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The Economic Operational Speed of a Time-Chartered Ship – A Cash-Flow Approach

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Based on joint work with Dominic Hudson (Shell professor of ship safety and efficiency, UoS) and Fangsheng Ge (PhD student, UoS, supported by Southampton Marine and Maritime Institute)

A working paper can soon be obtained on request from the author.

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Aims of talk

- Present a novel methodology to help explain how firms make optimal ***vessel speed decisions*** when using a time-chartered ship
- Focus on ***bulk carriers and tankers*** (42% of total merchant fleet, and 70% of global fleet deadweight capacity)
- Model analysis supports view that, ***ceteris paribus***, ship operators will benefit from choosing different speeds subject to ***charter contract conditions***.
- Research project proposal: invitation for expressions of interest

Decision environment

Ton-mile supply


Photo: Nordic Tankers

Hundreds of carriers trapped following OW Bunker crash

Fleet size

New arrivals, retirements, layups

Average steaming speed

Weaker demand and higher BFO price – ships slow down

Ship owners & Charterers

Speed and performance disputes

BFO prices

Ship design

Hull, engines, propellors, fuel type, CO2 design index

Ship Maintenance

Hull fouling; prevention & cleaning

Voyage

Distance, route, weather & water

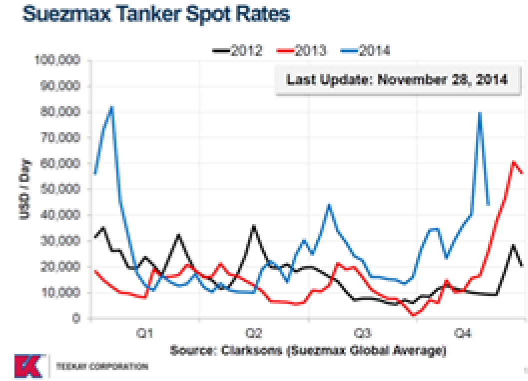
Port operations

Charges, efficiency, demurrage

Ton-mile demand

Global economy, stockpiling, strategic reserves, seasonal effects, maintenance

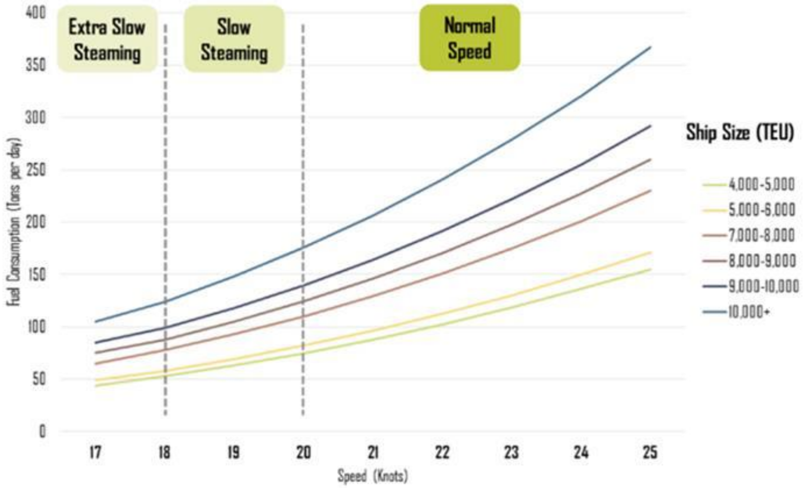
Spot rates



Contracts

Design, banks & creditors

Speed: trade-off



Source: adapted from Notteboom, T. and P. Carriou (2009) "Fuel surcharge practices of container shipping lines: Is it about cost recovery or revenue making?". Proceedings of the 2009 International Association of Maritime Economists (IAME) Conference, June, Copenhagen, Denmark.

- Lower speeds reduce daily fuel costs but also annual revenue potential
- Daily cost: e.g. $F(v) = \left(\frac{v}{v_o}\right)^3 F_o$ (Propeller law for ton fuel/day) or
  $F(v,W) = k\,(p + v^g)(W + A)^h$ (incl. deadweight W dependency)
- Long-term cycles ('7-years freight cycles') shows trends in long-term average speeds to match supply of ship type to transport demand.
- Short-term supply ('J-curve') shows how ship-owner set speeds such that marginal cost equals freight rate (or puts ship into lay-up).

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Prakash et al. (2016)

- Studied Panamax and Capesize dry bulk and Suezmax and VLCC tanker charter markets using empirical data from 2012 to 2015. They observed that actual speeds on both ballast and laden legs vary widely, and that ships travel at all available speeds within the vessel's range.

- Some illustrations taken from their report:

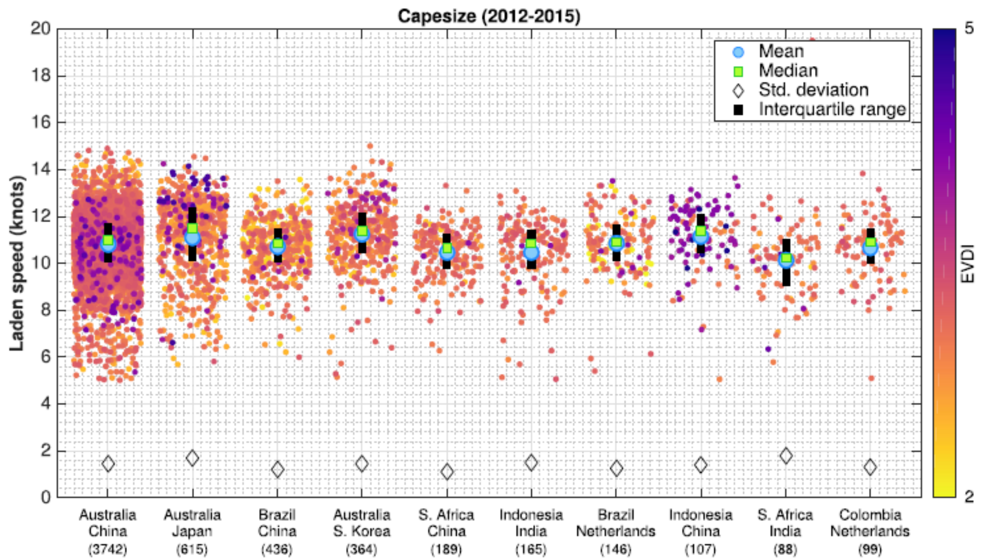


Figure 14: Laden speed for the Capesize fleet by route

Prakash et al. (2016)

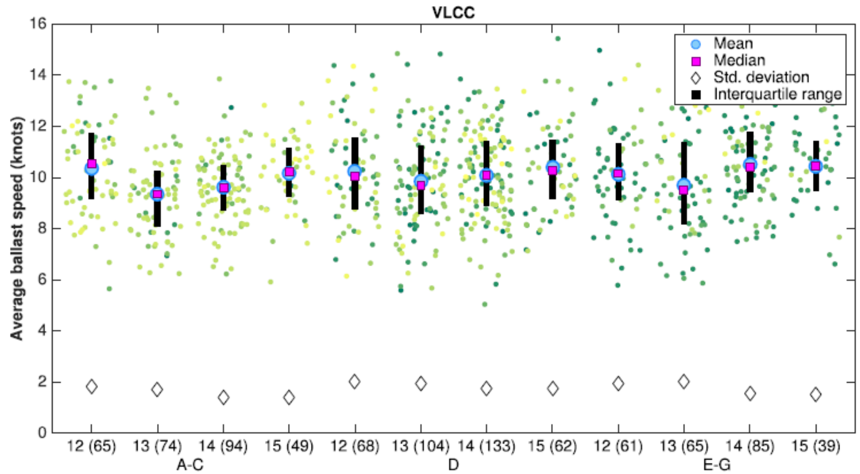
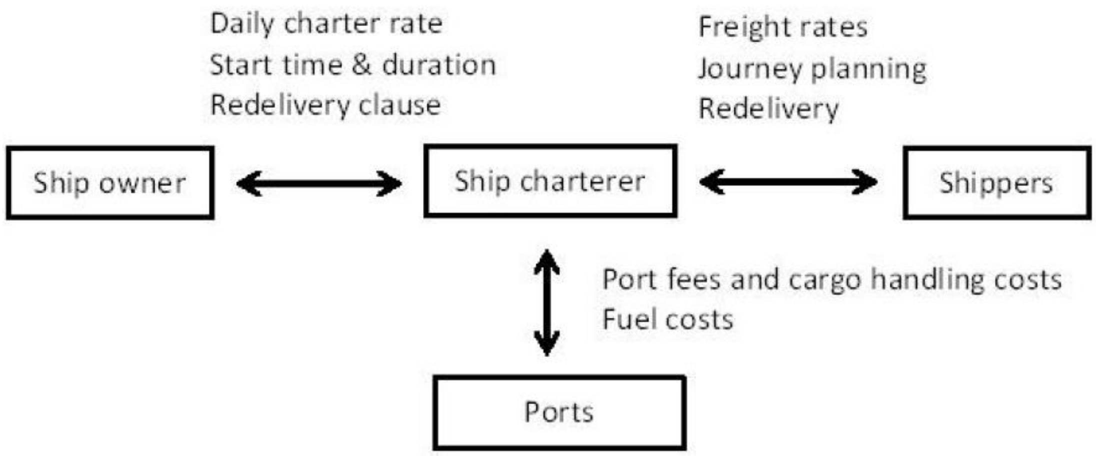


Figure 7: Annual average ballast speeds for the VLCC fleet

- "There is significant operational variability (especially in speed) within any given GHG Rating category, but no clear explanation can be attributed to why ships in the same category are operated at significantly higher or lower speeds than the median or average. …" (p.8, key finding 6)
- "Vessel speed remains a variable that is hard to fully explain or attribute, and significant variability exists within fleets of similar ship type, size, and technical specifications (including GHG Rating). Given speed's significance to operational energy efficiency, further work that examines the drivers of speeds will be important for understanding the sector's GHG emissions." (p. 10, implications for research.)

Charter contract



- Ship owner carries costs of crew, repair, maintenance, lubricants, supplies and capital costs.
- Charterer concerned with revenues and costs related to cargo handling, including costs of loading and unloading at ports, and main and auxiliary fuel costs.

Typical contract includes:

- Duration of charter party (H)
- Time charter hire (f^{TCH}), daily rate paid out by charterer to owner
- Redelivery clause, where and when to return vessel (e.g. $H \pm 45$ days)

Methodology

- The charterer's objective function is to maximise the Net Present Value (NPV) of the activity by taking a set of decisions $x \in X$:

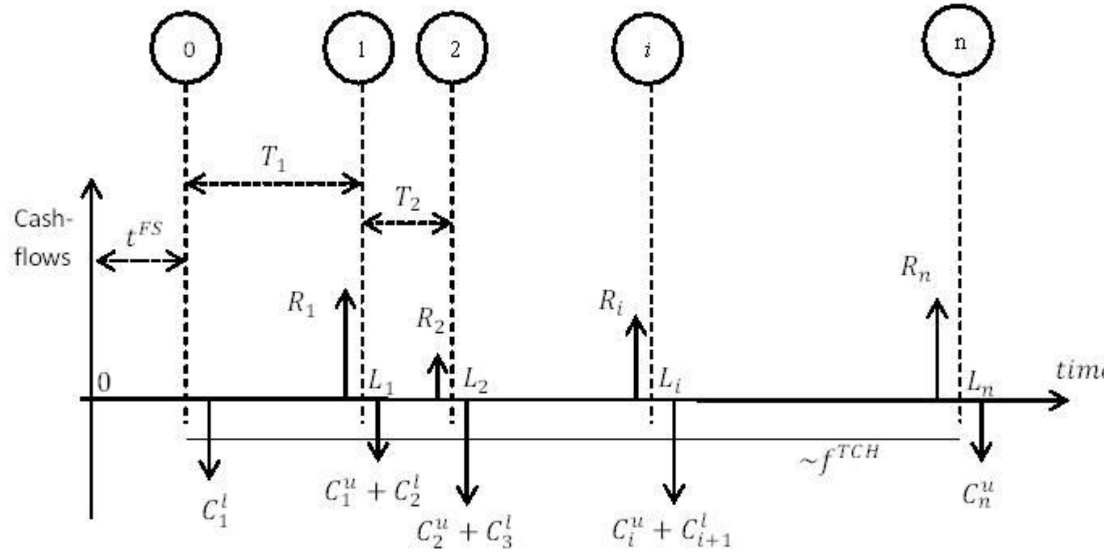
$$X^*(\alpha) = \arg\max \int_0^{H^*(x)} a(t,x)e^{-\alpha t}dt$$

subject to constraints.

- Cash-flow function $a(t,x)$ accounts for the timing of payments and NPV criterion ensures optimality with respect to opportunity cost of capital.

- Can account for the combined impact of ship characteristics, logistics decisions, and contract specifications.

Model set-up



- We define a ***journey*** of a single chartered ship as a scenario in which the ship visits a set of $n+1$ ports $(i = 0, 1, \dots, n)$.
- A ***leg*** i $(i = 1, \dots, n)$ is the process of moving the ship from port $i-1$ to i. The time T_i consists of: loading time at port $i-1$, sea voyage time to port i, waiting time at port i, and unloading time at port i. (Can include ballast legs.)
- Let v_i be the speed on the sea voyage of leg i, and $V_i^- = \{v_1, \dots, v_i\}$ and $V_i^+ = \{v_i, \dots, v_n\}$. The ***leg completion time*** $\boldsymbol{L_j}$ of leg j is then:

$$L_j(V_j^-) = \sum_{i=1}^{j} T_i(v_i),$$

where L_n represents the duration of the journey.

Three models P_1, P_M and P_∞

- **Model $\boldsymbol{P_1}$.**

$$\text{Max } NPV(V_n^-, \alpha);\ \text{subject to } v^- \le v_i \le v^+, \forall v_i \in V_n^-,$$

$$\text{where } NPV_1(V_n^-, \alpha) = \left[\sum_{j=1}^{n}\left(R_j e^{-\alpha(L_j-\delta_j)} - C_j^u e^{-\alpha(L_j+\varepsilon_j)} - C_j^l e^{-\alpha(L_{j-1}+\varepsilon_{j-1})}\right) - \frac{365 f^{TCH}(1-e^{-\alpha L_n})}{\alpha}\right] e^{-\alpha t_{FS}}$$

- **Model $\boldsymbol{P_M}$.** Let M be the **number of journey repetitions:**

$$\text{Max} \quad NPV_M(V_n^-, M, \alpha) = NPV_1 \frac{1-e^{-\alpha M L_n}}{1-e^{-\alpha L_n}};$$

$$\text{subject to } v^- \le v_i \le v^+, \forall v_i \in V_n^-, \text{ and } ML_n(V_n^-) \le H.$$

- **Model $\boldsymbol{P_\infty}$.** Let $\boldsymbol{M} \to \infty$**:**

$$\text{Max } AS(V_n^-, \alpha) = NPV_1 \frac{\alpha}{1-e^{-\alpha L_n}};\ \text{subject to } v^- \le v_i \le v^+, \forall v_i \in V_n^-$$

Special cases P_1 and P_∞

Using NPV Equivalence Analysis (Beullens and Janssens, 2014) , it can be shown that

- P_1
  - is the NPV equivalent of classic models that *maximise profits per nautical mile*, as in e.g. Psaraftis and Kontovas (2014), Corbett et al. (2009), Wen et al. (2017), … and many, many more articles.
  - represents the case of a trip time charter, where the duration H of the contract is part of the optimal decisions, and ***where the future use of the ship is irrelevant to the decision maker***.
- P_∞
  - is the NPV equivalent of classic models that *maximise the profits per unit of time*, as in Ronen (1982), Devanney (2010), and Fagerholt and Psaraftis (2015).
  - represents the idealised case of a time charter of very long duration (or the case of ship owners planning their own voyage charters), where it is assumed that ***the journey being optimised will be repeated at infinitum***.

Special cases P_1 and P_∞

- Comparison to classic models PK and R

Table 1: Optimal speeds for a laden-ballast journey

Variable / Model	P_1	P_∞	PK	R
v_1 (kn)	10.9	14.0	12.9	17.0
v_2 (kn)	12.5	16.3	12.5	12.5
L_n (days)	66.9	53.4	62.0	55.5
NPV (USD)	1,612,022	10,041,286 (*)	1,576,804	8,828,658 (*)
f^{TCE} (USD/day)	44,281	47,510	45,621	44,188

(*) AS (USD/year)

- Decomposition principle = optimal speed of a leg independent of speeds chosen on other legs, adopted in classic models.
- The decomposition principle adopted in classic models no longer holds in the NPV framework, because of the opportunity costs (rewards) of delayed future revenues (costs).
- A theorem proofs that maximising profits per unit of time using decomposition produces large errors as it will put too much emphasis on legs of relatively shorter duration. The approach only makes sense when optimising over the complete roundtrip journey time.

Special cases P_1 and P_∞

Table 3: Main drivers of ship speeds and profitability

Parameter / Model	P_1 speeds	P_1 NPV	P_∞ speeds	P_∞ AS
Fuel prices	$--$	$--$	$--$	$--$
Dwt carried	$--$	n/a	$--$	n/a
Freight rates	$+$	$++$	$++$	$++$
Time Charter Hire	$++$	$--$	0	$--$
Leg distance (with linearly increasing revenues)	$+\epsilon$	$+$	$+$	$+$
Leg distance (at constant revenues)	0	$--$	$--$	$--$
Fixed (un)loading costs	$-\epsilon$	$--$	$--$	$--$
Harbour times	0	$-$	$-$	$-$

- Assumptions about the future usage of the vessel greatly affect speed decisions.
- Reducing time spend in harbours will keep optimal vessel speeds either equal or increase speeds (in contrast to "expectation", see also Johnson and Styhre, 2015)
- Fagerholt and Psaraftis (2015) ignore harbour times "as it is constant" and maximise profits per unit of time over a single leg. Results from P_∞ show both these assumptions are weak in that this will not result in speed decisions maximising the NPV of the firm.
- Corbett et al. (2009) model a situation in which ships are used repeatedly but find optimal speeds from maximising profits over a single leg, a model ~ P_1. NPV shows that under these assumptions a model ~P_∞ or ~P_M(see further) will produce better results!

General case P_M

- For contracts of finite horizon H, P_M is superior to approaches whereby optimal speeds are determined from either P_1 or P_∞ first, and then fitting the optimal number of repetitions in the horizon.

Table 4: Performance of repeated laden-ballast journeys

Variable / Model	P_1	P_∞	P_M
$H = 335$ (days)			
H^* (days)	334.4	320.5	334.8
M^* (-)	5	6	6
v_1 (kn)	10.9	14.0	13.4
v_2 (kn)	12.5	16.3	15.5
NPV (USD)	7,828,927	8,514,068	8,829,191
$H = 268$ (days)			
H^* (days)	267.5	267.1	268.0
M^* (-)	4	5	5
v_1 (kn)	10.9	14.0	13.9
v_2 (kn)	12.5	16.3	16.3
NPV (USD)	6,308,705	7,136,261	7,158,921
$H = 365$ (days)			
H^* (days)	334.4	320.5	364.6
M^* (-)	5	6	7
v_1 (kn)	10.9	14.0	14.4
v_2 (kn)	12.5	16.3	16.8
NPV (USD)	7,828,927	8,514,068	9,618,736

General case P_M

NPV of charter contract in USD.

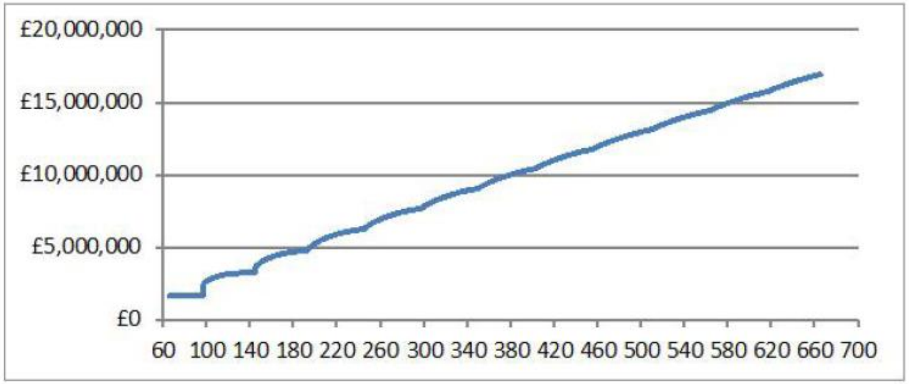


Figure 4: Optimal NPV profit (USD) as a function of H (days) in the base case example

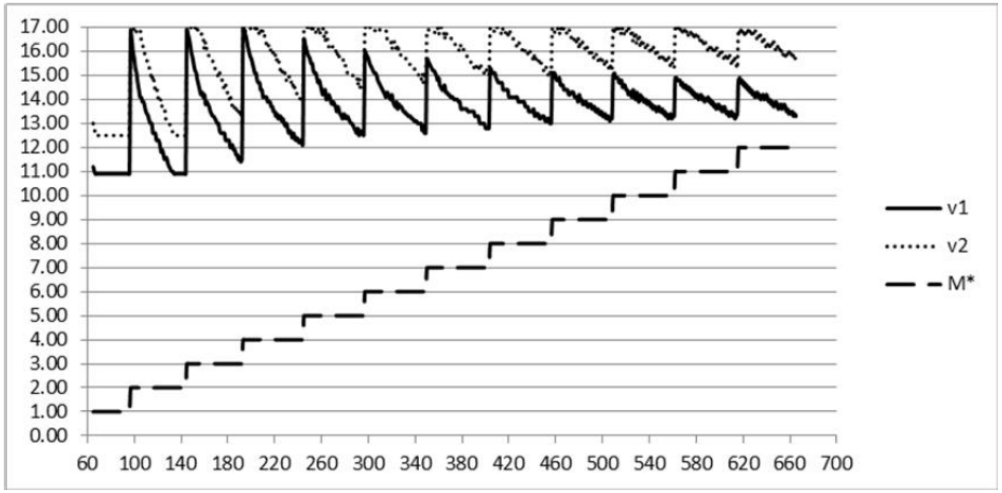


Figure 3: Optimal leg speeds (kn) and repetitions as functions of H (days) in the base case example

General case P_M

Impact from changes to parameter values on optimal speed values now highly dependent on:

- If M* remains constant: whether the contract horizon constraint is binding or non-binding
- If M* changes: speeds can change dramatically.

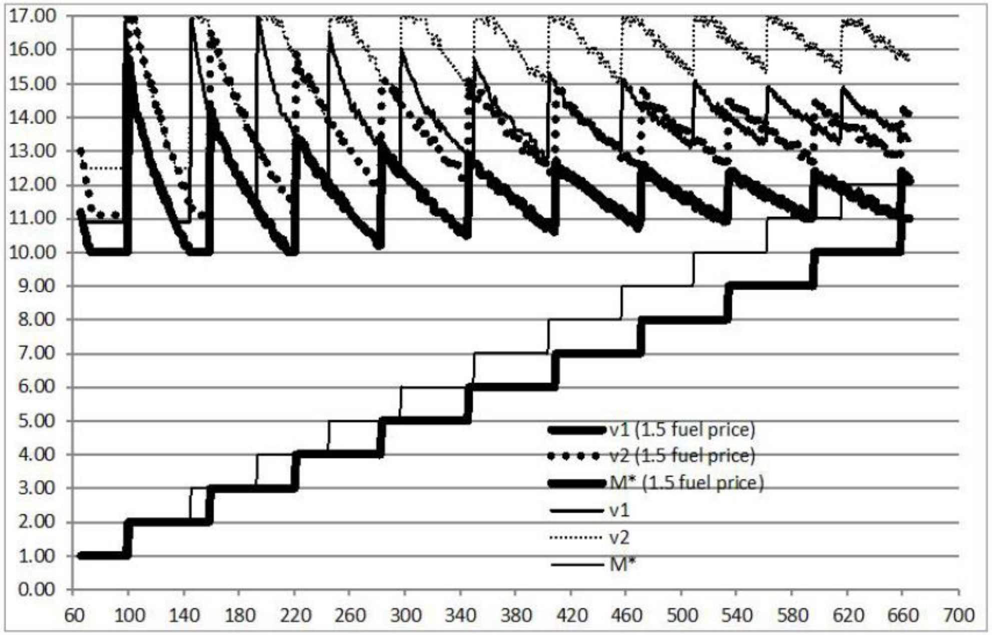


Figure 5: Optimal leg speeds and number of repetitions (fuel prices x 1.5)

Table 6: Main drivers of ship speeds in model P_M

Parameter / Model	P_M speeds (*)	P_M speeds (**)	M^* (***)	P_M speeds (***)
Fuel prices	≈ 0	$-$	$-$	$--$
Freight rates	≈ 0	≈ 0	$+$	$++$
Time Charter Hire	≈ 0	$+$	$-$	$--$
Fixed (un)loading costs	≈ 0	≈ 0	$-$	$-$
Harbour times	$+$	≈ 0	$-$	$-$

(*) For constant M^* such that $H^* \approx H$;
(**) for constant M^* such that $H^* << H$;
(***) for changes leading to new optimal M^* value.

Redelivery clause

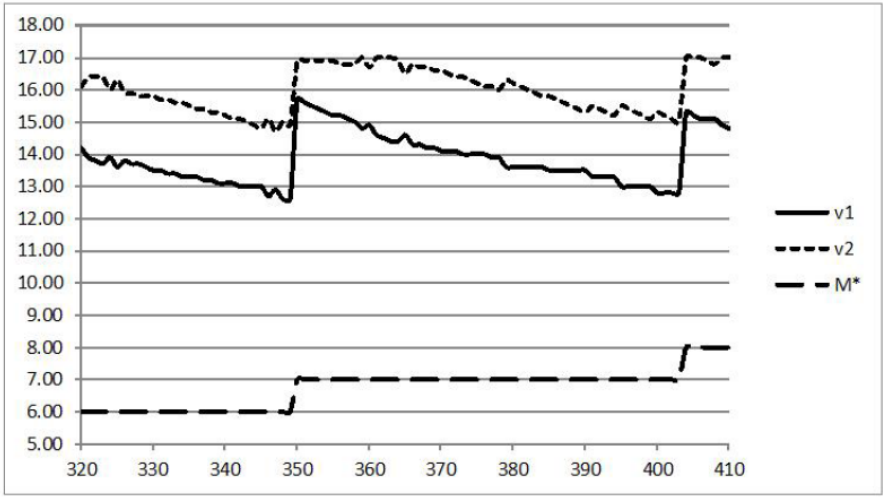


Figure 8: Close-up of Figure 3: $H = 365 \pm 45$ days

Target completion date	**V1 (laden)**	**V2 (ballast)**	**M***	**Buffer (risk measure)**
H + 45 days	15.0 kn	17.0 kn	8 journeys	0 days
H + 34 days	13.0 kn	15.0 kn	7 journeys	11 days

- Redelivery clause: Gives rise to a range of available speeds ("speed menu"). Depending on the approach to risk taking, charterers may end up making different choices for undertaking the (first few) journeys on the charter contract.

Decision dynamics

Charterer	V1 (laden)	V2 (ballast)	Ln
I	14.0 kn	16.3 kn	53.4 days
II	13.0 kn	15.0 kn	57 days

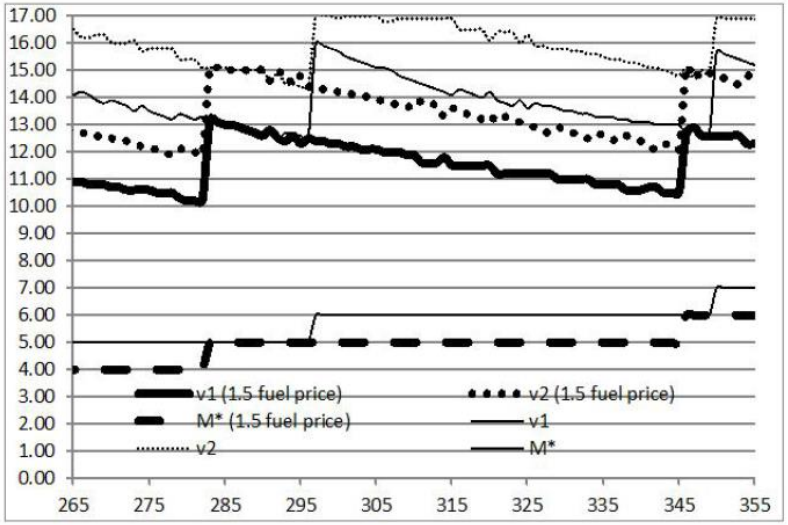


Figure 6: Close-up of Figure 5 for $H \in [265, 355]$.

- If fuel prices rise by factor 1.5 after first journey completed:

Charterer	New Buffer	V1 (laden)	V2 (ballast)	Ln
I	25 days	11.0 kn	12.6 kn	66.4 days
II	8 days	10.5 kn	12.1 kn	69.0 days

Fuel price rise has dramatic impact for both charterers.

- If fuel prices rise by factor 1.5 after four journeys completed:

Charterer	New Buffer	V1 (laden)	V2 (ballast)	Ln
I	6 days	11.6 kn	13.3 kn	63.3 days
II	2 days	12.3 kn	14.2 kn	60.0 days

Adjustments of speeds are result of updating info on uncertainty.

Fuel price rise has no impact on the decisions.

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Findings

- The optimal speed of a time-chartered ship is dependent on the economic trade-off between revenues and costs over the relevant future of the decision maker.
- Unlike classic models, decomposition is not an optimal algorithmic approach as speed choices on individual current voyages in the NPV framework are affecting the profit potential of the vessel's relevant future.
- The models developed are first to show how speed decisions are dependent on the charter contract:
  - trip time charters (USD/mile) are a special case leading to very different speed choices
  - models that maximise profits per unit of time (USD/day) are too idealised as they assume that the future is exactly the same as the present.
  - for regular time charter contracts, time remaining on the contract, redelivery clause details and attitude to risk taking determine speed choices and adjustments.
- Optimisation of the NPV over the relevant future is in general not equal to maximising Time Charter Equivalent Earnings (USD/day).

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Research project

- EEDI and EVDI provide theoretical GHG ratings, and as efficient ships should in theory be more economical, will these help the market to self select towards a preference for GHG efficient ships?
- Actual emissions are highly dependent on actual operational factors (speed, deadweight carried, hull condition, weather, …)
- Different technologies for retrofitting or newbuilding (see e.g. Craig Eason, 2015, Lloyd' List report) affect speed performance of a vessel, and valid speed ranges, differently. These will thus affect operational factors, and relative competitiveness of a vessel
- Who makes the investment in retrofitting or newbuilding green technologies and who reaps the operational rewards? In a charter contract setting, this creates split incentives.
- Charter contract clauses (duration, time charter hire, fuel performance guarantees, redelivery conditions, …) affect operational factors.

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Research project

- The NPV framework is highly suited to study such problems that need the explicitation of logistics decisions, ship characteristics, and contract types.
- Our current NPV models can handle different ship characteristics and thus the relative operational effectiveness of various green initiatives on a ship's optimal economic operational performance.
- The models are currently extended to include:
  - time-varying data (e.g. port-specific and time-dependent freight rates, bunker prices, …)
- We are keen to further develop approaches to handle
  - uncertainty from weather, port congestion/handling
  - incorporate broker/market aspects (expected local competition at port for next voyages)
  - investigate how to arrive at contracts in charter markets that offer better outcomes for owners and charterers
  - (… your ideas here!)

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Invitation to expressions of interest

A research project in the making for submission mid to late summer 2018

Would you like being part of the steering committee to direct the research questions and provide feedback on intermediate results, or become an active partner by providing data or test cases?

Please get in touch!

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