INTERNATIONAL MARITIME TRANSPORT UNDER CARBON PRICING,

POTENTIAL MERITS AND HAZARDS

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Introduction

One paradox in shipping?

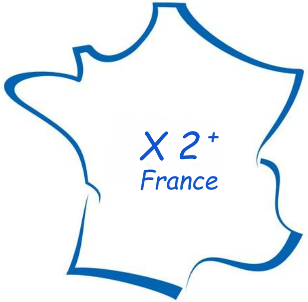
Large Energy efficiency

OOCL HONG KONG

MS ORE BRASIL

Ships capable to carry hundreds of thousand tons efficiently

Large CO_2 emissions



More than 800 mT of CO_2 per year due to international shipping

Introduction

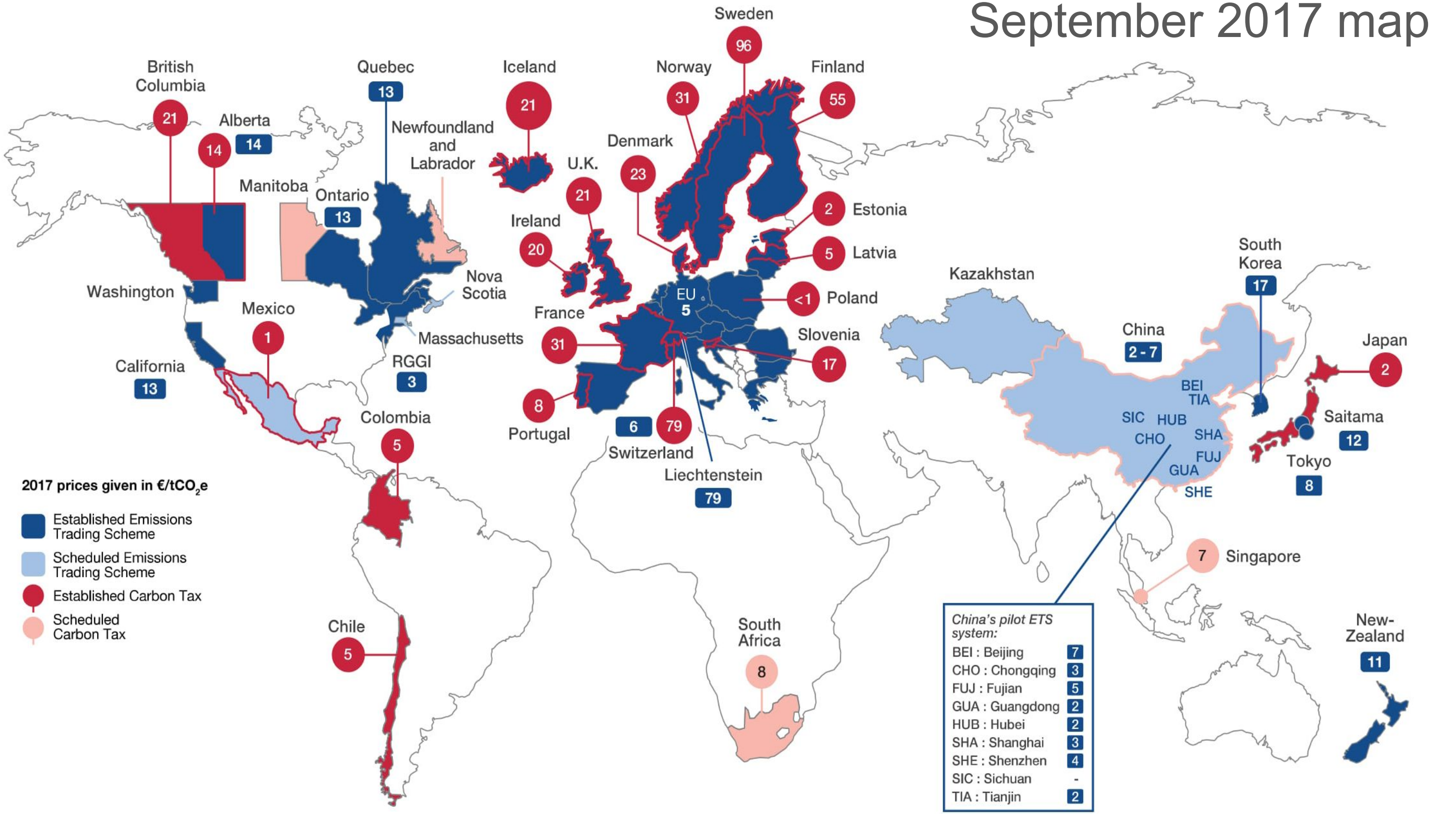
A brief Carbon Pricing history

Theory	→	SO2 charges	→	CO2 charges
		Post-communist countries *Tax since 1992*		European countries *Individual tax from 1990 and global cap-and-trade, since 2005*
Arthur Cecil Pigou *The Economics of Welfare,* 1920		Acid Rain Program, USA *Cap-and-trade since 1994*		Kyoto protocol *Offsetting since 1994*

Introduction

Carbon pricing in the aftermath of Paris agreement

September 2017 map, I4CE, €/tCO_2



Source: I4CE – Institute for Climate Economics with data from ICAP, IETA, World Bank and public information, September 2017

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Offsetting in International aviation (from 2020)

ICAO

Introduction

Question addressed in our research

- Could we compare carbon taxes and cap-and-trade principles in international shipping?

- Can effects of carbon pricing be quantitatively predicted? Under which conditions?

- How does variation in shipping market affect such policies?

Presentation of subject

Some existing analysis on carbon pricing

Topic addressed	Main Results	References
Importance of marginal cost knowledge, good communication with industries and technologies availability	A good understanding of technologies and market is needed.	Market efficiency and the U.S. market for sulfur dioxide allowances, 2016
Added cost for consumer	Large portion of pass-through cost is sent to final consumer, vary with industries	Ex-post investigation of cost pass-through in the EU ETS, 2015
Effect of carbon pricing on the number of patent submitted	Small push in number of green patents	Environmental policy and directed technological change: evidence from the European carbon market, 2016

Presentation of subject

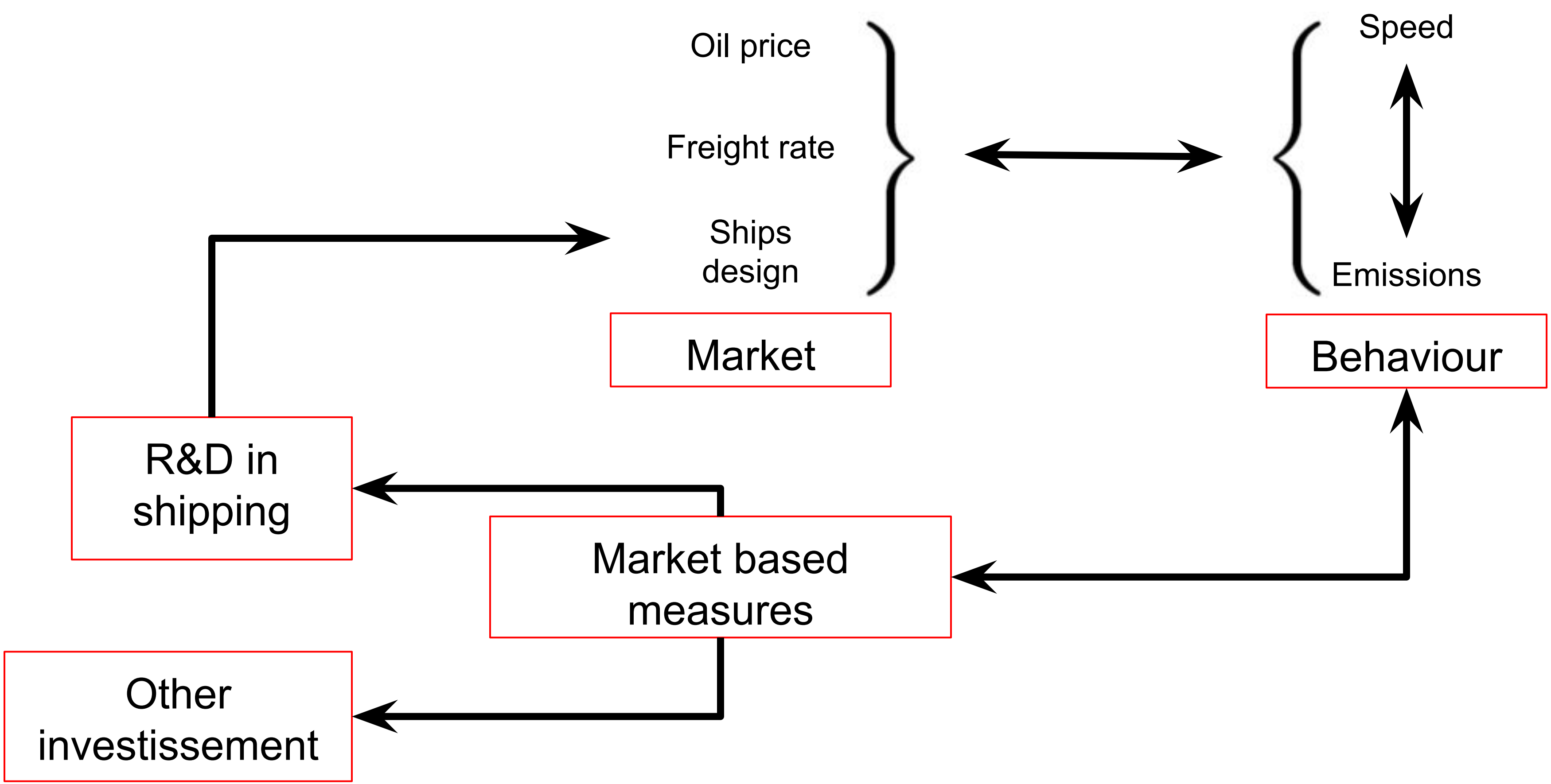
Literature review on shipping carbon emission

Topic addressed	Main Results	References
Transport cost for final consumer	Freight cost reach up to 10% of total product cost	UNCTAD and OECD yearly reports
Effect of changes in oil price and freight rates	Freight rates are correlated with oil price	Oil Prices and Maritime Freight Rates: An Empirical Investigation, 2010
New technologies adoption	Difficulties on the estimation of new technologies adoptions	Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures, 2011
Flexibility of the market	21 phases of oversupply and undersupply since 1743	Maritime Economics, 2009

Presentation of subject Literature review on shipping and carbon pricing

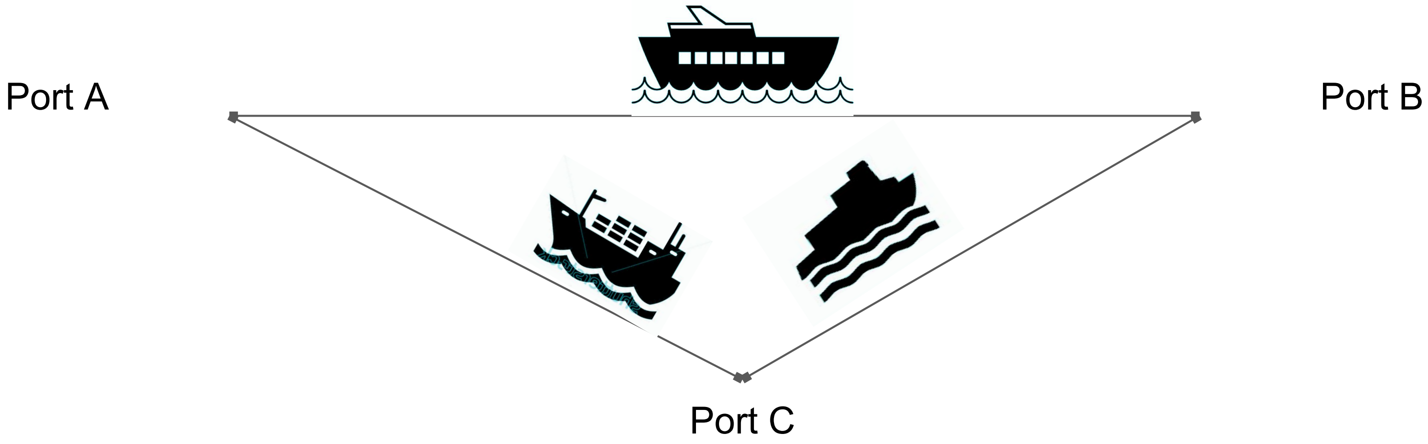
Topic addressed	Main Results	References
Effect of fuel cost and freight rate on speed	Higher fuel cost or lower freight rate will induce slow steaming	Effect of high fuel costs on liner service configuration in container shipping, 2008
Effect of carbon pricing on shipping emission	Estimations made on strong assumptions	Modeling the impacts of alternative emission trading schemes on international ship-ping, 2016
Slow steaming, effect on cost of time and emissions	Low effect on cost of time and high reduction in fuel consumption	Regulating speed: a short-term measure to reduce maritime GHG emissions, 2017

Interaction of parameters discussed



Generation of a simple model

Main parameters



Different types of ships (Containers, Bulk carriers, Tankers…) associated with different:

Design

Mass carried, in ton $Mass_{carried}$

Design speed, in knot v_0

Fuel consumption, in Ton/day $Fuel_{conso_i}(v_0)$

Markets

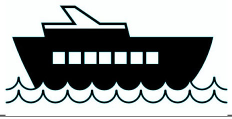
Uniform Freight Rate, in $/mass/distance FR

Port and canal fees factor $\rho Port$

Generation of a simple model

Costs and revenue over a voyage

Port A



Port B

Revenue

Transportation of goods

$$Mass_{carried}.FR.Distance$$

Costs

Fuel costs

$$Fuel_{conso}(v).Time_{travel}$$

Port, canal fees, cargo handling

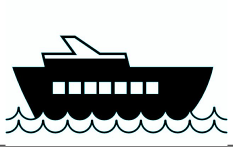
$$Mass_{carried}.FR.Distance.\rho_{Port}$$

Other operation and capital expenditure

$$OPEX_{Other} + CAPEX$$

Generation of a simple model

Evaluation of fuel consumption

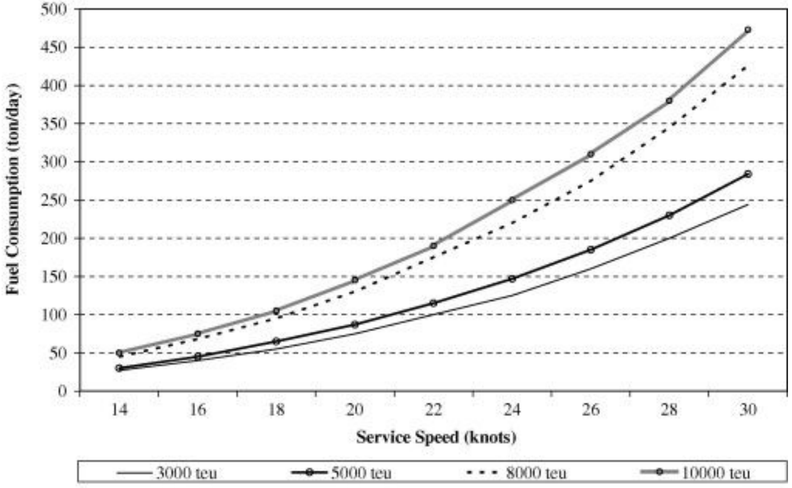


Port A

Port B

Fuel consumption/CO_2 emissions is highly related with the speed

$$Fuel_{conso}(v) = \frac{v^b}{v_0^b}.Fuel_{conso}(v_0)$$



Fuel consumption at various speed

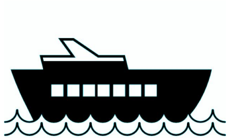
E. Notteboom and B. Vernimmen, "effect of high fuel costs on liner service configuration in container shipping"

Range of speed (knots)	5000 TEU	8000 TEU	12000 TEU
14-16	2.40	2.25	2.13
16-18	2.70	2.50	2.40
18-20	3.03	2.91	2.74
20-22	3.33	2.95	2.93
22-24	3.50	3.27	2.99
24-26	4.17	4.06	3.95

Personal calculation of b

Generation of a simple model

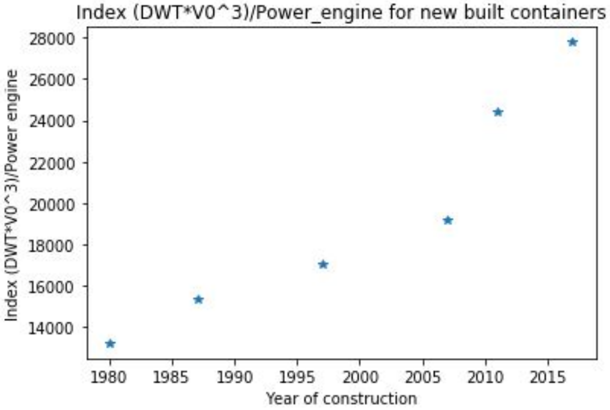
Optimisation of speed, long term period

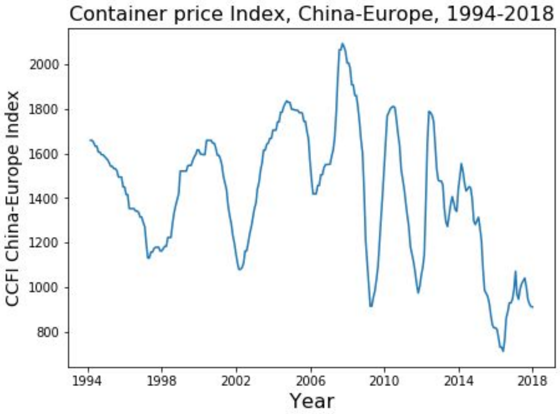


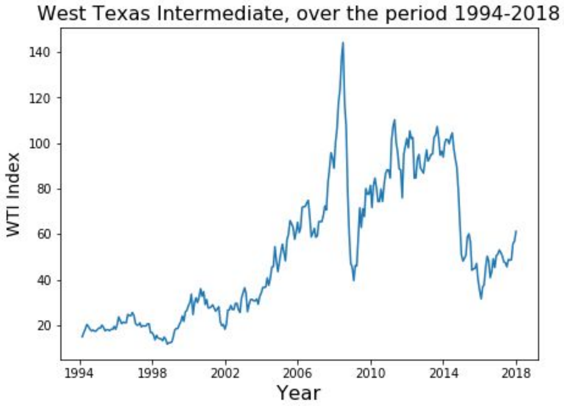
Port A   Port B

Optimisation of the route speed: $$\frac{\partial \pi}{\partial v} = 0 \longrightarrow v_i^* = \left(\frac{v_{0i}^b . Mass_{carried_i} . FR . (1-\rho_{Port})}{b.(Oil_{price} + Price_{CO2}).Fuel_{conso_i}(v_0)}\right)^{\frac{1}{b-1}}$$

Evaluation of indexes over the years, example of containers:





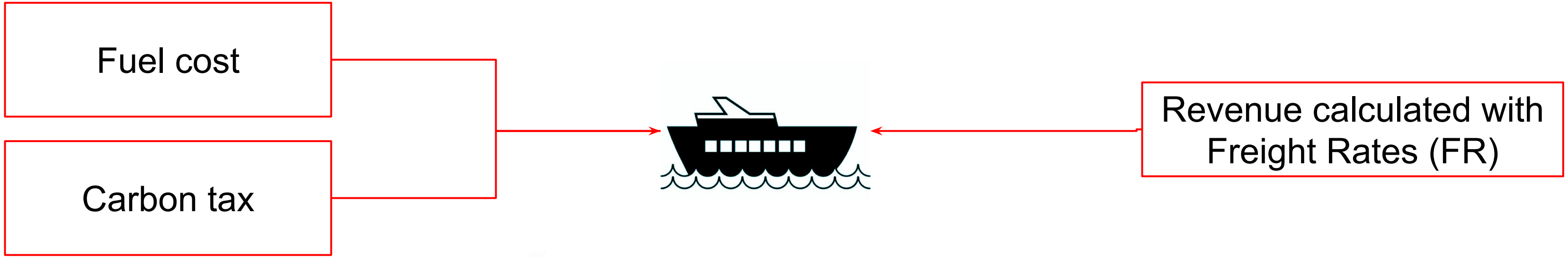


More information in annex

Generation of a simple model

Adjustment of FR, under carbon tax

Ship behaviour affected by variations of



Assumptions, for long term

- $\pi(FR_{new}, Oil_{price_{new}} + Tax_{CO2}) = \pi(FR, Oil_{price})$
- Speed equilibrium used
- No change in the ratio offer/demand for shipping, in order to dissociate effects of market volatility and carbon price.

$$\sum_{i=1}^{Nship'_{used}} Mass_{carried_i}.v_i^{*\prime} = \sum_{i=1}^{Nship_{used}} Mass_{carried_j}.v_j^{*}.\Delta_{Demand}$$

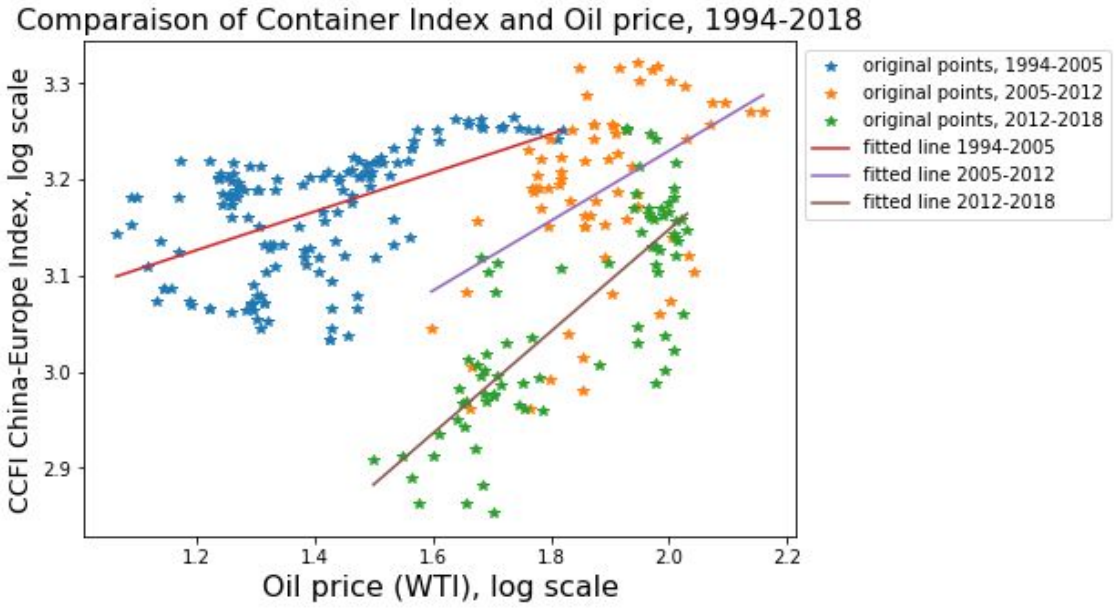
$$FR_{new} = FR.\left(1 + \frac{Tax_{CO2} + \Delta Oil_{price}}{Oil_{price}}\right)^{\frac{1}{b}}$$

Generation of a simple model

Adjustment of FR, under carbon tax

$$FR_{new} = FR.\left(1 + \frac{Tax_{CO2} + \Delta Oil_{price}}{Oil_{price}}\right)^{\frac{1}{b}}$$

Theoretical slope close to 1/b,
Should rise over the years (due to slow steaming)



Slope Containers

0.20 ⟶ 0.53

More information in annex

Generation of a simple model

Adjustment of FR, under carbon tax

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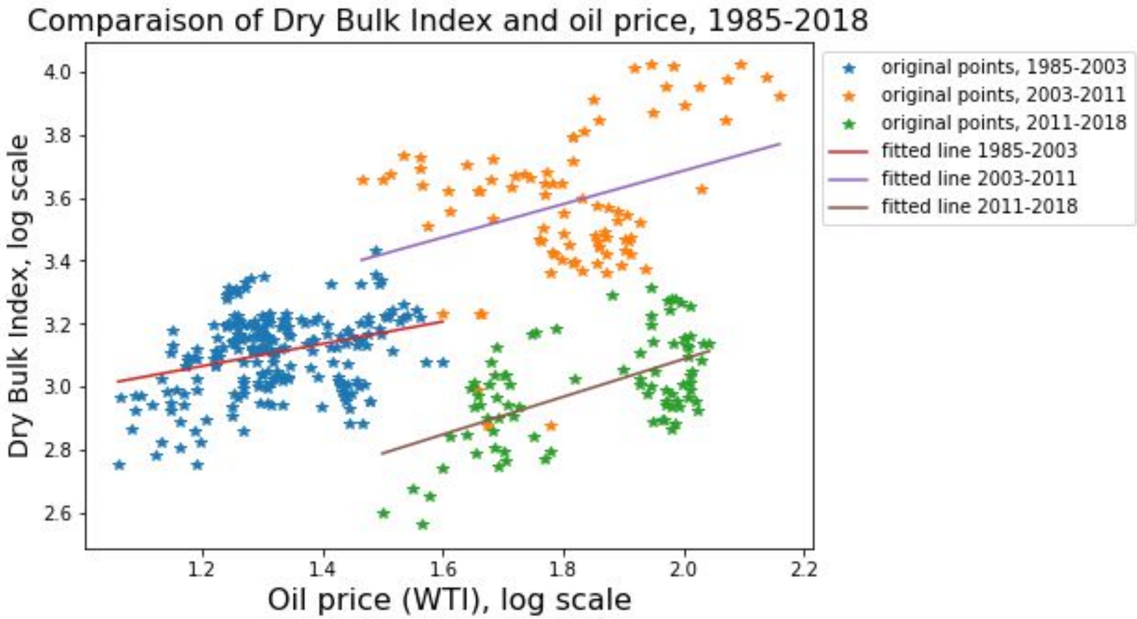

Slope Bulk carriers

0.35 → 0.60

More information in annex

Generation of a simple model

Adjustment of FR, under carbon tax

$$FR_{new} = FR.\left(1 + \frac{Tax_{CO2} + \Delta Oil_{price}}{Oil_{price}}\right)^{\frac{1}{b}}$$

Theoretical slope close to 1/b,
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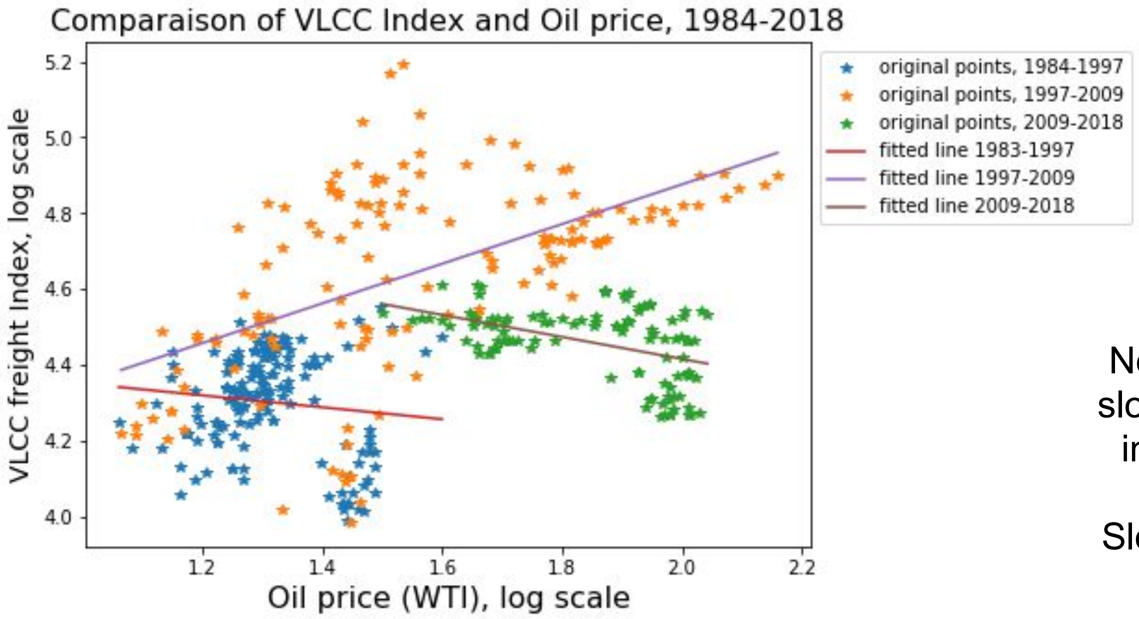


Slope Tankers

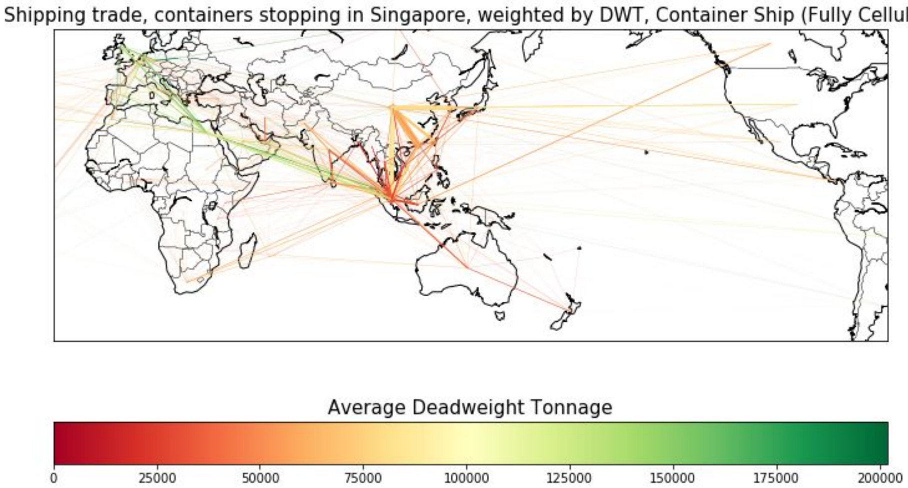
No conclusion on variations of the slope over the year due to changes in shipping demand and oil price

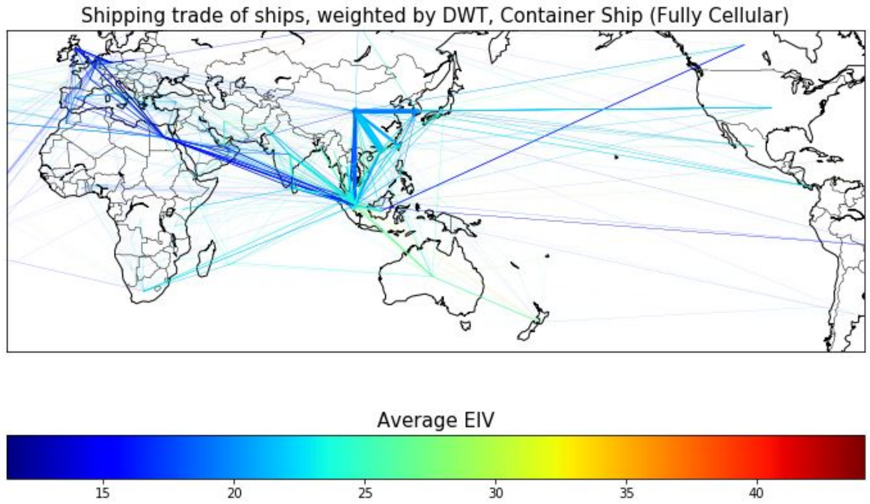
Slope equal to 0.42 over the whole period

More information in annex

Understand effects of carbon price on various consumers

In shipping, larger ships tend to be more energy efficient



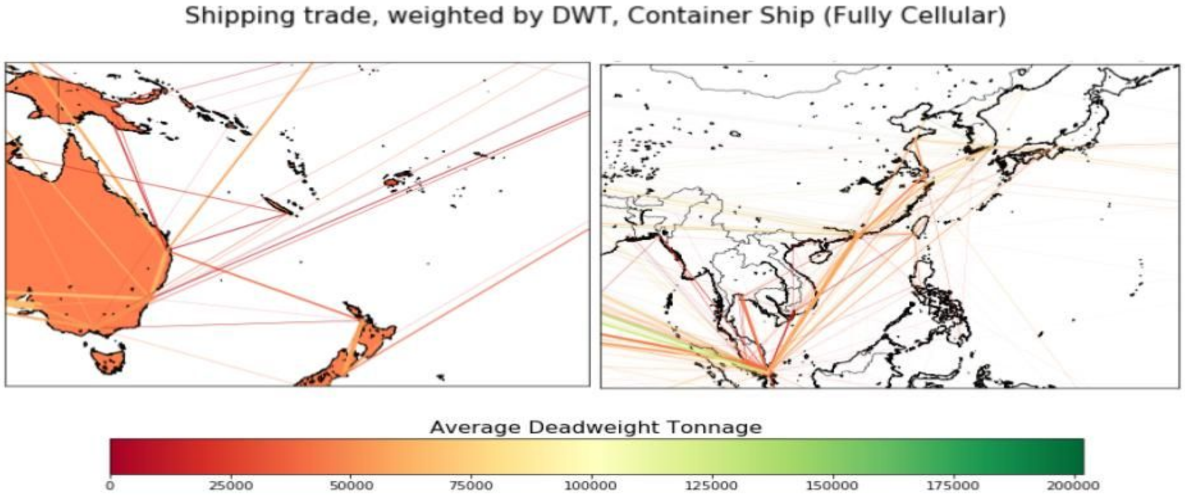


$$EIV = \frac{Carbon_{emission}}{Work_{Done}} \sim \frac{1}{Efficiency_{Design}}$$

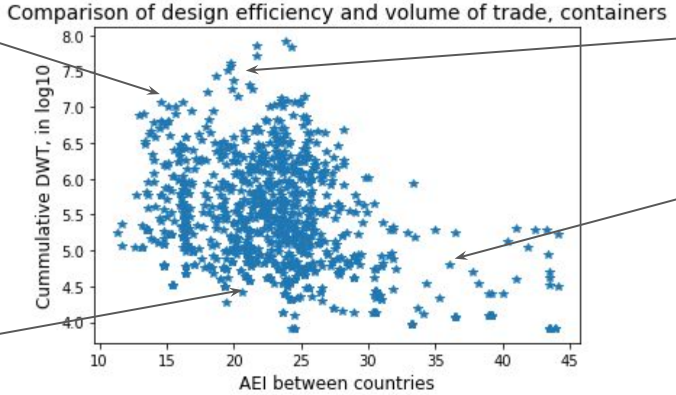
EIV is calculated according to design parameters

More information in annex

Understand effects of carbon price on various consumers



Singapore-
Egypt



China-
South Korea

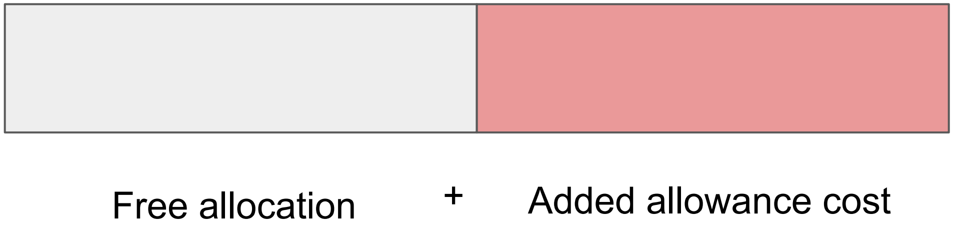
New Zealand -
New Caledonia

Singapore-
New Zealand

Potential vulnerability of
small island states

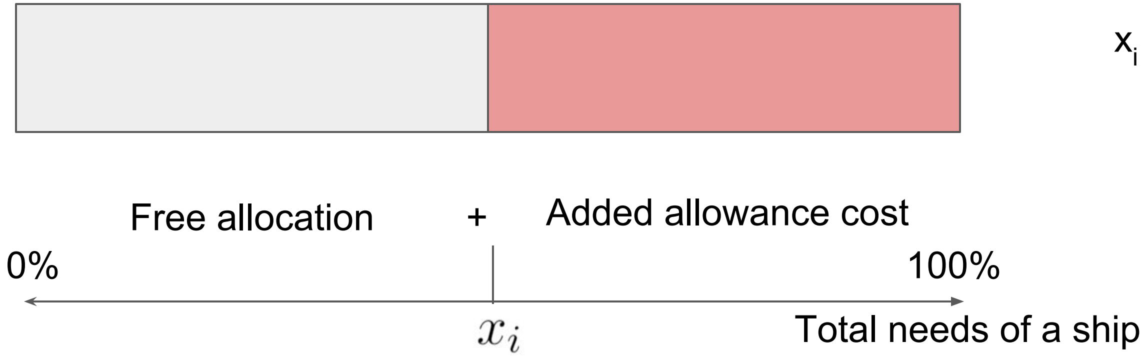
Two definitions of maritime cap-and-trade (ETS)

Variable free allocations



Optimal fuel need of the ship at year N0 equal to 100 ton of fuel per day

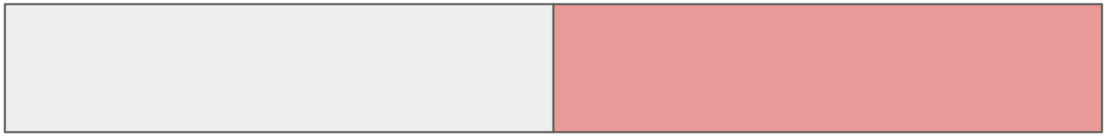
Fixed free allocations



x_i is equal for all industries in future formulas

Two definitions of maritime cap-and-trade (ETS)

Variable free allocations



Free allocation + Added allowance cost

Optimal fuel need of the ship at year N0+1 equal to 120 ton of fuel per day

Fixed free allocations

x_i is equal for all industries in future formulas

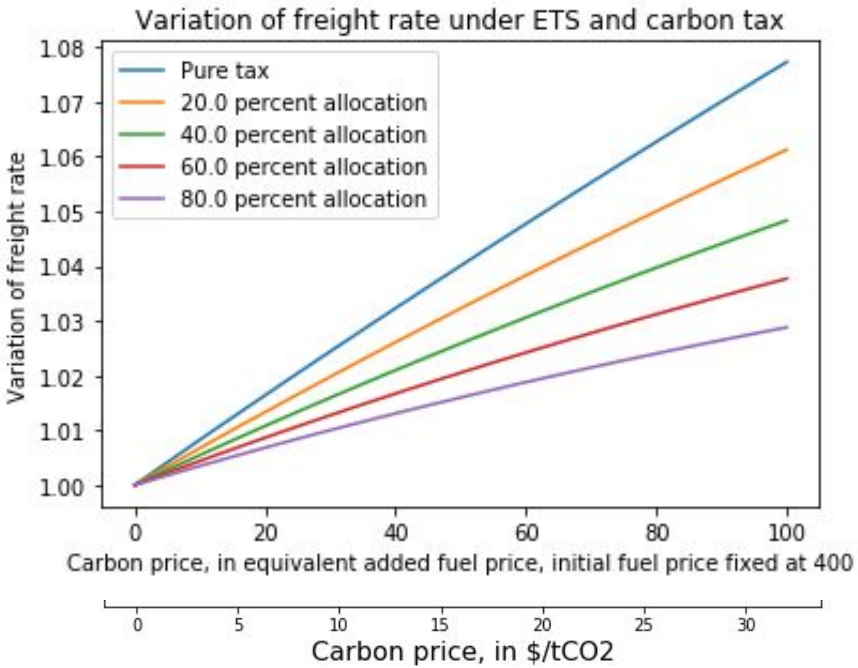
Free allocation + Added allowance cost

0% 120%

Total needs of a ship

Variable free allocations model

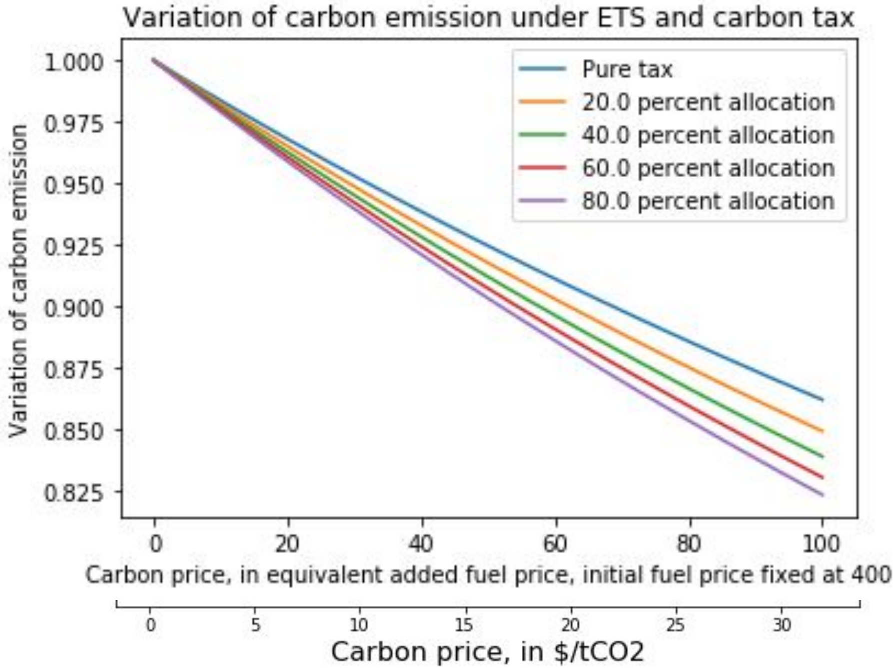
$$\frac{FR_{ETS}}{FR} = \left(1 + \frac{ETS_{price}}{Oil_{price}}\right)^{\frac{1}{b}} . \left(\frac{(b-1) + x_i}{(b-1) + x_i.(1 + \frac{ETS_{price}}{Oil_{price}})}\right)^{\frac{b-1}{b}}$$



b=3

Variable free allocations model

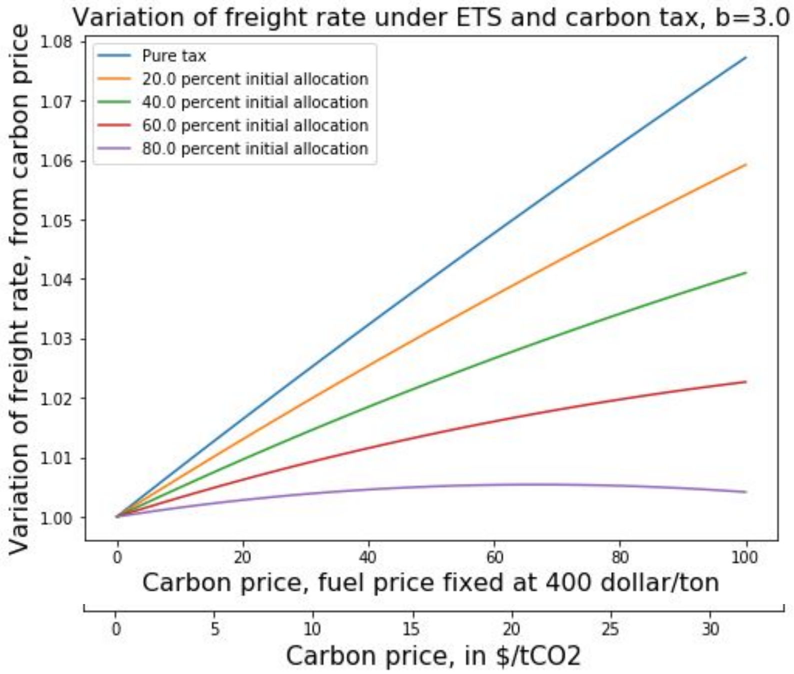
$$\left(\frac{Total'_{fuel}}{Total_{fuel}}\right) = \left(1 + \frac{ETS_{price}}{Oil_{price}}\right)^{\frac{1-b}{b}} . \left(\frac{(b-1) + x_i}{(b-1) + x_i.(1 + \frac{ETS_{price}}{Oil_{price}})}\right)^{\frac{b-1}{b}} .\Delta Demand$$



b=3
ΔDemand=1

Fixed free allocations model

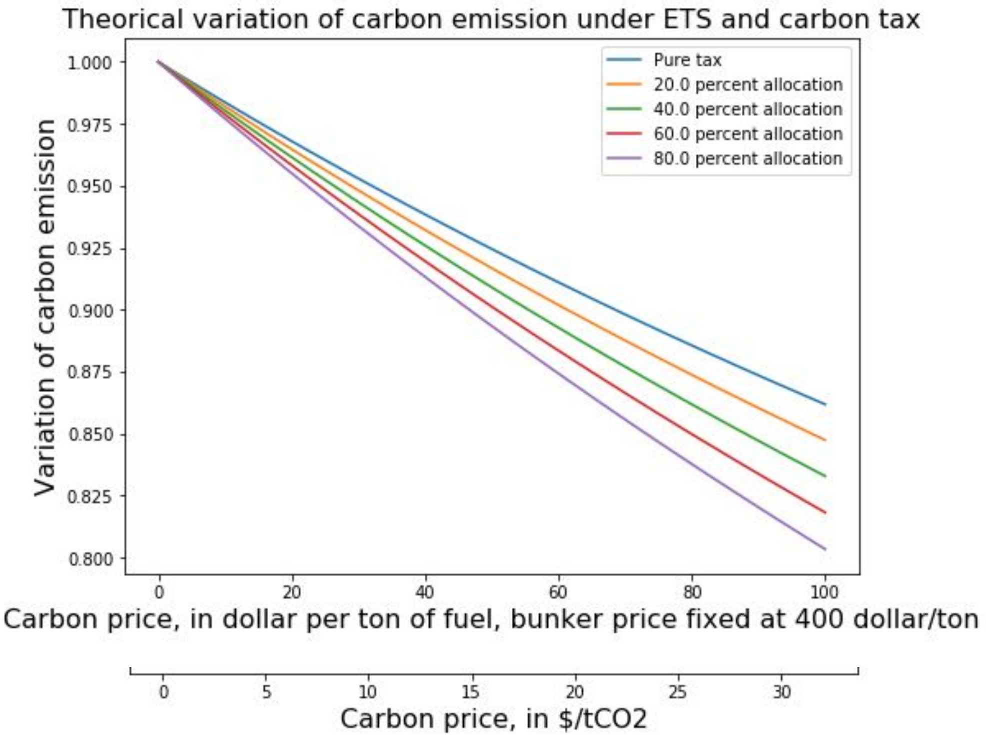
$$\left(\frac{FR_{ETS}}{FR_{ini}}\right) = \left(\frac{Oil_{price} + ETS_{price}}{Oil_{price_{ini}}}\right)^{\frac{1}{b}} \left(1 - \frac{x_i.ETS_{price}}{(b-1).Oil_{price_{ini}}}\right)^{\frac{b-1}{b}}$$



b=3
No change in oil price

Fixed free allocations model

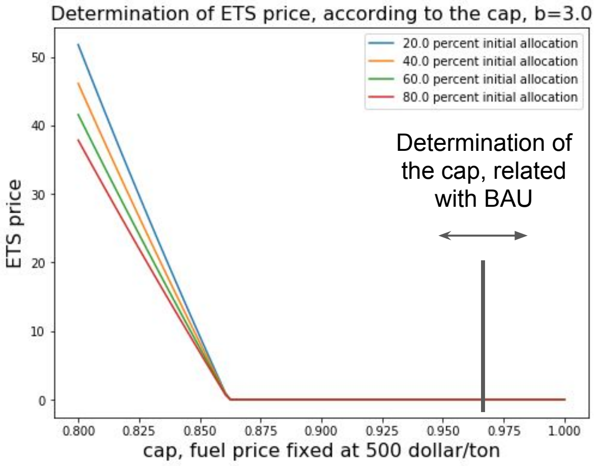
$$\left(\frac{Total'_{fuel}}{Total_{fuel}}\right) = \left(Oil_{price} + ETS_{price}\right)^{\frac{1-b}{b}} \left(Oil_{price_{ini}} - \frac{x_i.ETS_{price}}{(b-1)}\right)^{\frac{b-1}{b}} .\Delta Demand$$

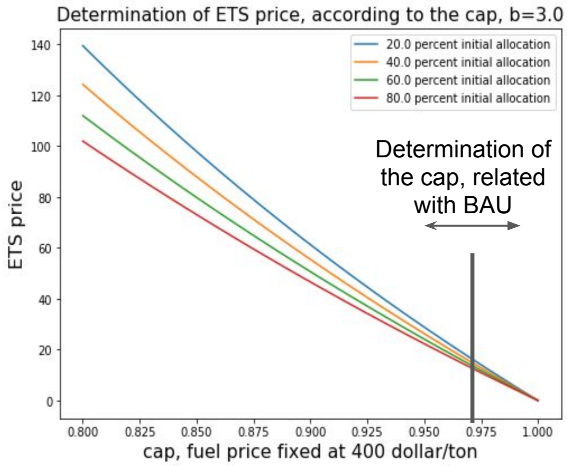


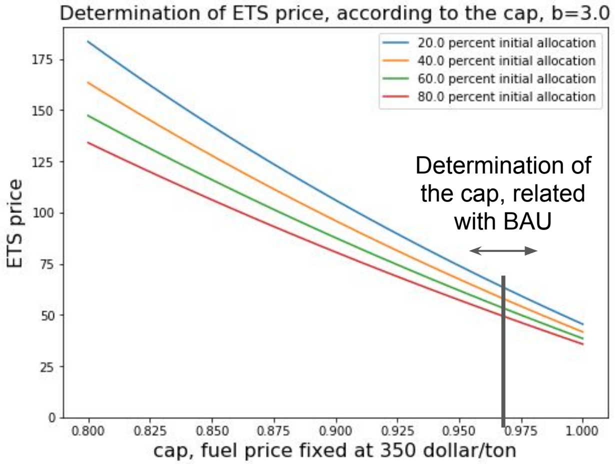
b=3
ΔDemand=1
No change in oil price

Effect of market and cap on ETS price

Fixed free allocations model, variation of ETS permit price ($/t$_{Fuel}$)





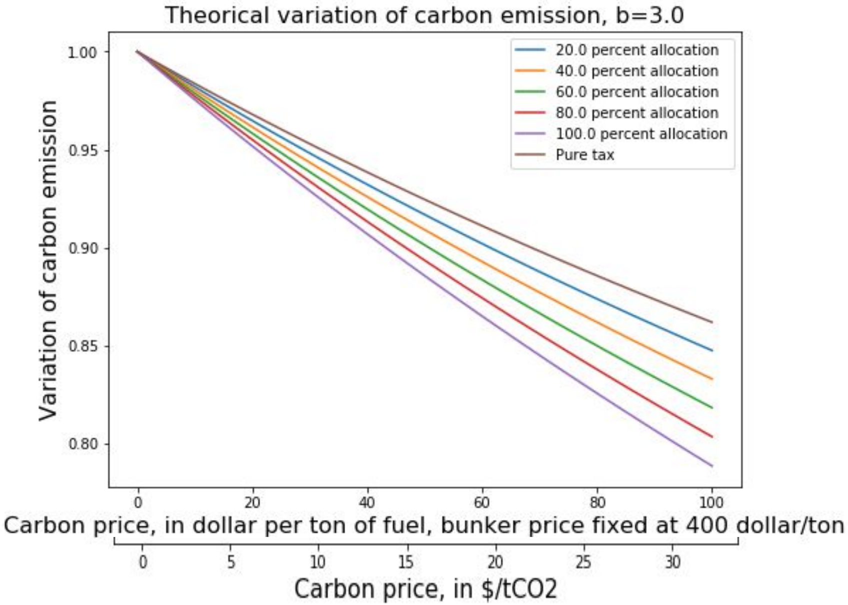


With fixed level of overall cap, ETS effect is highly dependant on the market conditions

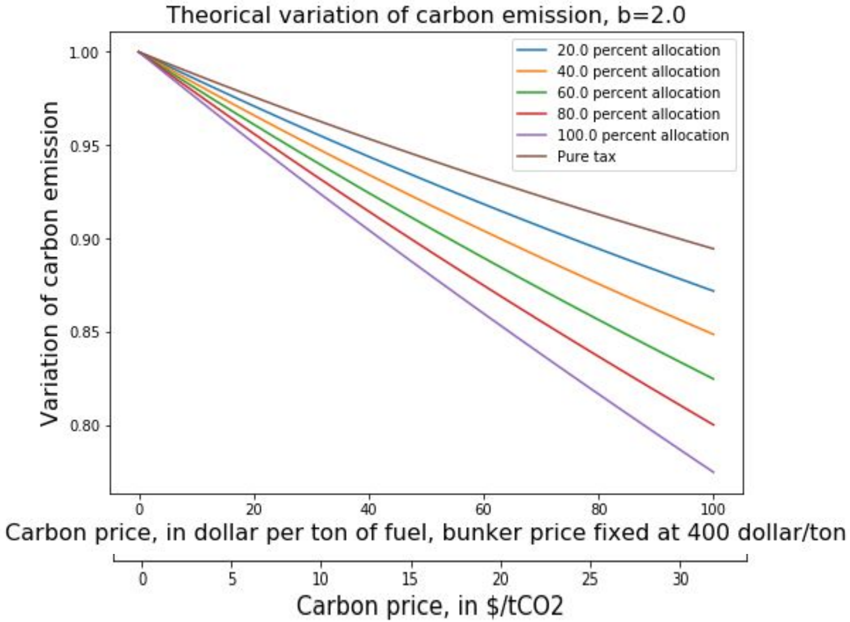
If an ETS is adopted, strong needs for stability tools

Effect of slow steaming on carbon pricing

Fixed free allocations model



Usual situation
b=3
$V^* \simeq V_{Design}$



Slow steaming
b=2
$V^* \leq V_{Design}$

Lower reduction of CO_2 under conditions of slow steaming, for similar carbon price

Question of new technologies adaptations

Financial condition on the adoption of technology (NVP)

$$\sum_{i=1}^{n_{year}} \frac{Revenue_{Added}}{(1+r)^i} \geq CAPEX$$

r Discount factor

n_{year} Expected year of investment return

$CAPEX$ Initial technology cost

Adoption of new technologies is uneasy, specially for retrofitting, NVP is too simple

If shipping speed and FR are perfectly adapted, carbon pricing cannot directly encourage the adoption of new technologies.

Still, a reduction of CAPEX is possible with investment in low TRL

Rebound effect equal to $\frac{1}{b-1}$

Conclusion

- For similar carbon prices, a cap-and-trade scheme induces higher carbon reduction and a lower cost to final consumer.
- But, a tax is robust and effective in all market conditions, contrary to a closed cap-and-trade scheme.
- If free allocations are based on market needs, all types of shipping markets would have similar reduction of emissions and rise of freight rate due to carbon pricing.
- Surges and falls in potential ETS price can be evaluated, according to shipping market conditions.

Future work

- Can we make sure that such policies would not affect in a negative way other emissions (ex: Diesel cars in France)?

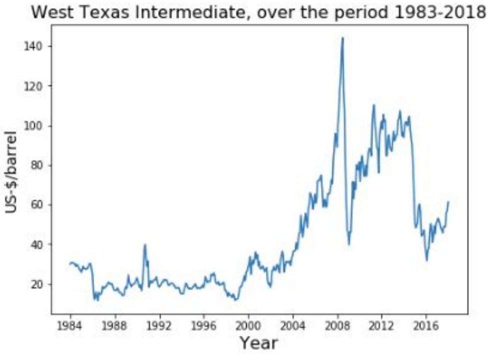
- Is it possible to quantify research fund effects on the adoption of new technologies?

- Can we study carbon leakage, through inland emissions or other way of international transportation?

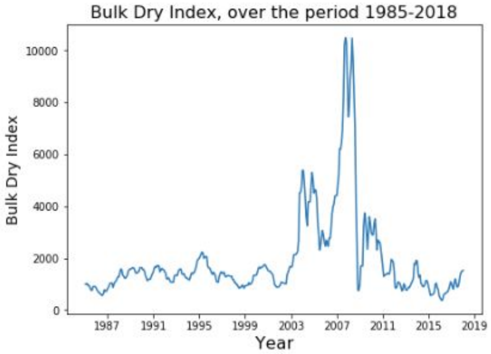
- Could we compare, with same methods, potential carbon offsetting and regulations on ship speed?

Annex I

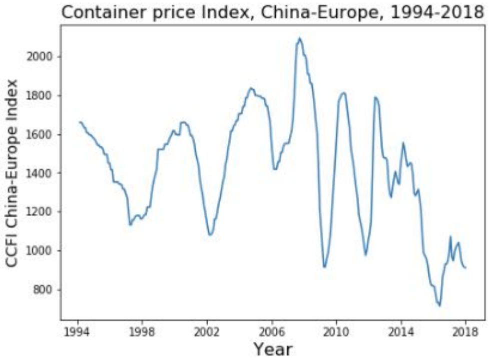
Estimation of FR



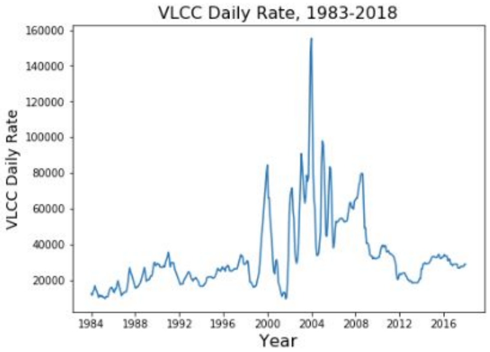
(a) Bunker price index



(b) Bulk Freight Price index



(c) Container Freight price index



(d) Tanker Freight price index

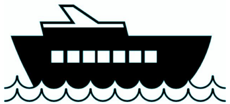
Figure 2: Data used in the study

- -WTI ($ per barrel) is used as an indicator for bunker price (in $ per ton), (multiplied by 5.21)

- For bulk ships, Bulk dry index is used
- For containers, China Containerized Freight Index from Shanghai exchange, Weighted by a factor, based in 2016, for the obtention of CCFI Asia-Europe
- For VLCC, daily rate in 5 year rent is used, for the period 1997-2018. WS index for the period 1984-1997.

Annex II

Optimisation of speed, personal calculation of optimized speed



Port A

Port B

Optimisation of the route speed:

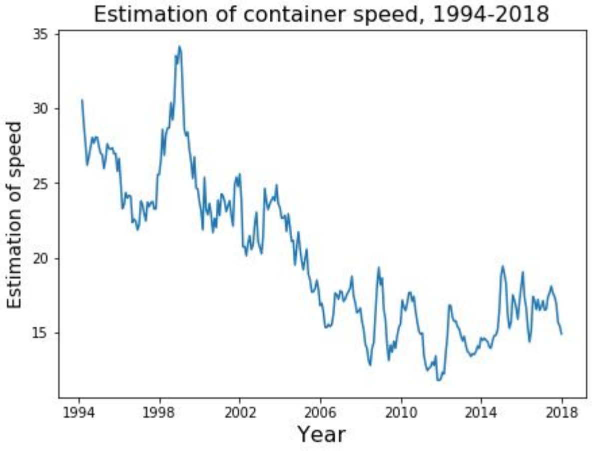
$$v_i^* = \left(\frac{v_{0i}^b . Mass_{carried_i} . FR . (1 - \rho_{Port})}{b . (Oil_{price} + Price_{CO2}) . (Fuel_{conso_i}(v_0))} \right)^{\frac{1}{b-1}}$$

Mass carried proportional to average DWT of the fleet

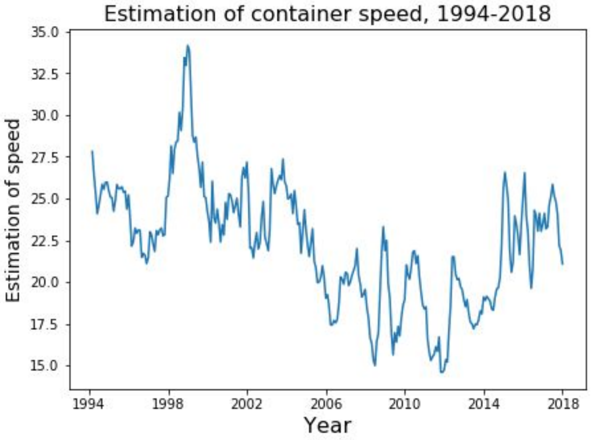
Fuel consumption is proportional to engine Power, with a linear 5% rise in diesel engine efficiency.

Bunker price proportional to WTI index

FR: China -> Europe (CCFI),
fee port =0.5



b=3



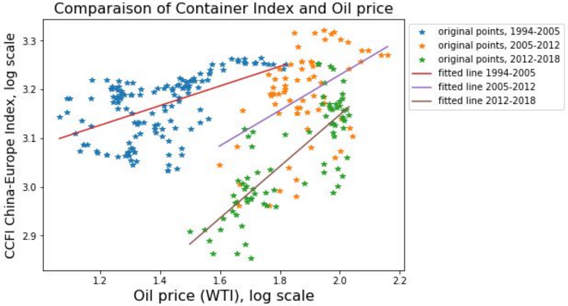
b=3.2 to 2.9

Annex III

ns	P > 0.05
*	P ≤ 0.05
**	P ≤ 0.01
***	P ≤ 0.001

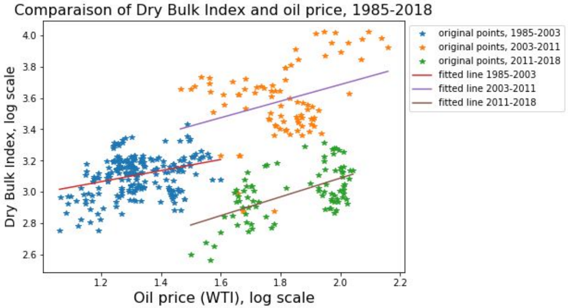
Adjustment of FR, under carbon tax

$$FR_{new} = FR.\left(1 + \frac{Tax_{CO2} + \Delta Oil_{price}}{Oil_{price}}\right)^{\frac{1}{b}}$$



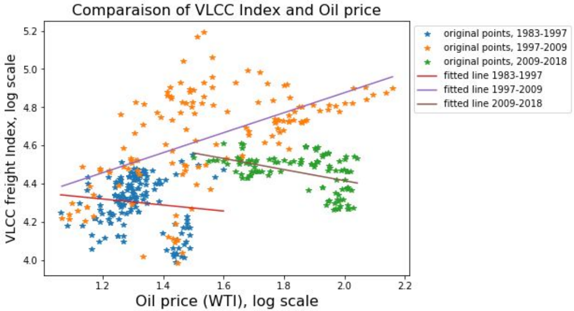
Range of year	Slope	95% confidence interval	R^2	p
1994-2005	0.20	(0.14,0.26)	0.27	***
2005-2012	0.36	(0.19,0.54)	0.20	***
2012-2018	0.53	(0.44,0.62)	0.62	***
1994-2018	0.04	(0.00,0.08)	0.01	ns

Container market



Range of year	Slope	95% confidence interval	R^2	p
1985-2003	0.35	(0.21,0.49)	0.10	***
2003-2011	0.53	(0.20,0.86)	0.11	**
2011-2018	0.60	(0.41,0.78)	0.33	***
1985-2018	0.35	(0.26,0.44)	0.14	***

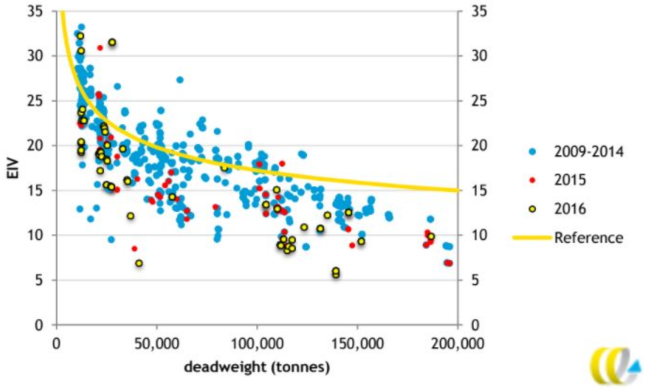
Bulk market



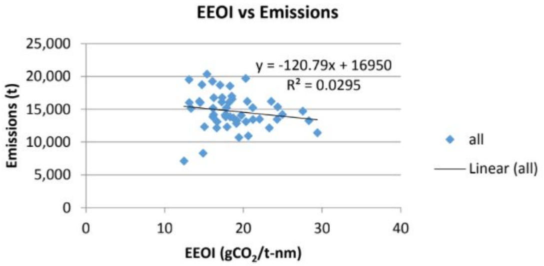
Range of year	Slope	95% confidence interval	R^2	p
1984-1997	-0.16	(-0.37,0.05)	0.01	ns
1997-2009	0.52	(0.39,0.66)	0.29	***
2009-2018	-0.29	(-0.40,-0.18)	0.20	***
1983-2018	0.32	(0.25,0.39)	0.16	***

VLCC market

Annex IV



Source: CE Delft.



Source:MEPC 72/7/1, INTERTANKO

$$Estimated\ Index\ Value = 3.1144 \cdot \frac{190 \cdot \sum_{i=1}^{NME} P_{MEi} + 215 \cdot P_{AE}}{Capacity \cdot V_{ref}}$$

Use of Design efficiency index (EIV, as a simplified form of EEDI), is easier to obtain than operational index EEOI (EEDI, with operational parameters)..

EEOI is not a good indicators on emissions.

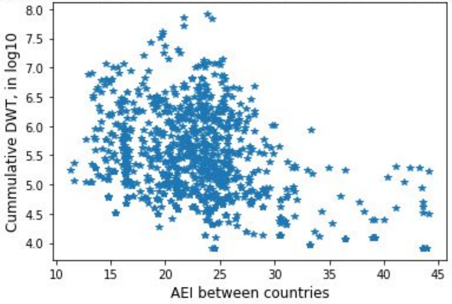
Under personal model:

$$Fuel_{conso_i} = \frac{FR^{\frac{b}{b-1}}.Mass_{carried_i}^{\frac{b}{b-1}}.v_{0_i}^{\frac{b}{b-1}}.(1-\rho_{Port})^{\frac{b}{b-1}}}{(b(Oil_{price}+Carbon_{price}))^{\frac{b}{b-1}}.Fuel_{conso}(v_{0_i})^{\frac{1}{b-1}}}$$

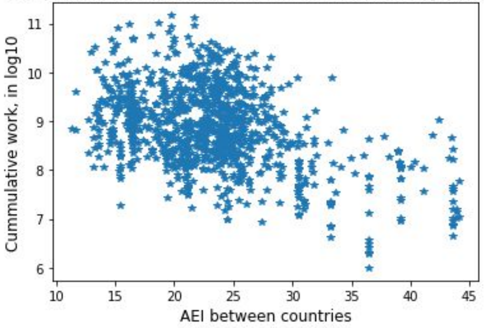
Annex V

Comparison of some indicators in trade

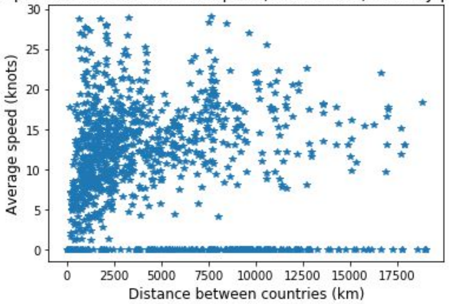
Comparison of AEI and volume of trade, containers, country precision



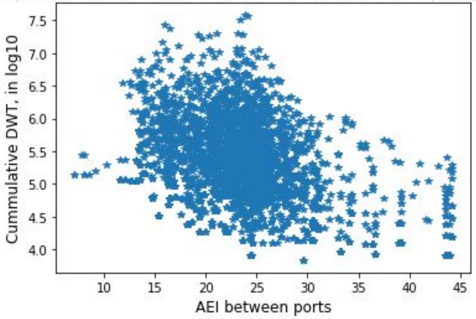
Comparison of AEI and work, containers, country precision



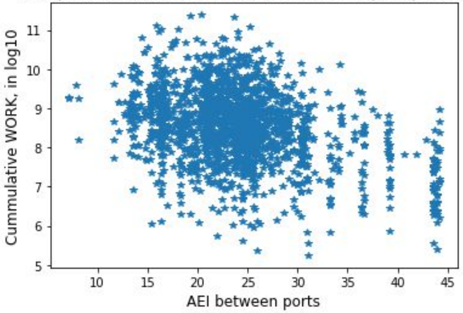
Comparison of distance and speed, containers, country precision



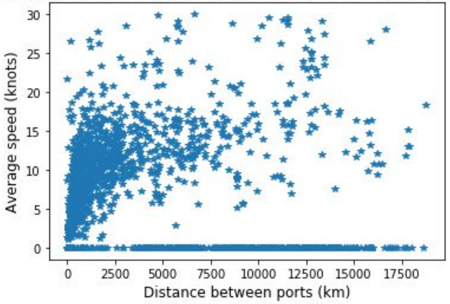
Comparison of AEI and volume of trade, containers, port precision



Comparison of AEI and work, containers, port precision



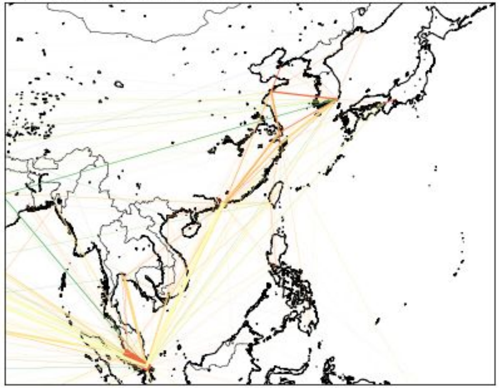
Comparison of distance and speed, containers, port precision

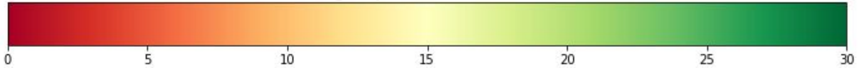


Annex VI

Some added speed information

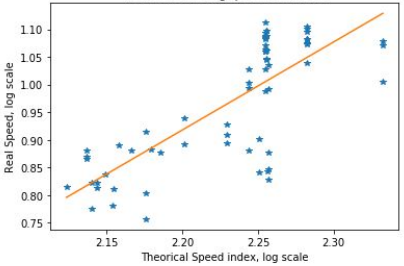
Shipping trade of ships, weighted by DWT, Container Ship (Fully Cellular)



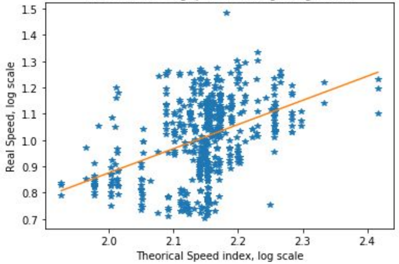


Average speed of travel, port precision

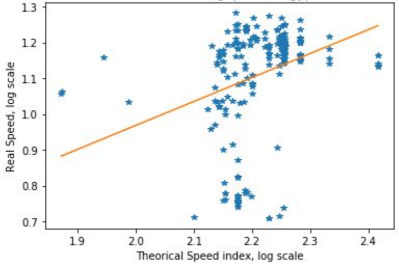
RMQ: cannot be studied directly there



Slope log= 1.59
R-squared = 0.59



Slope log= 0.92
R-squared = 0.18



Slope log= 0.67
R-squared = 0.10

Annex VII

$$\frac{\partial \pi}{\partial v} = 0 \longrightarrow \qquad v_i^* = \left(\frac{v_{0i}^b.Mass_{carried_i}.FR.(1-\rho_{Port})}{b.(Oil_{price}+Price_{CO2}).Fuel_{conso_i}(v_0)} \right)^{\frac{1}{b-1}}$$

$$Fuel_{conso_i} = \frac{FR^{\frac{b}{b-1}}.Mass_{carried_i}^{\frac{b}{b-1}}.v_{0_i}^{\frac{b}{b-1}}.(1-\rho_{Port})^{\frac{b}{b-1}}}{(b(Oil_{price}+Carbon_{price}))^{\frac{b}{b-1}}.Fuel_{conso}(v_{0_i})^{\frac{1}{b-1}}}$$

Individual daily fuel consumption,

a multiplication by (oil price+carbon price) and a coefficient (dependant of b) will provide f, used bellow

Caused by freight rate - all port charges

Caused by fuel consumption

$$CashFlow_{Time_{Year}} = \left(\frac{1}{b^{\frac{1}{b-1}}} - \frac{1}{b^{\frac{b}{b-1}}}\right).f(FR+fr, Carbon_{price}+ETS_{price})$$
$$-CAPEX_{Year} - OPEX_{Year} + \frac{x_i.f(FR, Oil_{price})}{b^{\frac{b}{b-1}}}.\left(1+\frac{Carbon_{price}}{Oil_{price}}\right)$$

= 0 for tax

Need to replace FR by FR + fr and Oilprice by Oilprice+CO2price in variable allocation

Cash flow, inside the fixed allocation model

It’s development will give the new freight rate, in ETS or carbon tax model

Annex VIII

Example for b=3, and ΔDemand=1

$$\sum_{i=1}^{Nship'_{used}} Mass_{carried_i}.v_i^{*\prime}$$

Is the new demand

For b=3, and ΔDemand=1 (conservation of Demand), Rent is a design index

$$\sum_{i=1}^{Nship'_{used}} Rent(i).\sqrt{\frac{FR_{ETS}.(1-\rho_{Port})}{3.(Oil_{price}+ETS_{price})}} = \sum_{j=1}^{Nship_{used}} Rent(j).\sqrt{\frac{FR.(1-\rho_{Port})}{3.Oil_{price}}}$$

With the equation on FR

$$\sum_{i=1}^{Nship'_{used}} Rent(i).(1+\frac{ETS_{price}}{Oil_{price}})^{-\frac{1}{3}}.\left(\frac{2+x}{2+x.(1+\frac{ETS_{price}}{Oil_{price}})}\right)^{\frac{1}{3}} = \sum_{j=1}^{Nship_{used}} Rent(j)$$

Coming back to the total fuel emission:

$$Total'_{Fuel} = \sum_{i=1}^{Nship'_{used}} Rent(i).\frac{FR^{\frac{3}{2}}.(1-\rho_{Port})^{\frac{3}{2}}}{(3(Oil_{price}))^{\frac{3}{2}}}.(1+\frac{ETS_{price}}{Oil_{price}})^{-1}.\left(\frac{2+x}{2+x.(1+\frac{ETS_{price}}{Oil_{price}})}\right)^{1}$$

Total fuel consumption can be compared to the previous one