The economic and environmental dimensions of slow-steaming

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Outline

- Role of speed
- Some basics
- Speed optimization
- Slow steaming vs speed limits
- Issues and prospects

Role of ship speed

- Has always been important
- Increasingly important in recent years
- Economic considerations
- Environmental considerations (emissions)

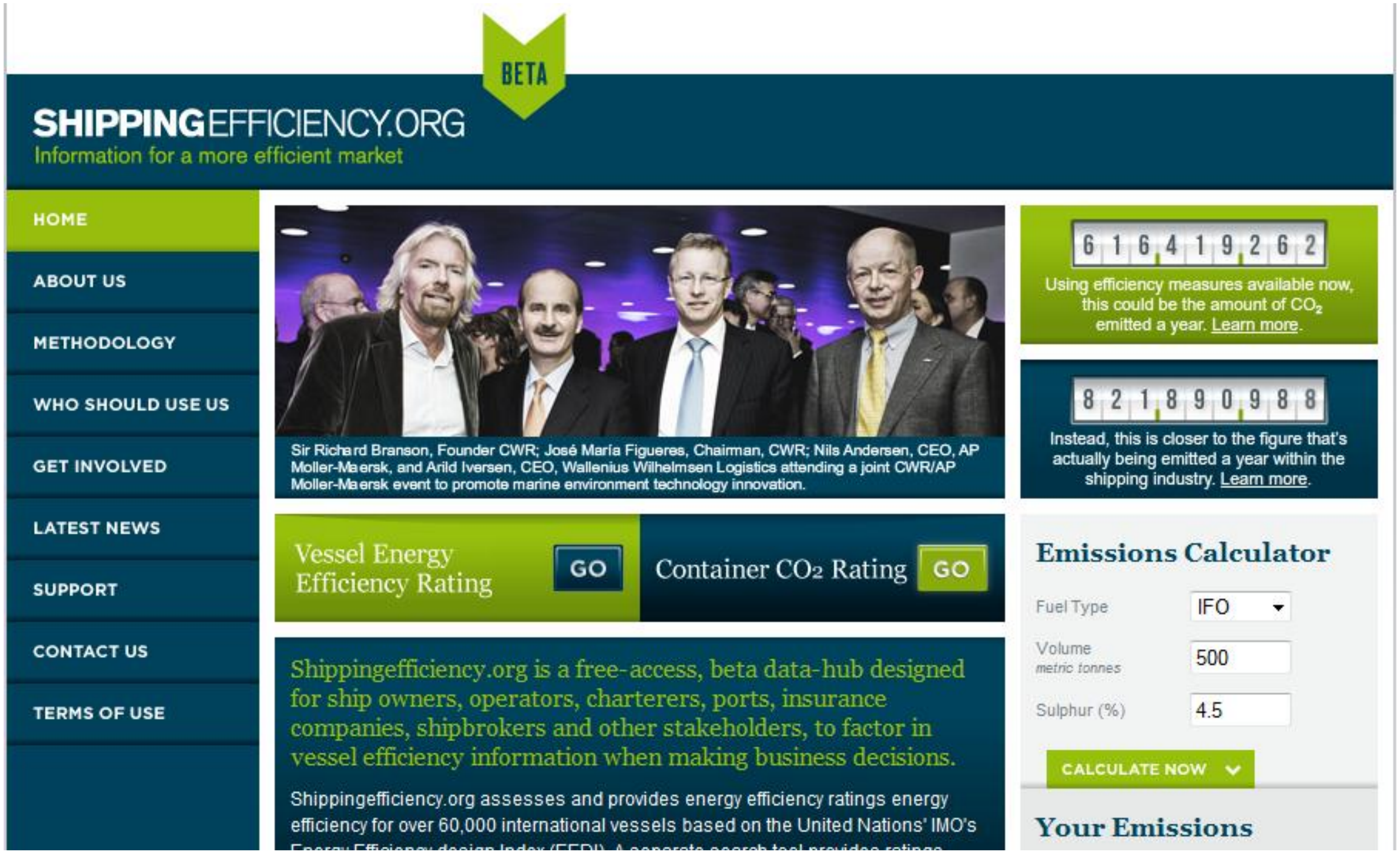
Types of emissions

- Green House Gases-GHGs (mainly CO_2, but also CH_4 , N_2O and others)
- Non-GHG (mainly SO_2, but also NO_x and others)
- P.M., etc

Era of GHG non-regulation in shipping:

- Officially ended July 2011 (adoption of EEDI)
- STILL: Measures to curb future CO_2 growth are being sought with a high sense of urgency.
- As CO_2 is the most prevalent of these GHGs, any set of measures to reduce the latter should primarily focus on CO_2.

Shipping under pressure



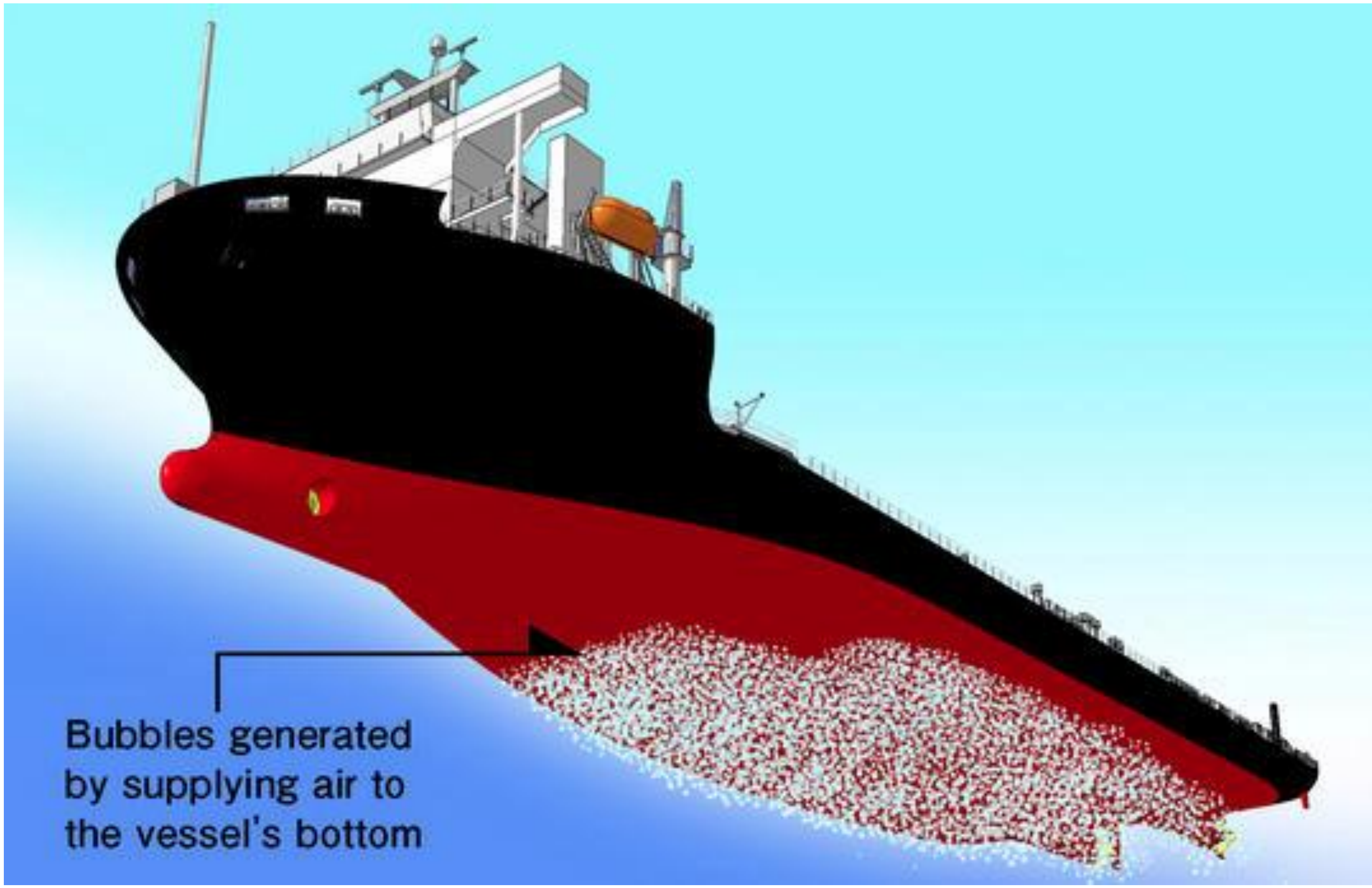
Measures contemplated

- Technological
  - More efficient (energy-saving) engines
  - More efficient ship designs
  - More efficient propellers
  - Cleaner fuels (low sulphur content, LNG)
  - Alternative fuels (fuel cells, biofuels, etc)
  - Devices to trap exhaust emissions (scrubbers, etc)
  - Energy recuperation devices
  - "Cold ironing" in ports

- Operational (logistics-based) measures
  - Speed optimization
  - Optimized routing
  - Several others

- Market-based
  - Emissions Trading Scheme (ETS)
  - Carbon Tax/Levy on Fuel
  - Several others


SkySails
BELUGA PROJECTS


Bubbles generated
by supplying air to
the vessel's bottom

Emissions 101

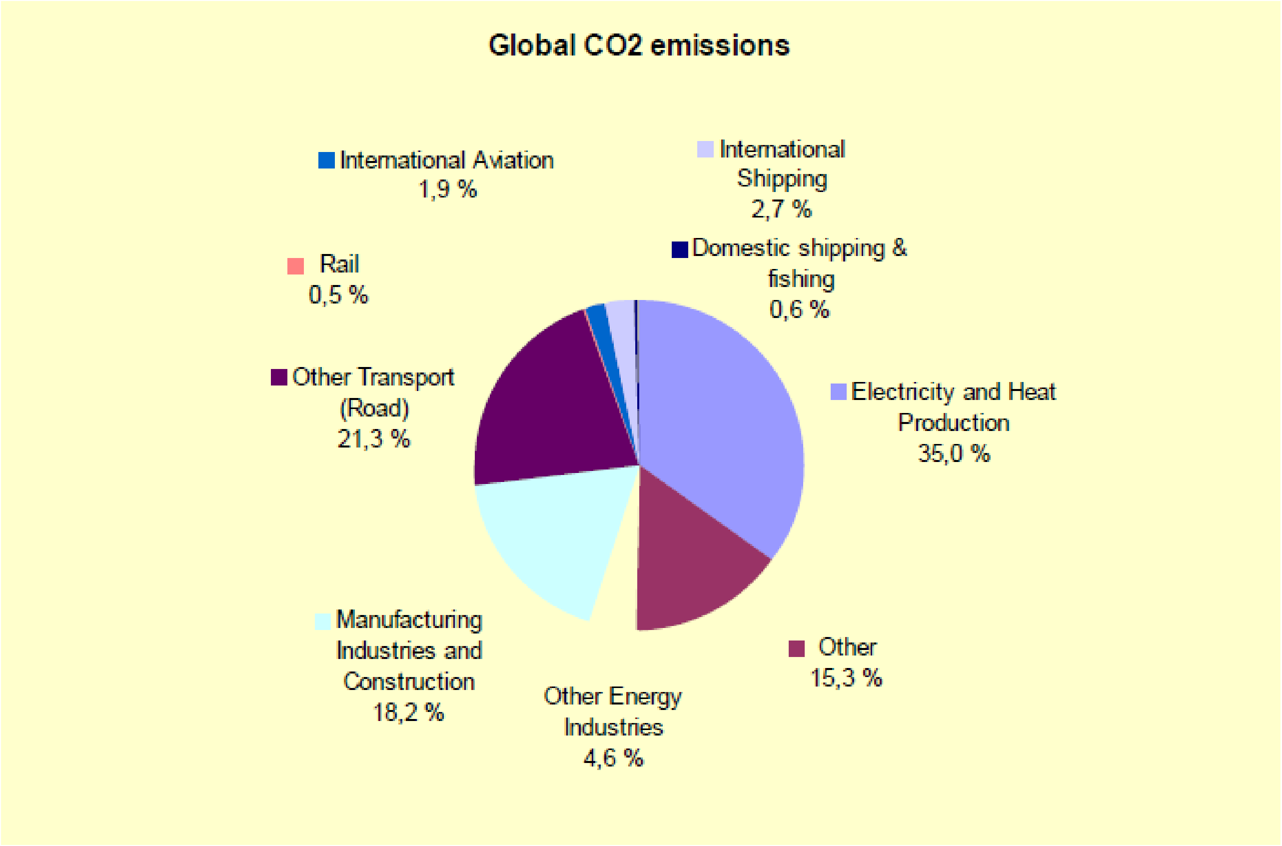
- Q: If we burn a ton of fossil fuel (heavy fuel oil, diesel, or other), how much CO_2 is generated?

- A: Between 3.02 and 3.11 tons, depending on the fuel

How much CO_2 is produced by international shipping?

- Problem: Even estimates of past marine fuel sales are impossible to make
- Most global emissions estimates are based on **modeling** (even of past emissions)

Share of global CO_2 emissions



Emissions of CO_2 from shipping compared with global total emissions for 2007 (Source: Second IMO GHG Study 2009)

GHG marine emissions estimates

- IMO latest update of GHG study (2009)

Table 1.1 *Summary of GHG emissions from shipping* during 2007*

	International shipping (million tonnes)	Total shipping	
		million tonnes	CO_2 equivalent
CO_2	870	1050	1050
CH_4	Not determined*	0.24	6
N_2O	0.02	0.03	9
HFC	Not determined*	0.0004	≤6

* A split into domestic and international emissions is not possible.

Future projections

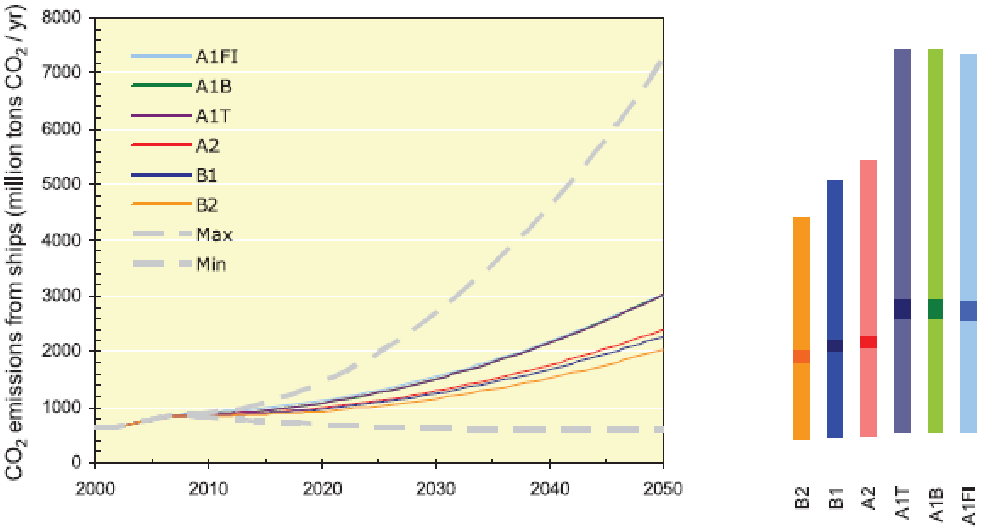


Figure 1.2 *Trajectories of the emissions from international shipping. Columns on the right-hand side indicate the range of results for the scenarios within individual families of scenario.*

- A scale of 10:1 between worst case and best case!

Measures contemplated

- Technological
  - More efficient (energy-saving) engines
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- Operational (logistics-based) measures
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  - Optimized routing
  - Several others

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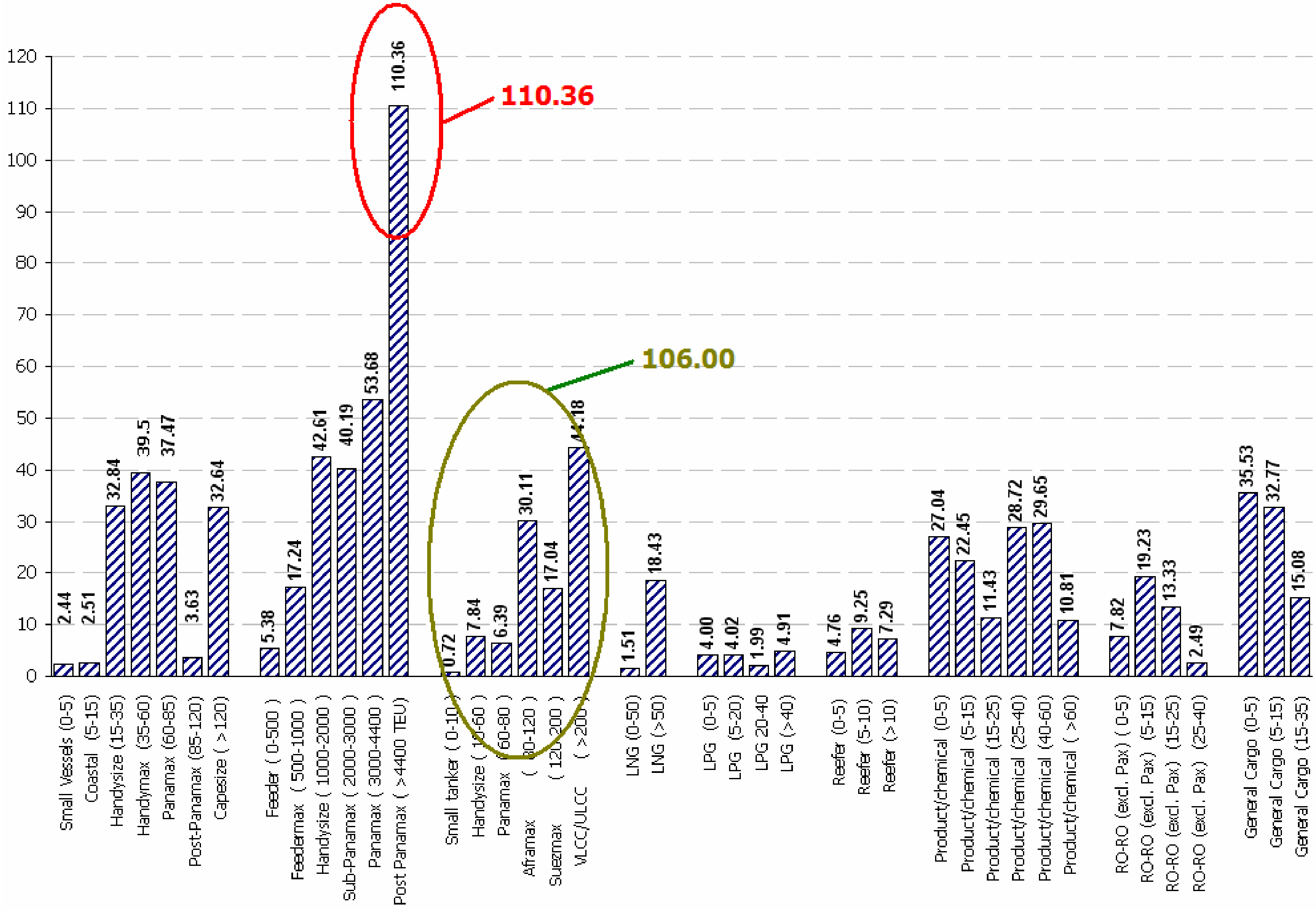
CO2 emissions per vessel category (million tonnes)



*Psaraftis, H.N. and C.A. Kontovas (2009), "CO2 Emissions Statistics for the World Commercial Fleet", WMU Journal of Maritime Affairs, 8:1, pp. 1-25.

Speed reduction

- An obvious way to reduce emissions

- Killing 3 birds with one stone?

- Pay less for fuel
- Reduce CO_2 (and other) emissions
- Help sustain a volatile market

Dual targetting

- OPERATIONAL
- Operate existing ships at reduced speed (derate engines)
- Slow steaming kits

- STRATEGIC (DESIGN)
- Design new ships that cannot go very fast (have smaller engines)

How much slower?

- From 20-25 knots, go down to 14-18
- New Maersk 18,000 TEU ships: 19 knots
- Project ULYSSES: Go 5-6 knots!

Some basics

- Ships do NOT trade at predetermined speeds.
- Those who pay for the fuel, that is, the ship owner if the ship is in the spot market on voyage charter, or the charterer if the ship is on time or bareboat charter, will **choose an optimal speed** as a function of
  - (a) bunker price, and
  - (b) the state of the market and specifically the spot rate

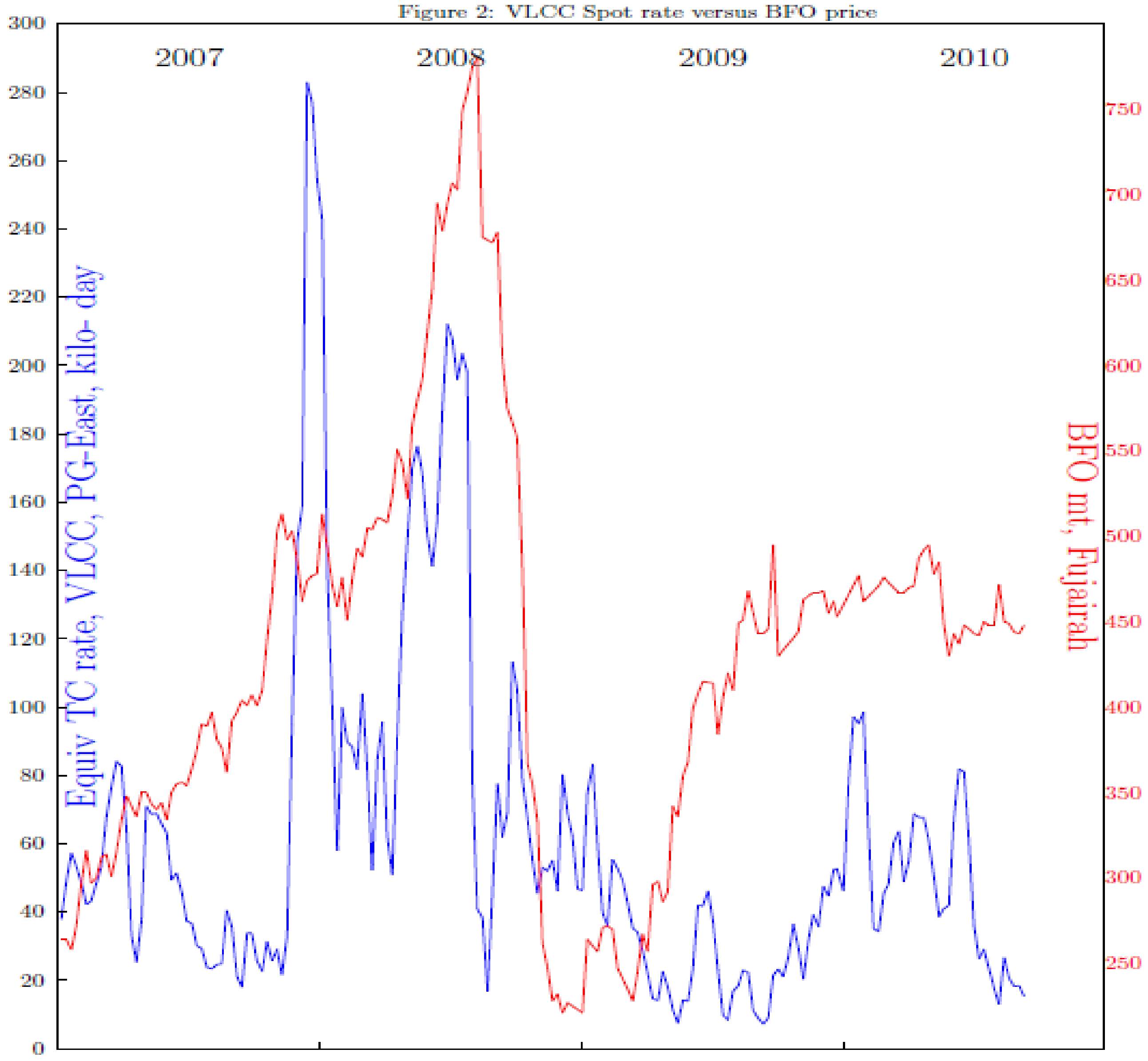


Figure 2: VLCC Spot rate versus BFO price
2007
2008
2009
2010
Equiv TC rate, VLCC, PG-East, kilo- day
BFO mt, Fujairah
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
250
300
350
400
450
500
550
600
650
700
750

Basics ii

- Even though the owner's and time charterer's speed optimization problems may seem at first glance different, for a given ship the optimal speed (and hence fuel consumption) is in both cases the same.
- In that sense, it makes no difference who is paying for the fuel, the owner, the time charterer, or the bareboat charterer.

Owner in spot market

- OBJECTIVE: Maximize average per day profits
- s: spot rate ($/tonne)
- C: payload (tonnes)
- p: fuel price
- F(v): fuel consumption at speed v
- D: route r-trip distance
- E: OPEX ($/day)

$$\max_{v} \left\{ \frac{sC}{\frac{D}{24v}} - pF(v) - E \right\}$$

Time charterer

- OBJECTIVE: Minimize average per day costs
- R: demand requirements (tonnes/day)
- T: time charter rate ($/day)

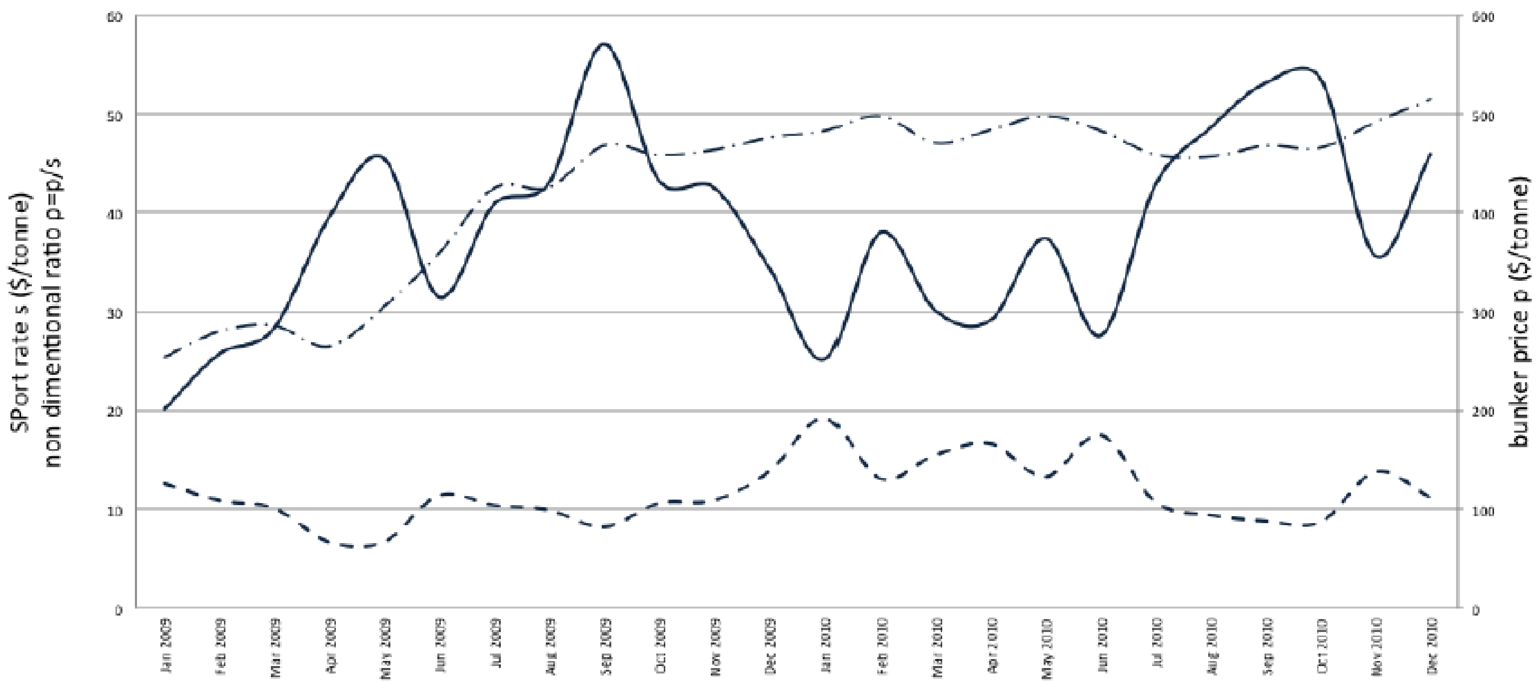
$$\min_{v} \left\{ s \left(R - \frac{C24v}{D} \right) + T + pF(v) \right\}$$

Role of ratio ρ= p/s

- Both problems reduce to:

$$\min_v \{ (p/s)f(v) - Cv/d \}$$

Ratio ρ=p/s



	Jan 2009	Feb 2009	Mar 2009	Apr 2009	May 2009	Jun 2009	Jul 2009	Aug 2009	Sep 2009	Oct 2009	Nov 2009	Dec 2009	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010	Jul 2010	Aug 2010	Sep 2010	Oct 2010	Nov 2010	Dec 2010
s ($/tonne)	12.6	10.9	10.1	6.7	6.7	11.4	10.4	9.9	8.2	10.6	10.9	13.8	19.2	13.1	15.5	16.6	13.3	17.5	10.7	9.4	8.8	8.7	13.8	11.2
ρ=p/s	20.16	25.69	28.32	39.55	45.52	31.49	40.87	43.03	57.07	43.3	42.57	34.49	25.16	38.02	30.09	29.16	37.44	27.6	42.9	48.62	53.18	53.56	35.65	45.98
p ($/tonne)	254	280	286	265	305	359	425	426	468	459	464	476	483	498	471	484	498	483	459	457	468	466	492	515

Figure 4: Evolution of bunker price p, spot rate s and their ratio ρ=p/s. Data Source: Drewry's Shipping Economist (2009-2010).

Cost function

- Fuel costs
- Time charter costs
- Cargo inventory costs

Fuel costs

- On a leg from A to B of distance L
- If ship speed is v (n. miles/day)
- Fuel cost = P_{FUEL}*(L/v)*FC(v)
- Where FC(v) is the ship’s daily fuel consumption

Fuel costs

- FC = kV^3 (cubic)
- Reasonable approximation in many cases

- Problem: exponent may be >3
- Problem: FC=0 for v=0

More general FC

- $FC = a+bV^n$ ($n \geq 3$)

- Problem: FC depends on ship's loading condition

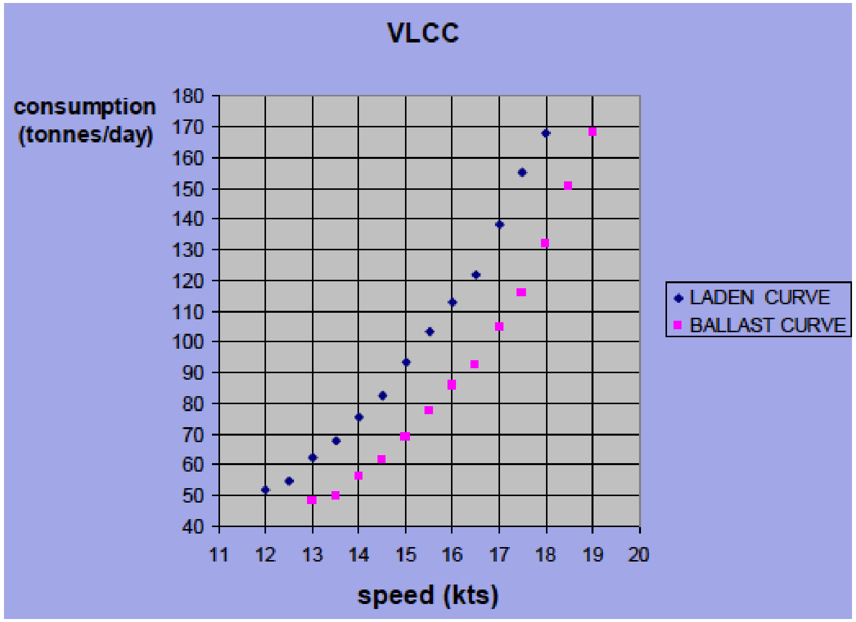
Even more general FC

- $FC = (A+BV^n)\Delta^{2/3}$

Δ= ship's displacement

- FC =f(V,w) (general)

- Depends on speed V and payload w



Time charter costs

- Assume ship on time charter
- Time charter rate F ($/day)
- F exogenous, determined by market conditions
- Cost proportional to overall time of trip (which depends on speeds of ship on each leg of route)

Cargo inventory costs

- Due to delay in delivery of cargo
- Assume cargo is available for loading in a JIT fashion
- Per unit volume and per unit time inventory cost is equal to β
- Inventory cost accrues from time cargo is on the ship until cargo is delivered.
- This cost can be important mainly for long-haul problems and/or high valued cargoes

What is β?

- Lower bound in β is PR/365

- Where P is CIF value of cargo
- R is cargo owner's cost of capital

- (β high for expensive cargoes)

Important observation

- Ship speed impacts all three categories of costs

- Fuel costs in a positive way
- Time charter costs in a negative way
- Cargo inventory costs in a negative way

Taxonomy of speed models

- Psaraftis & Kontovas (2012)
- Non-emissions related
- Emissions-related

Classification according to

- Optimization criterion: cost, profit, or other
- Shipping market/context
- Who is the decision maker
- Fuel price an input?
- Freight rate an input?
- Fuel consumption function? Cubic/general
- Optimal speeds in various legs
- Logistical context

Classification ii

- Size of fleet? Single ship, multiple ships
- Adding more ships an option?
- Inventory costs included?
- Emissions considered?
- Modal split considered?
- Ports included in formulation?

Sample output

TABLE 3a: Taxonomy part I

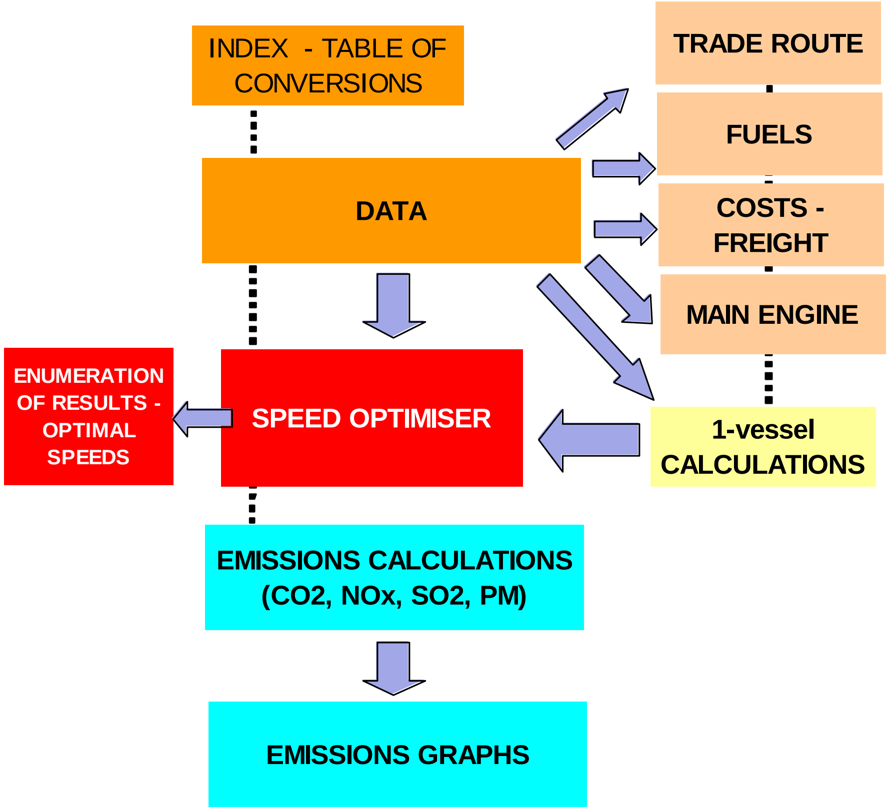
Taxonomy parameter \ paper	Alderton (1981)	Bausch et al (1998)	Benford (1981)	Brown et al (1987)	Cariou (2011)	Cariou and Cheaitou (2012)	Corbett et al (2010)	Devanney (2007)	Devanney (2010)	Eefsen and Cerup-Simonsen (2010)
Optimization criterion	Profit	Cost	Cost	Cost	Cost	Cost	Profit	Profit	Cost or profit	Cost
Shipping market	General	Tanker/ barge	Coal	Tanker	Container	Container	Container	Tanker	Tanker (VLCC)	Container
Decision maker	Owner	Owner	Owner	Owner	Owner	Owner	Owner	Owner	Either	Owner
Fuel price an explicit input	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Freight rate an input	Input	No	No	No	No	No	Input	Computed	Computed	No
Fuel consumption function	Cubic	Unspecified	Cubic	Unspecified	Cubic	Cubic	Cubic	Cubic	General	Cubic
Optimal speeds in various legs	Yes	No	No	Only ballast	No	No	No	Yes	Yes	No
Optimal speeds as function of payload	Yes	No	No	No	No	No	No	No	No	No
Logistical context	Fixed route	Routing and scheduling	Fleet deployment	Routing and scheduling	Fixed route	Fixed route	Fixed route	World oil network	Fixed route	Fixed route
Size of fleet	Multiple ships	Multiple ships	Multiple ships	Multiple ships	Multiple ships	Multiple ships	Multiple ships	Multiple ships	One ship	Multiple ships
Add more ships an option	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Inventory costs included	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes
Emissions considered	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Modal split considered	No	No	No	No	No	No	No	No	No	No
Ports included	Yes	Yes	No	No	No	Yes	No	Yes	No	Yes

TABLE 3b: Taxonomy part II

Taxonomy parameter \ paper	Faber et al (2010)	Fagerholt (2001)	Fagerholt et al (2010)	Gkonis Psaraftis (2011abcd)	Kontovas Psaraftis (2011)	Lindstad et al (2011)	Norstad et al (2011)	Notteboom Vernimmen (2010)	Papadakis Perakis (1989)	Perakis (1985)
Optimization criterion	No/A	Cost	Cost	Profit	Cost	Pareto analysis	Cost	Cost	Cost	Cost
Shipping market	Various	General	Liner	Tanker, LNG, LPG	Container	All major ship types	Tramp	Container	Tramp	Tramp
Decision maker	No/A	Owner	Owner	Owner	Charterer	Owner	Owner	Owner	Owner	Owner
Fuel price an explicit input	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No
Freight rate an input	No	No	No	Input	Input	No	No	No	No	No
Fuel consumption function	Cubic	Cubic	Cubic	General	Cubic	Cubic	Cubic	Unspecified	General	Cubic
Optimal speeds in various legs	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Optimal speeds as function of payload	No	No	No	No	Yes	Yes	No	No	No	No
Logistical context	Fixed route	Pickup and ...	Fixed route	Fixed route	Fixed route	Fixed route	Pickup and ...	Fixed route	Fleet ...	Fleet ...

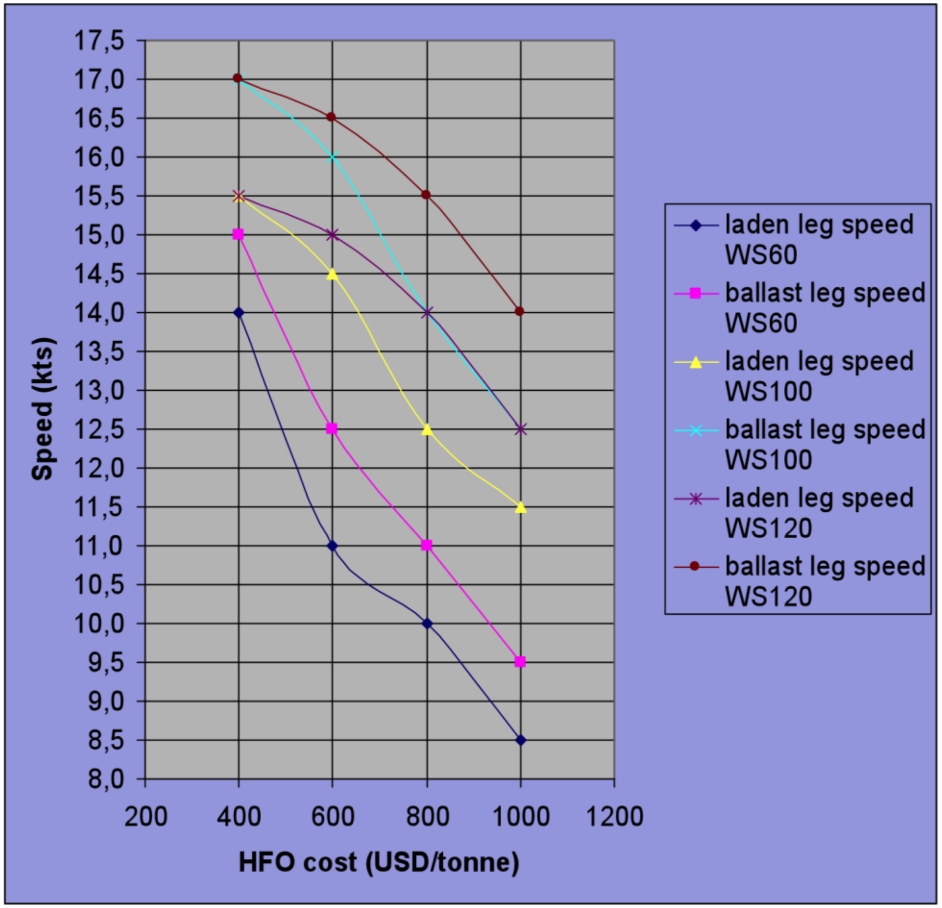
VLCC speed model

- Gkonis & Psaraftis (2012)



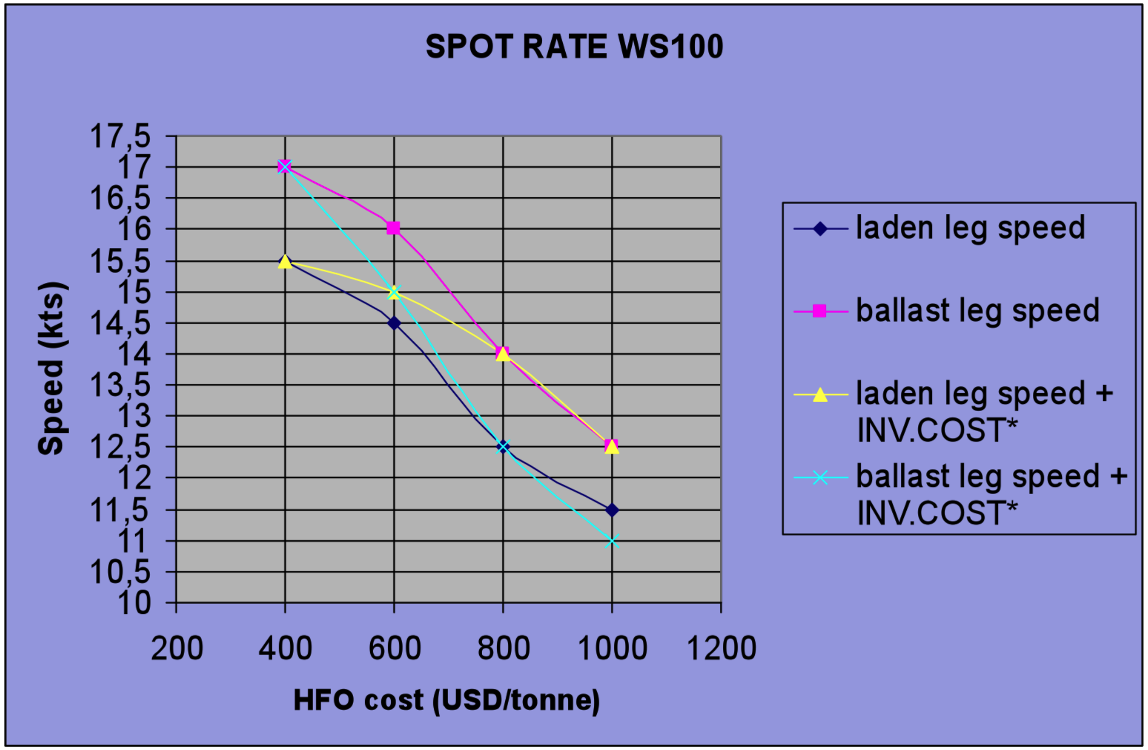
VLCC results

- Route: Gulf-Japan
- Optimize both laden and ballast speeds



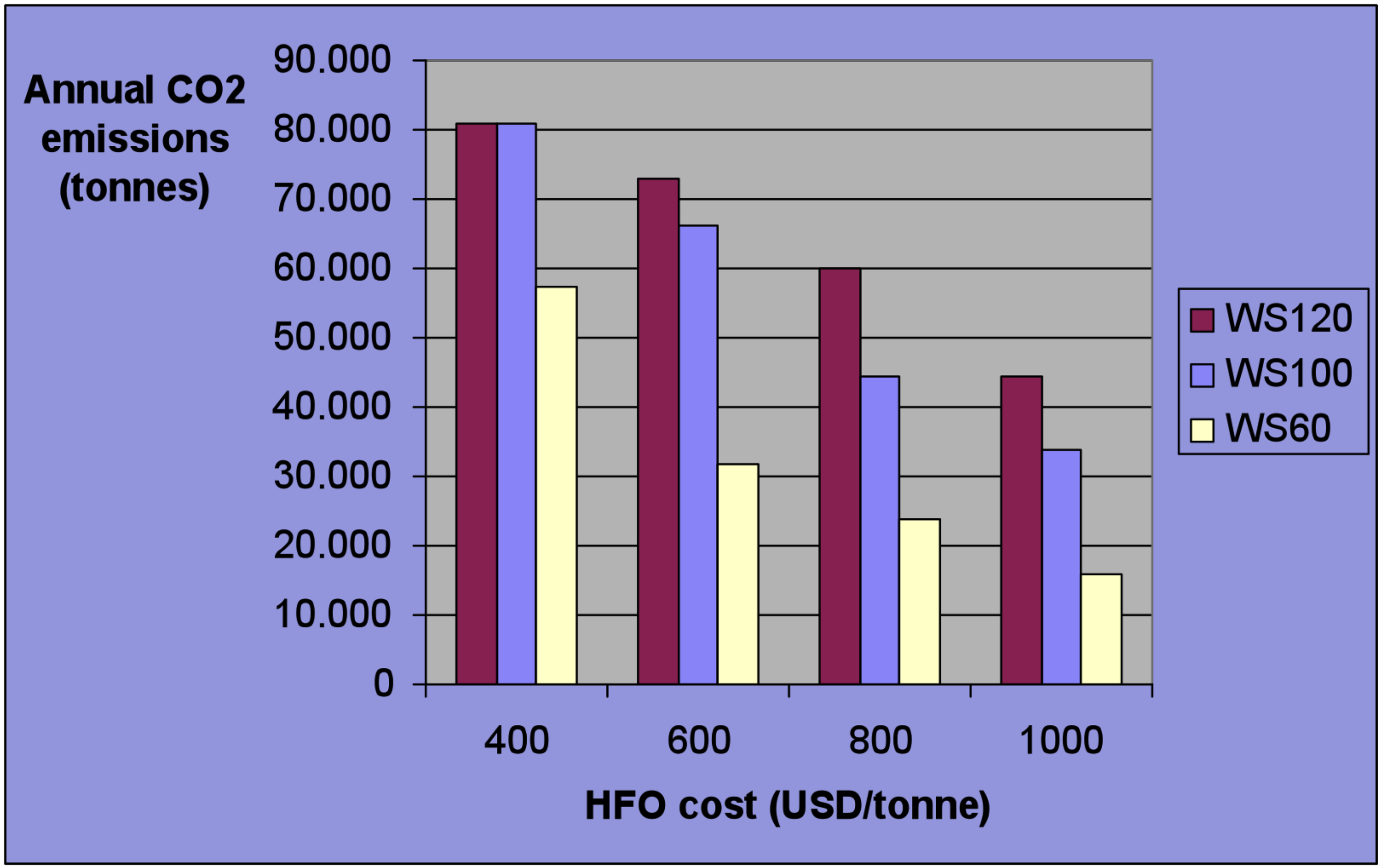
VLCC cont'd

- Include cargo inventory costs



Effect of fuel price on emissions

•



parenthesis

- A Levy on fuel will take care of slow steaming **automatically**- this will not happen with any of the other proposed market based measures (ETS, hybrid MBMs, etc)

- At the STRATEGIC level, this will also push to improve ship design (better hulls, engines, propellers, etc)

Speed decision can be decomposed from routing decision

- Assuming the ship is at port A and is set to sail to port B, the total cost on leg (A, B) is equal to

- $COST(A,B) = [P_{FUEL} f(v, w) + \beta w + F](s_{AB}/v)$,

Where:

- v: ship speed during leg
- w: ship payload during leg

Decompose speed cont'd

- Factor out s_{AB}

- INCR(A,B) = $\min_{v \in S} \{[P_{FUEL} f(v, w) + \beta w + F]/v\}$, with

with $S=\{v: v_{LB}(w) \leq v \leq v_{UB}(w)\}$

(per mile total cost)

- Observation: Speed decision is independent of A or B

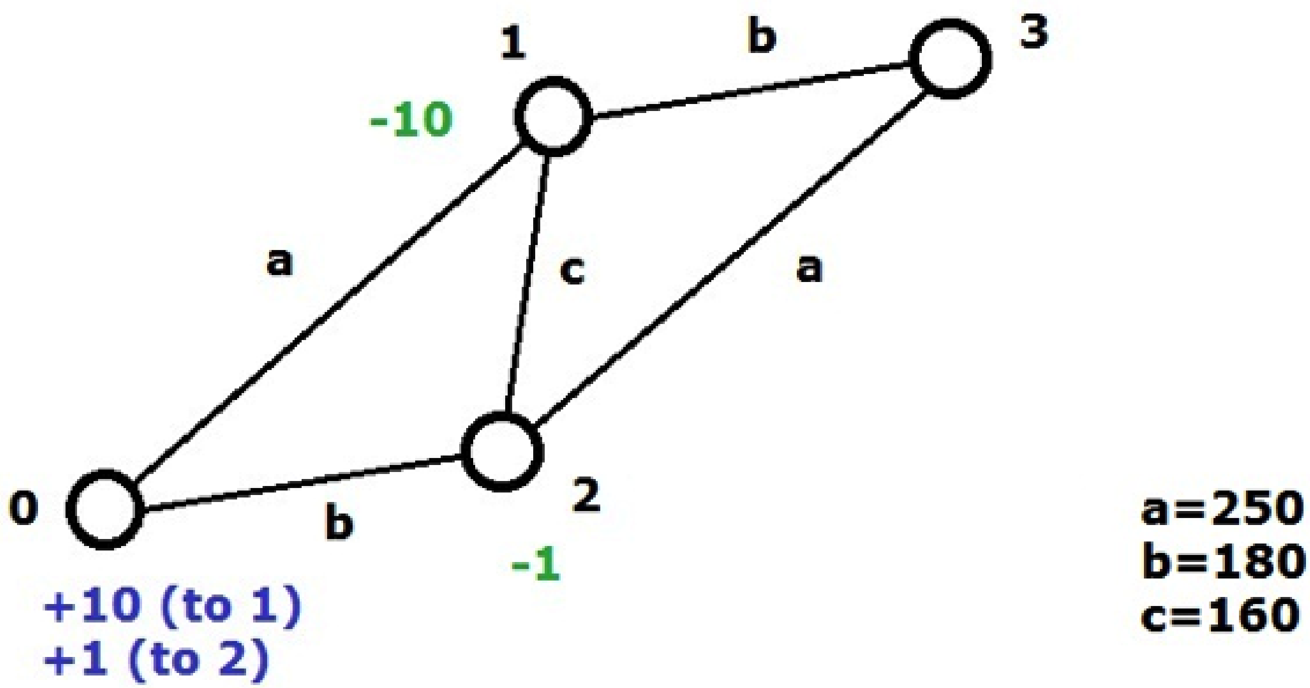
2^{nd} observation

- Input parameters $P_{FUEL,}$ F and β are key determinants of the speed decision
- Higher values of P_{FUEL} would reduce optimal speed
- Higher values of F or β would increase optimal speed

3rd observation

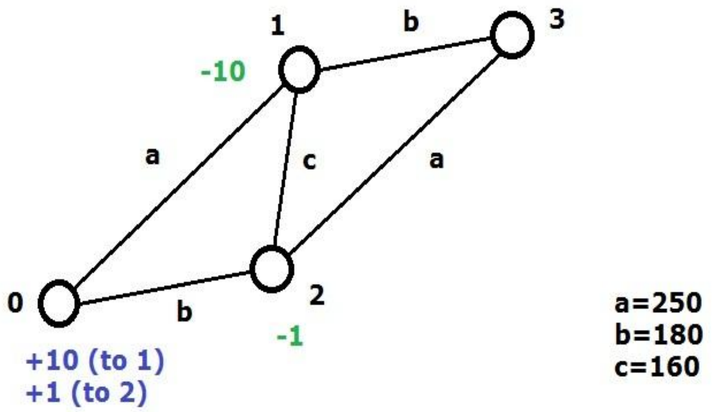
- Input parameters $P_{FUEL,}$ F and β can also influence the ROUTING decision!

Example: ship of Q=11 (000 tons)



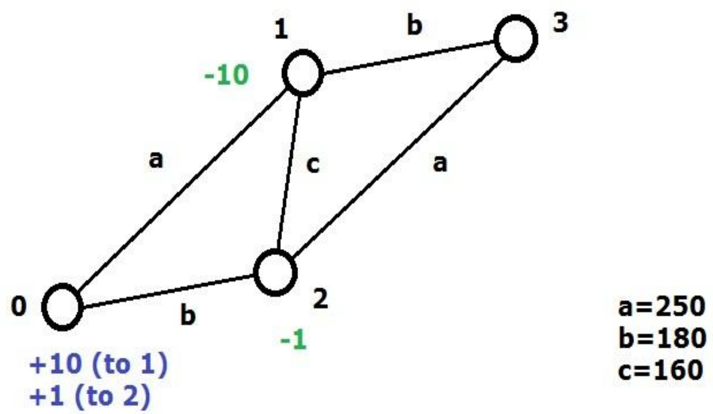
Minimum fuel cost (F=β=0)

- v between 8 and 14 knots
- Cubic FC function
- FC dependence on w
- Fuel price $600/ton



- Sail at minimum speed
- Optimal route: 0-1-2-3
- even though total distance sailed (660 nautical miles) is more than that of route 0-2-1-3 (480 nautical miles).
- Reason: heavier cargo is delivered first

If F > $450/day



- Optimal route: 0-2-1-3
- Different speeds in each leg
- Speeds depend on F (higher if F increases)

Possible barrier to slow steaming

- Some spot charter agreements force ships to sail at a specific speed (which may be higher than the optimal one)
- Result: ships go faster in laden leg and slower in ballast leg (whereas the reverse is typically the case if speeds are chosen freely) → MORE CO_2!
- Market imperfection: Possible issue for regulatory action?

Enter the speed limiters!

- 2 ways to regulate speed:

- (A) Indirect way: Via EEDI
- (B) Direct way: Mandate it (set a speed limit)

Energy Efficiency Design Index (EEDI)

- Defined as

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

- Ratio of installed power divided by (capacity* speed) [gr CO_2/ton-mile]

EEDI contd

- Mandatory for newbuildings
- All will have to have: EEDI ≤ EEDI ref. line
- Ref. line = f(ship type, DWT) = $a(DWT)^{-c}$
- Ref. line more stringent in future years

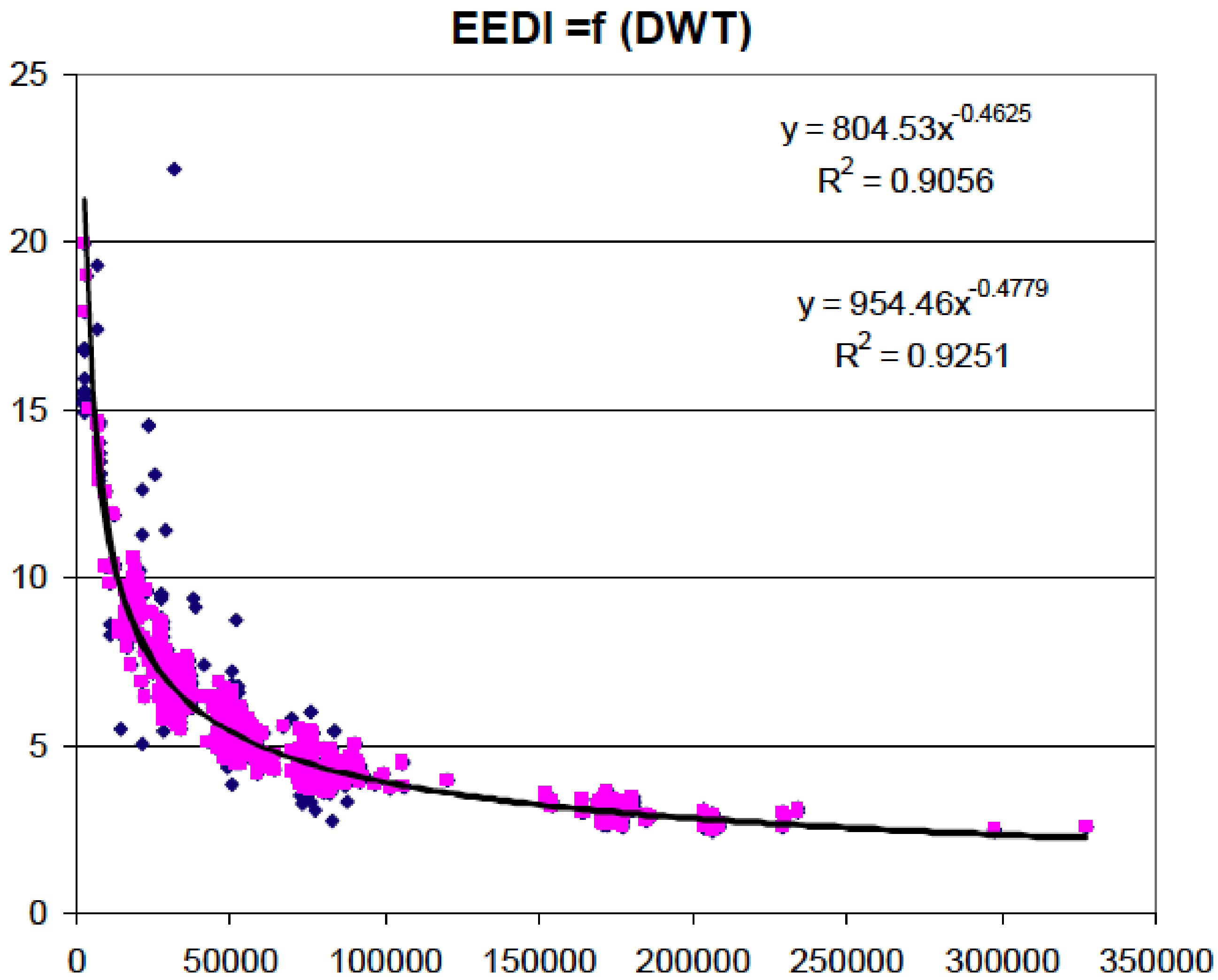


Figure 1: Dry bulk carriers

All data: 2,259 ships. Without outliers (shown in blue ◆): 2,218 ships

Concerns

- To reach required EEDI, **the correct solution** would be to **optimize hull, engine and propeller**
- **The easy solution** would be to **reduce design speed**
- This could lead to **underpowered ships**
- More CO2 to maintain speed in bad weather
- It could also lead to **modal shifts**

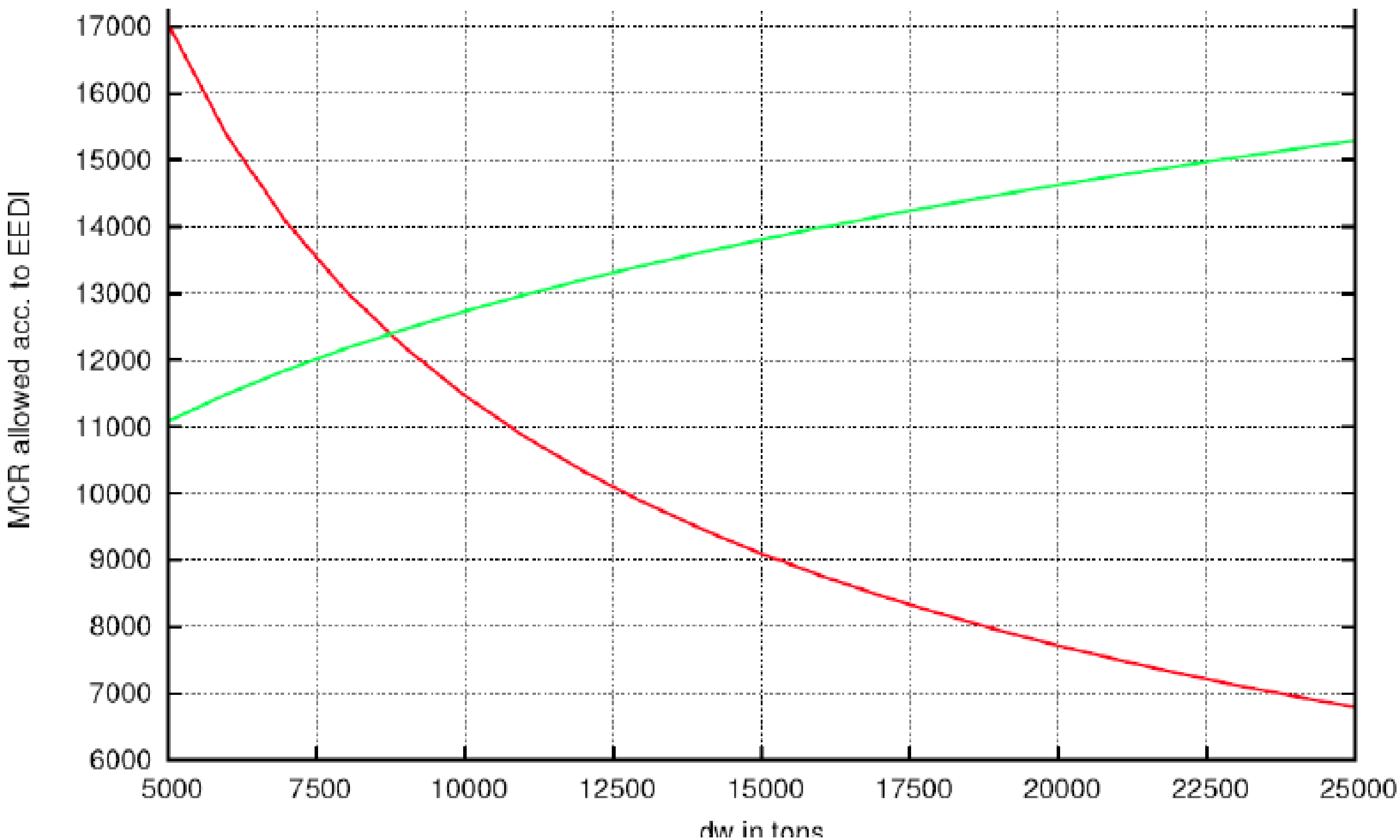
Compromise on safety?

- A ship needs to have adequate power to maintain speed in bad weather, manoeuvering, etc
- IACS et al submission at MEPC 62 (minimum power requirements)
- ICS submission at MEPC 62 (minimum safe speed of 14 knots)

Prof. Krüger's analysis

- Max allowable power to be EEDI-compliant GOES DOWN as ship size goes up
- Among all ship types, only containerships do not have this problem!
- Problem particularly acute for Ro/ro's.

Ro/ro breakdown



Setting a speed limit

- If speed limit is ABOVE optimal slow steaming speed, superfluous
- If speed limit is BELOW optimal slow steaming speed, distortions may occur

- SHORT TERM: higher freight rates
- LONG TERM: build more ships than you need

Parenthesis: direct speed limits at IMO

- Proposal by Clean Ship Coalition at MEPC 61: *"Speed reduction should be pursued as a regulatory option in its own right and not only as possible consequences of market-based instruments or the EEDI."*

- The proposal was NOT supported: *"The Committee agreed that speed considerations would be addressed indirectly through the EEDI, the SEEMP and by a possible market-based mechanism and, therefore, decided that no further investigation of speed reductions as a separate regulatory path was needed."*

Speed limits distortions

- Building more ships to match demand throughput
- Increasing cargo inventory costs due to delayed delivery
- Increasing freight rates due to a reduction in ton-mile capacity
- Inducing reverse modal shifts to land-based modes (mainly road)
- Implications on **SAFETY**.

More ships to match demand throughput

- Total fuel cost is still lower, BUT:
- More ships means more CO_2 due to shipbuilding and scrapping (life cycle analysis)
- It also means more maritime traffic, with negative implications on safety
- More port congestion
- More crews to fly around (more aviation CO_2)
- Etc etc

Another side-effect of speed reduction

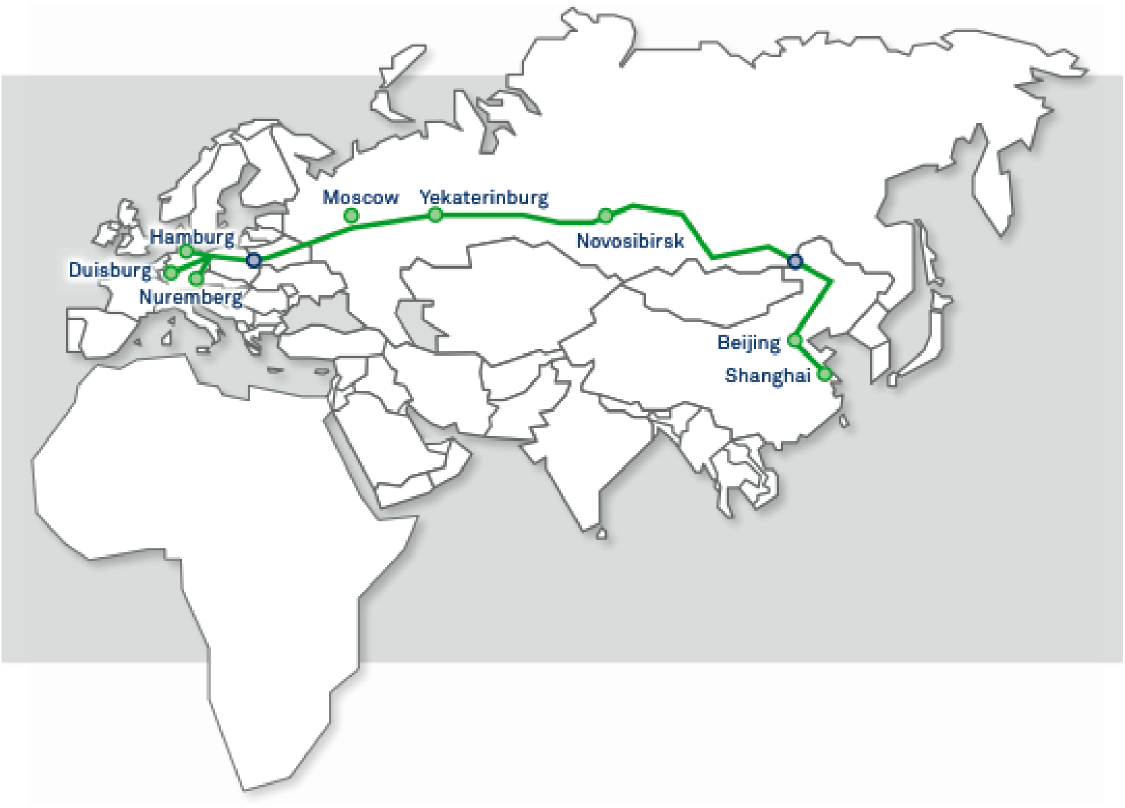
- Cargo may shift to land-based modes, if these are available
- This may result in more CO_2

- European short-sea shipping
- Even in deep-sea shipping

Possible modal shifts: Tran-siberian railway example

- Psaraftis, H.N., Kontovas, C.A. (2010) "Balancing the Economic and Environmental Performance of Maritime Transportation", Transportation Research D 15, 458-462

TEE
TRANS EURASIA EXPRESS



Trans-siberian railway

Far East to Europe by boat

- 43,000 km
- 7.8 gr CO_2/tkm at full speed
- **Reduce speed by 40%**
- **2.8 gr CO_2/tkm at reduced speed**
- 150,000 tons of cargo produce **18,000 tons of CO_2**

Far East to Europe by rail

- 12,000 km
- Cargo arrives 26 days earlier
- Lower inventory costs
- **18 gr CO_2/tkm**
- 150,000 tons of cargo produce **32,000 tons of CO_2**

Net result

- TOTAL ΔCO_2 may be >0 or <0, depending on scenario
- Result unclear for more complex network scenarios
- Reducing CO_2 in one mode may result in more CO_2 overall
- **SHORT SEA SHIPPING MAY ALSO SUFFER FROM SPEED REDUCTION, AS CARGOES MAY SHIFT TO ROAD (RESULT: MORE CO2)- EU TRANSPORT POLICY IS JUST THE OPPOSITE**

Last but not least: safety

- Setting speed limits will reduce installed engine power
- But a ship needs to have adequate power to maintain speed in bad weather, manoeuvering, etc
- IACS et al submission at MEPC 62 (minimum power requirements)
- ICS submission at MEPC 62 (minimum safe speed of 14 knots)

MEPC 63: last Feb-March

MEPC 63 cont’d

- EEDI

- Continued discussion on how to best implement it
- Adoption of guidelines

Guidelines adopted

- 2012 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships;
- 2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP);
- 2012 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI); and
- Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI).

MBM proposal groups

- International GHG Fund (Denmark et al) (LEVY)
- Emissions Trading Schemes (Norway, UK, France, Germany)
- Various hybrids, based on EEDI (USA, Japan, WSC)
- Port-based (Jamaica)
- Rebate mechanism (IUCN)
- Bahamas proposal

MEPC 63: Greece's proposal

- Keep on table only Levy and ETS proposals
- Put on hold hybrid MBMs (US, Jap., WSC)
- Discard all others (Bahamas, Jamaica, IUCN)

MEPC 63: Greece's proposal

- Keep on table only Levy and ETS proposals
- Put on hold h[illegible]brid MBMs (U[illegible] Jap., WSC)
- Discard all othe[illegible] Jamaica, IUCN)
- **KEEP ALL ON [illegible]ABLE**

MEPC 63

- Draft Resolution on Technical Co-operation and Transfer of Technology

- Brought forward by developing countries (China, India, Brazil, etc)

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- **NO CONSENSUS**

Opposition

MEPC 63

- Proposal for an Impact Assessment Study on MBMs
- Brought forward by the Chairman of MEPC
- Supported by developed countries

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- Supported by [illegible]tries

- **NO CONSENS[illegible]**

Opposition

Enter European Commission!

- Has supported IMO process, BUT:
- Has stated very clearly that if IMO drags its feet, EU will proceed on its own
- Specifically, if no decision by EU-27 by Dec. 31, 2011, Commission will develop its own proposals
- IMO decision on EEDI: not enough

What will the EU propose?

- Rumor: ETS (like in airlines)
- Officially: all options open
- Several studies under way
- Some stakeholders are against **regional** measures

2011 Transport White Paper

- Sets a goal of reducing GHG emissions from transport (all modes) by 60% by 2050
- IMO has equally ambitious goals to reduce EEDI by 30% by 2030

- Main challenge: how can international shipping grow and be profitable in the face of such ambitious environmental goals

Conclusions

- Slow steaming may serve the dual goal of profitable and greener shipping
- Have to be careful however not to confuse slow steaming with speed limits, as this may create distortions and other undesirable side effects
- A holistic approach is recommended so as to not lose the forest for the trees

Thank you very much!

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