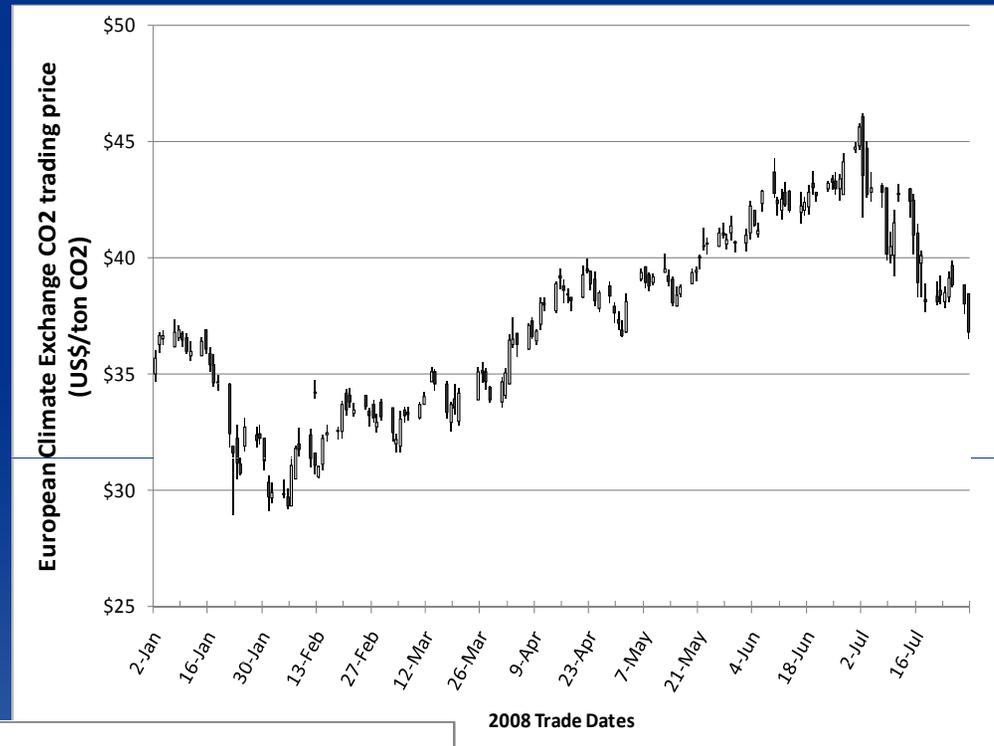
$$s_{1k} = \left( \frac{(C_k + P \cdot AF_k) \cdot s_{0k}^3}{2P \cdot MF_k} \right)^{1/3}$$



## Policy Implication

- CO<sub>2</sub> emission is directly related to trade
  - Regulations regarding the emissions from international shipping will effect international trade
  - More coordination between IMO and WTO
- Countries and commodities would be hit unequally if there were a CO<sub>2</sub> reduction cost
  - Though bigger countries are responsible for most emissions, small countries are most severely hurt
  - Heavy goods are most affected
  - True for both Cap-and-Trade and Emission Levy

- Speed reduction is one of solutions to CO<sub>2</sub> from ships
- CO<sub>2</sub> price is higher than current market prices
  - Even without consideration of extra ships



## Future Work

- The marginal cost when extra ships are taken into considerations
  - Fewer CO<sub>2</sub> reduction
  - More cost
  - Higher marginal cost
  - A separate carbon market?
- Its influence on international trade
  - Empirical works linking low transport cost with growing trade
  - What is the opposite

# Discussion Welcome

Save the Environment and Ocean Is the Responsibility of  
Our Generation

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