Information barriers in shipping: Assessing effects on stakeholder decision-making with respect to the energy efficiency of vessels in the time charter market

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A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

UCL Energy Institute
December 2020
Declaration

I, Jean-Marc Bonello confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Jean-Marc Bonello
Abstract

Given the increasing pressure for emission reduction through the Paris Agreement and the International Maritime Organisation’s emission reduction ambition set in 2018, energy performance in shipping is more important than ever. Several studies have identified information barriers lead to uncertainty around energy efficiency and vessel performance. This prevents more efficient vessels from being rewarded and discourages the uptake of energy efficiency technologies and operational measures. Poor in-service data quality, suboptimal performance modelling and information asymmetry between stakeholders regarding vessel performance result in challenging decision-making when choosing energy efficiency technologies, operational measures or when fixing a vessel for a charter. There is very little literature focused on investigating decision-making practices in relation to vessel and technology performance to expose specific problems related to information use.

This work explores these problems and evaluates the effect of information related shortcomings in vessel efficiency on decision-making in deep sea cargo shipping. A mixed-methods approach is proposed, starting with an exploratory case study. The aim is to understand the use of information and identify information asymmetries encountered by all parties involved when making decisions on fixtures or energy efficiency technology selection. The insights from
the case study are used to develop a probabilistic techno-economic model which quantifies uncertainties arising from identified information asymmetries and the impact they have on different stakeholders. A game theoretic framework is used as a basis for the model. As a third step, solutions to reduce uncertainty are tested. These solutions are focused on increasing transparency between stakeholders and are shown to provide a mutually beneficial scenario for both charterers and owners. The novel model developed can be used as a tool to evaluate risk stemming from stakeholder behaviour and the impact this has on operating profit for owners and charterers based on assumptions related to information flow and use. The work is aimed towards creating an evidence base for targeted commercial tools and policy designed to promote and reward vessel efficiency by bridging the information gap between technical and commercial sides of the shipping industry.
Impact statement

This work is intended to develop a greater understanding of how information barriers affect the international shipping sector’s behaviours with regards to energy performance. It is envisaged to drive the market to become more transparent in its sharing and use of performance data, encouraging technical development and adoption at scale. It provides a tool for creating an evidence base to help inform sector stakeholders and policy makers towards better environmental decisions in shipping practice. This can extend to decisions such as fixing vessels, energy efficiency technology investment, contracting and operational practice.

Individual players such as charterers and owners can becoming independent in their strategic responses to energy and climate change issues if they have enough information to do so. This model developed in this thesis can empower stakeholders to develop positive commercial responses to a wide variety of economic, technical and policy interventions. This can stimulate stakeholders to be more ambitions in transparency initiatives, to reduce uncertainty regarding vessel performance and have a better understanding for financial and environmental risk in their operations.

The model can be used to identify gaps in the current transport supply market and provide evidence for financing more efficient new builds with zero-
emissions technologies. This will be especially important if market-based measures related to environmental constraints are launched.

International shipping has significant societal impacts; from free movement of goods and people to negative health impacts from pollution and global greenhouse gas emissions. Regional, national and port authorities are introducing a raft of regulations and requirements regarding the operation of ships in sensitive areas. Subsequently, this model will empower charterers to take a proactive approach decisions on each individual charter to minimise environmental impact while driving up the demand for more efficient vessels. This in turn stimulates investment and employment in the production of greener vessels and upskills the workforce in new energy technology. The reduction of market barriers could also lead to the development of new business paradigms for example the bringing together of charterers and ship builders and owners.
The research work disclosed in this publication is partially funded by the Endeavour Scholarship Scheme (Malta). Scholarships are part-financed by the European Union - European Social Fund (ESF) - Operational Programme II – Cohesion Policy 2014-2020 “Investing in human capital to create more opportunities and promote the well-being of society”.

European Union – European Structural and Investment Funds Operational Programme II – Cohesion Policy 2014-2020 “Investing in human capital to create more opportunities and promote the well-being of society” Scholarships are part financed by the European Union - European Social Funds (ESF) Co-financing rate: 80% EU Funds; 20% National Funds
Dedication

To my grandparents.
Acknowledgements

Sincere thanks go to the Rocky Mountain Institute, especially James Mitchell, for jointly funding this research. I am eternally grateful to Dr Tristan Smith and Dr Nishatabbas Rehmatulla for their invaluable guidance, industry connections and for making me instantly welcome in the shipping research group at the UCL Energy Institute. The same gratitude is expressed to all the shipping team at the EI and UMAS, past and present.

Special thanks to my partner, parents and friends for supporting me throughout this journey, warts and all.
Contents

Acronyms \hspace{1cm} 24

1 Introduction \hspace{1cm} 26

2 Literature review \hspace{1cm} 29

\hspace{1cm} 2.1 The energy efficiency gap in shipping and barriers to improvement \hspace{1cm} 29
\hspace{1cm} 2.2 Options for energy efficiency measures and technologies \hspace{1cm} 33
\hspace{1cm} 2.3 Information barriers \hspace{1cm} 36
\hspace{1cm} \hspace{1cm} 2.3.1 Imperfect information \hspace{1cm} 36
\hspace{1cm} \hspace{1cm} 2.3.2 Asymmetric information \hspace{1cm} 43
\hspace{1cm} 2.4 Decision-making and energy efficiency in shipping \hspace{1cm} 50
\hspace{1cm} \hspace{1cm} 2.4.1 Rewarding energy efficiency \hspace{1cm} 53
\hspace{1cm} 2.5 Summary of findings \hspace{1cm} 57

3 Methodology and research questions \hspace{1cm} 60

\hspace{1cm} 3.1 Research question design \hspace{1cm} 60
\hspace{1cm} 3.2 Proposed research methodology \hspace{1cm} 63
\hspace{1cm} 3.3 Summary \hspace{1cm} 77

4 Qualitative case study \hspace{1cm} 79

\hspace{1cm} 4.1 Aim and objective \hspace{1cm} 79
4.2 Case study construct design ........................................ 79
4.3 Data collection ....................................................... 82
  4.3.1 Semi-structured interviews ................................ 84
  4.3.2 Technical documentation .................................. 85
  4.3.3 In-service data ................................................ 87
4.4 Data analysis ......................................................... 92
  4.4.1 Semi-structured interviews ................................ 92
  4.4.2 Technical documentation .................................. 103
  4.4.3 In-service data ................................................ 106
4.5 Discussion ............................................................. 110
  4.5.1 Structure and stakeholder involvement ................. 112
  4.5.2 Information and data use in decision-making .......... 113
4.6 Chapter Summary .................................................. 114

5 Quantitative modelling of stakeholder interaction .......... 118
  5.1 Aim and objectives .............................................. 118
  5.2 Chartering mechanics .......................................... 120
    5.2.1 Performance clause analysis ............................. 121
  5.3 Theoretical mapping of stakeholder interaction in chartering . 125
    5.3.1 Game design .............................................. 125
    5.3.2 Utility function definition ............................... 129
  5.4 Quantitative modelling ......................................... 133
    5.4.1 In-service data pre-processing for performance modelling 135
    5.4.2 Performance model ....................................... 145
    5.4.3 Strategic performance declaration ..................... 150
    5.4.4 Charterer estimate of bunker ........................... 153
    5.4.5 Expected operating profit estimate .................... 155
    5.4.6 Baseline scenario ....................................... 158
5.5 Results ................................................................. 166
  5.5.1 Performance modelling ........................................ 166
  5.5.2 Charterer perspective ......................................... 169
  5.5.3 Strategic performance declaration ........................... 170
  5.5.4 Performance claim determination ............................ 173
  5.5.5 Owner perspective ............................................ 175
5.6 Chapter Summary ................................................ 175

6 Uncertainty reduction and transparency measures 180
  6.1 Aims and objectives ............................................. 180
  6.2 Proposed transparency measures ............................... 180
  6.3 Data quality and acquisition method for improved model quality 184
    6.3.1 Data collection frequency and measurement error ....... 184
    6.3.2 Length of dataset .......................................... 187
  6.4 Performance modelling for supporting transparency .......... 190
    6.4.1 Weather based parametric models ......................... 190
  6.5 Information asymmetry reduction .............................. 197
    6.5.1 Communication of vessel performance in consumption clauses ............................................. 197
  6.6 Integration of operational vessel efficiency in contracting - an EET application ........................................... 205
    6.6.1 Utility function adaptation ................................ 206
    6.6.2 Quantitative modelling ...................................... 216
  6.7 Chapter summary ................................................ 226

7 Discussion .......................................................... 229
  7.1 Research in context ............................................. 229
  7.2 Appropriateness of method and theoretical framing .......... 231
List of Figures

2.1 Focus of research within the EE barrier framework (Rehmatulla and Smith [2015a]) ................................. 30
2.2 The barriers encountered in shipping (Jafarzadeh and Utne [2014]) 32
2.3 Sources of uncertainty in in-service data-based vessel performance models (Aldous et al. [2015]) .................. 40
2.4 Stakeholder relationship diagram for shipping (Rehmatulla [2014]) 45
2.5 Principal-agent cash-flow for TC and VC (adapted from Rehmatulla and Smith [2015a]) ................................. 48
2.6 PA models for moral hazard and adverse selection (adapted from Rasmusen [2007]) ................................. 49
3.1 Research methodology framework ................................. 63
3.2 PA model for adverse selection with signalling representing voyage charter (Bergantino and Veenstra [2002]) .... 74
3.3 PA model for adverse selection adapted from Rasmusen [2007] 75
3.4 Model development cycle (Refsgaard and Henriksen [2004]) 75
3.5 Research methodology and thesis framework ................................. 78
4.1 Method framework - Chapter 4 ................................. 80
4.2 Embedded mixed methodology design ................................. 81
4.3 Hypothesised relationship diagram for EE retrofit implementation
4.4 Revealed relationship diagram for EER implementation (parties directly involved in case study highlighted)
4.5 Themes and associated overarching questions
4.6 Methodology for performance estimation from in-service data
4.7 Illustrative example of power-speed characteristics for speed loss evaluation
4.8 Typical performance indicator (denoted as H in this case) time series plot showing reference (R) and evaluation (E) periods (BSI, 2016a)
4.9 Entity-relationship diagram based around MPP vessel
4.10 Technical department structure within SM company
4.11 Speed loss time series following BSI (2016b), before and after corrections denoted by shading
4.12 Speed loss time series with 6 month reference and evaluation periods for interventions including dataset start
4.13 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic
5.1 Method framework - Chapter 5
5.2 Typical TC routine showing stakeholders and information flow during pre-fixture and charter execution
5.3 Two-player game framework
5.4 Pay-off matrix for information asymmetry in owner-charterer dynamic
5.5 Techno-economic model schematic showing key inputs
5.6 Speed-consumption performance model development
5.7 Draught time series and loading condition allocation
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.8</td>
<td>Pre (left) and post (right) basic filtering</td>
</tr>
<tr>
<td>5.9</td>
<td>Histograms showing the primary variables before filtering</td>
</tr>
<tr>
<td>5.10</td>
<td>Histograms showing the primary variables after filtering</td>
</tr>
<tr>
<td>5.11</td>
<td>SOG and STW comparison for CM (left) and NR (right) data</td>
</tr>
<tr>
<td>5.12</td>
<td>Speed-consumption scatters for different loading (left) and weather conditions (right)</td>
</tr>
<tr>
<td>5.13</td>
<td>Speed-consumption curve, laden condition, NR data</td>
</tr>
<tr>
<td>5.14</td>
<td>Speed-consumption curve, ballast condition, NR data</td>
</tr>
<tr>
<td>5.15</td>
<td>Speed-consumption curves in common commercial format</td>
</tr>
<tr>
<td>5.16</td>
<td>Model residual histograms for loading conditions</td>
</tr>
<tr>
<td>5.17</td>
<td>QQ model residual plots for loading conditions</td>
</tr>
<tr>
<td>5.18</td>
<td>Residual scatters against speed and weather</td>
</tr>
<tr>
<td>5.19</td>
<td>Warranted based TPD on speed-consumption curve</td>
</tr>
<tr>
<td>5.20</td>
<td>Frequency distribution for $T\frac{PD}{wHT}$ based on quadratic model including uncertainty</td>
</tr>
<tr>
<td>5.21</td>
<td>Scatter plot of measured data set for determination of days liable to performance claims based on single point warranted performance</td>
</tr>
<tr>
<td>5.22</td>
<td>Scatter plot of measured data set for determination of days liable to performance claims based on the speed-consumption curve</td>
</tr>
<tr>
<td>5.23</td>
<td>Market conditions for product Handymax (Clarksons 2018b)</td>
</tr>
<tr>
<td>5.24</td>
<td>Annual consumption in relation to sailing days (dashed line showing 95% CI)</td>
</tr>
<tr>
<td>5.25</td>
<td>Proportion of time and annual bunker consumption consumed on days above BF4</td>
</tr>
<tr>
<td>5.26</td>
<td>Speed distribution for laden condition (CM data)</td>
</tr>
</tbody>
</table>
5.27 Measured and fitted speed distributions used as input to the model in HT cases ........................................ 164

5.28 Modelling schematic for HT bunker estimate ........................................ 165

5.29 Bunker consumption and charterer operating profit estimates under different transparency regimes .......................... 169

5.30 Effect of owner strategic warranty declaration on bunker consumption estimate ........................................ 171

5.31 GT pay-off matrix - baseline case ........................................ 172

5.32 Percentage of days sailing liable to performance claims and prospective claim value ........................................ 173

5.33 Effect of strategic $TPD_w$ change on bunker consumption and using only laden warranted performance (left) and laden and ballast (right) ........................................ 174

5.34 GT pay-off matrix - baseline case, including HT-based claim ........................................ 176

6.1 Method framework - Chapter 6 ........................................ 181

6.2 Speed-consumption curve, ballast condition, CM data ........................................ 186

6.3 Speed-consumption curve, laden condition, CM data ........................................ 187

6.4 Speed-performance curve, laden, 3 months, CM data ........................................ 188

6.5 Sensitivity of annual fuel consumption estimate to dataset length, CM data ........................................ 189

6.6 Speed-consumption curves, ballast, CM data, power law fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest ........................................ 191

6.7 Speed-consumption curves, laden, CM data, power law fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest ........................................ 192
6.8 Speed-consumption curves, ballast, CM data, quadratic fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest 193

6.9 Speed-consumption curves, laden, CM data, quadratic fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest 194

6.10 Parametric performance model, power law fit, ballast (left) and laden (right) 195

6.11 Weather condition probability distribution - CM data 196

6.12 Parametric model annual consumption estimation 196

6.13 Bunker and charterer operating profit estimates under different transparency regimes - Parametric model 201

6.14 GT pay-off matrix - parametrised performance model 202

6.15 Determination of days liable to performance claims with parametric speed-consumption curve 203

6.16 Effect of application of performance variation margin on fuel overconsumption and days involved 204

6.17 GT pay-off matrix - parametrised performance model with 5% variation allowance 205

6.18 Propeller duct tow tank test performance (adapted from Svardal and Mewis [2011b]) 212

6.19 Assumed power reduction distribution characterising performance of EET 213

6.20 Estimated daily bunker savings 219

6.21 Daily savings and consumption distribution 219

6.22 Annual savings and consumption distribution 220

6.23 GT pay-off matrix - with EET 221
6.24 Charterer cost comparison for extreme Cases 1.1 and 2.2  
6.25 Charterer cost comparison for extreme Cases 1.1 and 2.2 - normalised  
6.26 Bunker and charterer operating profit estimates under different transparency regimes - with EET  
6.27 Break-even point based on average annual savings  
7.1 Performance based smart contracting clause  
A.1 Flowchart for application of ISO 19030 to vessel in-service data (BSI, 2016b)  
A.2 Speed loss time series with 6 month reference and evaluation periods for interventions including dataset start  
A.3 NR power-speed scatter for filtered dataset including trial characteristic  
A.4 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic  
A.5 Case 1 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic  
A.6 Case 2 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic  
A.7 Case 3 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic  
A.8 Case 4 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic  
A.9 Speed analysis for Suezmax vessels and warranted speed deviation from design speed  
A.10 Delta speed and consumption for Suezmax sample fleet
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Emission reduction technologies and measures with associated reduction potential (adapted from Bouman et al. (2017))</td>
<td>34</td>
</tr>
<tr>
<td>2.2</td>
<td>Stakeholder decisions and required information</td>
<td>37</td>
</tr>
<tr>
<td>2.3</td>
<td>Stakeholder cost allocation associated with charter markets</td>
<td>44</td>
</tr>
<tr>
<td>4.1</td>
<td>Sources used for case study data collection</td>
<td>83</td>
</tr>
<tr>
<td>4.2</td>
<td>List of key informant interviews</td>
<td>85</td>
</tr>
<tr>
<td>4.3</td>
<td>Four-part interview structure</td>
<td>86</td>
</tr>
<tr>
<td>4.4</td>
<td>Size of dataset (in days) for variables measured</td>
<td>90</td>
</tr>
<tr>
<td>4.5</td>
<td>Interventions for performance improvement</td>
<td>91</td>
</tr>
<tr>
<td>4.6</td>
<td>Steps in the retrofit decision-making process as elicited by the case study</td>
<td>98</td>
</tr>
<tr>
<td>4.7</td>
<td>Comparison of speed loss dependant on reference period</td>
<td>109</td>
</tr>
<tr>
<td>4.8</td>
<td>Information barrier categories and artefacts identified</td>
<td>115</td>
</tr>
<tr>
<td>4.9</td>
<td>Identified shortcomings in data and performance modelling</td>
<td>116</td>
</tr>
<tr>
<td>4.10</td>
<td>Identified information asymmetries</td>
<td>117</td>
</tr>
<tr>
<td>5.1</td>
<td>Summary of TC performance clause analysis</td>
<td>121</td>
</tr>
<tr>
<td>5.2</td>
<td>Player optimum outcome classification</td>
<td>126</td>
</tr>
<tr>
<td>5.3</td>
<td>Overall typical vessel characteristics</td>
<td>136</td>
</tr>
</tbody>
</table>
5.4 Sequential data filtering outcome on dataset size . . . . . . . . 138
5.5 Measurement error associated with fuel consumption moni-
    toring (Aldous 2015, Faber et al. 2013, Hunsucker et al. 2018) . 142
5.6 Annual operating profile data . . . . . . . . . . . . . . . . . . 159
5.7 Benchmark operating profile and market assumptions . . . . . 161
5.8 Description of modelling scenario assumptions . . . . . . . . . 165
5.9 Performance model statistics . . . . . . . . . . . . . . . . . . 166
5.10 Baseline results showing estimated bunker consumption and
    expected operating profit for owner and charterer . . . . . . . . 169
5.11 Baseline scenario results - including claims . . . . . . . . . . . 175
5.12 Summary of model insights and comparison to literature and
    case study findings . . . . . . . . . . . . . . . . . . . . . . . 178

6.1 Proposed barrier mitigation strategies to increase transparency
    and reduce uncertainty . . . . . . . . . . . . . . . . . . . . . 184
6.2 Performance models - CM data . . . . . . . . . . . . . . . . . 185
6.3 Performance model annual fuel estimate comparison - dataset
    length . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 189
6.4 Parametric model annual fuel estimate comparison - fit type . . . 195
6.5 Example of proposed performance declaration . . . . . . . . . . 199
6.6 Description of increased transparency modelling scenario as-
    sumptions - parametric models . . . . . . . . . . . . . . . . . 200
6.7 Baseline scenario - parametrised performance model results . . 200
6.8 Drivers and barriers related to EET implementation for owners
    and charterers . . . . . . . . . . . . . . . . . . . . . . . . . . 207
6.9 Utility function terms definition . . . . . . . . . . . . . . . . . 208
6.10 Description of modelling scenario assumptions - introduction of
    EER . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 217
6.11 Benchmark operating profile, market and EER assumptions . . 218
6.12 Baseline scenario - application of EET implementation . . . . 221

A.1 Data retention statistics (after filtering and normalisation as per BSI (2016b)) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 261
A.2 Performance models - NR Data - 3 months . . . . . . . . . 276
A.3 Performance models - HR Data - 3 months . . . . . . . . . 276
A.4 Performance models - CM Data - 3 months . . . . . . . . . 277
A.5 Performance models - NR Data - 6 months . . . . . . . . . 277
A.6 Performance models - HR Data - 6 months . . . . . . . . . 277
A.7 Performance models - CM Data - 6 months . . . . . . . . . 278
A.8 Performance models - HR data - all dataset . . . . . . . . . 278
Acronyms

AIS Automatic Identification System
ANN Artificial Neural Network
BAU Business-As-Usual
BDN Bunker Delivery Note(s)
BF Beaufort
CAPEX Capital Expenditure
CFD Computational Fluid Dynamics
CI Confidence Interval
CII Carbon Intensity Index
CM Continuous Monitoring
CoV Coefficient of Variation
CP Charter Party
DAQ Data Acquisition
DCS Data Collection System
DD Dry-Docking
EE Energy Efficiency
EEP Energy Efficiency Premium
EER Energy Efficiency Retrofits
EET Energy Efficiency Technology(ies)
EPC Energy Performance Certification
ESCO Energy Service Company(s)
EU European Union
EVDI Existing Vessel Design Index
FOC Fuel Oil Consumption
GHG Greenhouse Gas(es)
GPS Global Positioning System
GT Game Theory
HC Hull Cleaning and Coating
HT High Transparency
IM Investment Manager
IMO International Maritime Organisation
IRR Internal Rate of Return
ISO International Standards Organisation
KPI Key Performance Indicator(s)
LT Low Transparency
MC Monte Carlo
Chapter 1

Introduction

Shipping has been shown to contribute approximately 3% of Greenhouse Gas (GHG) emissions in 2018, with that figure expected to reach 90 - 130% of 2008 levels by 2050 if no action is taken (Faber et al., 2020). After many years of debate, the International Maritime Organisation (IMO) set the course for the reduction of emissions from shipping by at least 50% of 2008 levels by 2050 at Marine Environment Protection Committee (MEPC) 72 (IMO, 2018). Given these projections and emission reduction ambition, it is becoming clear that the shipping industry must make a step change in order to keep up with the global drive towards decarbonisation (Lloyd’s Register and UMAS, 2019).

This increased environmental pressure has been accompanied by a sustained down turn in markets since 2009 (UNCTAD, 2020), resulting in a very competitive scenario with excess tonnage and shrinking margins (Faber and ‘t Hoen, 2015). With bunker costs making up a significant proportion of voyage costs of merchant vessels (Stopford, 2009), efficiency is a high priority for fleet managers and owners, with most having strategies in place to improve fleet performance (DNV-GL, 2015, Rehmatulla, 2012, Rehmatulla et al., 2015, Rojon and...
Financing institutions have rallied with schemes such as the Poseidon Principles (Poseidon Principles Association 2021) and the Climate Bonds Initiative (CBI 2020). These schemes seek to motivate financing of assets based on their operational performance and alignment to the emission reduction ambitions to mitigate obsolescence risk and stranded assets.

Energy Efficiency (EE) is one of the routes by which ships can reduce their emissions through operational or technological interventions (Bouman et al., 2017; Xing et al., 2020). Several solutions have been developed to improve vessel EE, however, these have struggled with uptake which is low even for measures with short payback periods (Faber, Behrends and Nelissen, 2011; Poulsen and Sornn-Friese, 2015; Rehmatulla and Smith, 2015b; Wang et al., 2010).

Information barriers have been consistently found to be one of the more significant market failures hindering decision-making related to EE. On the vessel owner side, this concerns appraisals of Energy Efficiency Technology(ies) (EET) while for charterers, it involves the selection of vessels to fix (Johnson and Andersson, 2016; Rehmatulla and Smith, 2015b).

In addition to information barriers, low quality data and information overload around vessel performance also make decision-making challenging (Eppler and Mengis, 2004; Jafarzadeh and Utne, 2014; Rehmatulla and Smith, 2015a). Another layer of complexity is added due to stakeholder relationships in shipping which harbour a lot of information asymmetry. This information asymmetry arises from lack of transparency and due to split incentives emerging from the nature of chartering practices. This further increases uncertainty when it comes to making decisions on EET investment and prohibits better performing
vessels on the market from being rewarded (Agnolucci et al., 2014, Poulsen and Johnson, 2016, Poulsen and Sornn-Friese, 2015).

This research sets out to investigate the role of information asymmetries and data quality within decision-making related to vessel performance and EET uptake in shipping. The research will identify shortcomings of current practice and explore opportunities to increase transparency and reduce uncertainty. While these opportunities do not guarantee an increase in overall EE and emission reductions, they will help inform discussions on vessel and technology appraisals for both owners and charterers. They will also inform decisions taken by industry stakeholders including financiers, regulators and policy makers.

In the following chapter, an overview of current literature surrounding information barriers, decision-making and EE in shipping will be critically analysed to identify gaps. Through this, research questions and methodology proposal will be elucidated in Chapter 3.
Chapter 2

Literature review

This chapter sets out the current literature landscape relevant to this research covering three main themes: EE gap and barrier theory, information barriers and stakeholder decision-making with regards to energy performance in shipping. The structure sequentially covers over-arching barrier theory then focuses on information barriers and how these barriers affect decision-making with regards to vessel selection and EET selection. Drawing on research in other industries as well as shipping, this chapter reviews the current state-of-the-art literature to identify gaps that the research in this thesis will attempt to bridge.

2.1 The energy efficiency gap in shipping and barriers to improvement

Despite the availability of techno-economical viable solutions towards EE for stakeholders, investment is restricted due to various barriers (Sorrell et al.)
This situation, known as an efficiency gap, is defined by [Brown (2001)] as the difference between the actual level of investment in EE and the higher level of investment that would be cost effective when considering the increased performance. Interview and survey based studies have shown an uptake by between 50% and 65% of respondents for EE measures despite ease of implementation of operational measures and EET with short payback periods (Faber, Behrends and Nelissen, 2011; Poulsen and Sornn-Friese, 2015; Rehmatulla and Smith, 2015b; Wang et al., 2010).

A significant body of work has been carried out to identify and classify barriers to EE in different contexts, largely based on classical economics (Blumstein et al., 1980; Jaffe and Stavins, 1994; Sorrell et al., 2004, 2000; Thollander et al., 2010; Weber, 1997). An overview of the barriers generally identified in barrier theory literature is presented in Figure 2.1 (with those being focused on in this work highlighted). More comprehensive explanations and examples of specific barriers found in Thollander et al. (2010) and Sorrell et al. (2004).

Figure 2.1: Focus of research within the EE barrier framework (Rehmatulla and Smith, 2015a)
The application of barrier theory to energy efficiency (EE) in shipping is a relatively young field of literature. Most studies rely on interviews or surveys with a small sample size (usually less than 20) of industry experts and stakeholders (Faber et al., 2012, Jafarzadeh and Utne, 2014, Johnson and Andersson, 2016). In some cases, these studies are limited to one sector or a particular technology (Johnson et al., 2014, Nelissen et al., 2016, Rehmatulla et al., 2015). Rehmatulla and Smith (2015a) take a statistical approach based on a large scale survey with 150 respondents (Rehmatulla, 2012) and identify market failures as the main barrier to implementation of EE measures. They single out inter-organisational (split incentive, lack of control due to owner-charterer relationship) information barriers and problems raising capital as the main challenges. This corroborates findings by Faber et al. (2012) and Maddox Consulting (2012).

Capturing most of the findings from general EE barrier work in shipping, Jafarzadeh and Utne (2014) develop the categorisation shown in Figure 2.2 while proposing a framework for overcoming the barriers identified. Given the importance of information barriers noted in all literature related to shipping, this is chosen to be the focus of this study as they are also found to be the root cause for other barriers, more specifically, the imperfect and asymmetric information barriers. Whilst acknowledging all barriers present specific challenges and sustain an EE gap, literature covering information barriers in shipping is limited to mostly qualitative analysis or quantitative uncertainty studies which focus on the challenges to performance. These two types of analysis are not considered together leaving a gap that has been overlooked.
Figure 2.2: The barriers encountered in shipping (Jafarzadeh and Utne, 2014)

<table>
<thead>
<tr>
<th>Barriers Level</th>
<th>Dimensions Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information barriers</td>
<td>- The lack of information</td>
</tr>
<tr>
<td>Economic barriers</td>
<td>- The overload of information</td>
</tr>
<tr>
<td>Intra-organizational barriers</td>
<td>- New-building contracts not including information technologies</td>
</tr>
<tr>
<td>Inter-organizational barriers</td>
<td>- Not using information</td>
</tr>
<tr>
<td>Technological barriers</td>
<td>- Not maintaining information</td>
</tr>
<tr>
<td>Policy barriers</td>
<td>- The inaccuracy of information</td>
</tr>
<tr>
<td>Geographical barriers</td>
<td>- The improper form of information</td>
</tr>
</tbody>
</table>

- Cultural differences regarding the required information
- Adverse selection
- Moral hazard and principal-agent relationships
- The lack of credibility and trust in the source of information
- Variations in circumstances
- Changing staff
- The lack of interest in investing in information (technologies)

- Limited access to capital
- External risk
- Business risk
- Hidden costs
- Heterogeneity
- Imperfect budgeting
- Unrealistic basis for cost-benefit analyses

- Organizational culture
- Uncertainty
- Bounded rationality
- The lack of power
- The lack of trust in the organization
- The lack of time
- Crew's lack of competence
- Not maintaining training
- Managers without technical background
- Communication problems
- The lack of trust in technologies

- Split incentives
- The ownership of vessels
- Difference in risk perception

- Incompatibility between technologies and ship types
- Incompleteness
- Technical risk
- Interference with main processes
- The complexity of measures
- Improvement likelihood
- Incompatibility between technologies and operations
- Mutually exclusive energy saving measures

- Conflicting regulations
- Piracy area
- The route dependency of energy efficiency
2.2 Options for energy efficiency measures and technologies

Ship owners have several options for improving energy efficiency (EE) through operational measures and technologies that are intended to reduce inefficiencies arising due to design or operating factors. Bouman et al. (2017) provide an extensive literature review of available technologies and measured to reduce greenhouse gas (GHG) emissions. These can be broadly grouped into five categories: hull design, power and propulsion systems, alternative fuels, alternative energy sources and operational. Several sources discuss the potential emissions reductions for these options (Bouman et al., 2017; Hüffmeier and Johanson, 2021; Xing et al., 2020) and develop marginal abatement cost curves (Faber, Behrends and Nelissen, 2011; Faber et al., 2020) linking GHG abatement potential and costs.

Table 2.1 presents the potential CO$_2$ reduction range based on an extensive review of literature. The range of reduction for some is very wide expressing the variability of estimated or measured savings based on different assumptions and applications of the same technologies and measures. One should also note that the interaction between technologies is also challenging to model especially and does not necessarily lead to a summation of the reduction of each individual technology.

Broadly speaking, the options presented in Table 2.1 can further be classified based on the ease, cost and time required for implementation. Firstly, technologies such as changing to alternative fuels and hull design involve high capital expenditure and significant design considerations in the design phase. Air lubrication systems (Silberschmidt et al., 2016) and wind assist (Chou et al., 2021) offer such an example of an EE technology that has to be implemented
Table 2.1: Emission reduction technologies and measures with associated reduction potential (adapted from Bouman et al. [2017])

<table>
<thead>
<tr>
<th>Category</th>
<th>Emission reduction technology or measure</th>
<th>CO₂ reduction potential range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull design</td>
<td>Vessel size</td>
<td>4 - 83</td>
</tr>
<tr>
<td></td>
<td>Hull shape</td>
<td>2 - 30</td>
</tr>
<tr>
<td></td>
<td>Lightweight materials</td>
<td>0.1 - 22</td>
</tr>
<tr>
<td></td>
<td>Air lubrication</td>
<td>1 - 15</td>
</tr>
<tr>
<td></td>
<td>Resistance reduction devices</td>
<td>2 - 15</td>
</tr>
<tr>
<td></td>
<td>Ballast water reduction</td>
<td>0 - 10</td>
</tr>
<tr>
<td></td>
<td>Hull coating</td>
<td>1 - 10</td>
</tr>
<tr>
<td>Power and propulsion system</td>
<td>Hybrid power/propulsion</td>
<td>2 - 45</td>
</tr>
<tr>
<td></td>
<td>Power system/machinery</td>
<td>1 - 35</td>
</tr>
<tr>
<td></td>
<td>Propulsion efficiency devices</td>
<td>1 - 25</td>
</tr>
<tr>
<td></td>
<td>Waste heat recovery</td>
<td>1 - 20</td>
</tr>
<tr>
<td></td>
<td>On board power demand</td>
<td>0.1 - 3</td>
</tr>
<tr>
<td>Alternative fuels</td>
<td>Bio fuels</td>
<td>25 - 84</td>
</tr>
<tr>
<td></td>
<td>LNG</td>
<td>5 - 30</td>
</tr>
<tr>
<td>Alternative energy sources</td>
<td>Wind power</td>
<td>1 - 50</td>
</tr>
<tr>
<td></td>
<td>Fuel cells</td>
<td>2 - 20</td>
</tr>
<tr>
<td></td>
<td>Cold ironing</td>
<td>3 - 10</td>
</tr>
<tr>
<td></td>
<td>Solar power</td>
<td>0.2 - 12</td>
</tr>
<tr>
<td>Operational measures</td>
<td>Speed optimisation</td>
<td>1 - 60</td>
</tr>
<tr>
<td></td>
<td>Capacity utilisation</td>
<td>5 - 50</td>
</tr>
<tr>
<td></td>
<td>Voyage optimisation</td>
<td>0.1 - 48</td>
</tr>
<tr>
<td></td>
<td>Other operational measures</td>
<td>1 - 10</td>
</tr>
</tbody>
</table>
early in the vessel design cycle and requires substantial investment.

A second category of technologies includes those that can be retrofitted or applied with some modifications to existing vessels such as changes in bulbous bow design (Luo and Lan, 2017), addition of hydrodynamic energy-saving devices (Prins et al., 2016) or changing of propellers due to engine derating. These interventions are usually undertaken due to a change in operating profile from the vessels design point (speed and/or draught) and come at a lower cost than the examples mentioned previously. Given that these technologies are retrofitted on vessels that are already operational, a period of down time when the vessel is out of service needs to be factored into the sunk costs of implementation.

Finally, operational measures and periodic maintenance can be grouped in a further category of measures that involve low initial investment and exploit the operational changes as a means of increasing EE. Weather routing, speed optimisation (Zaccone et al., 2018), just-in-time and virtual arrival (Arjona Aroca et al., 2020, Jia et al., 2017, Kontovas and Psaraftis, 2013) and hull and propeller cleaning (Adland, Cariou, Jia and Wolff, 2018), Gundermann and Dirksen (2016) are examples of these measures that are considered to be low hanging fruit in terms of EE. A combination of all types of measures can be significantly more beneficial to vessels than if applied in isolation such as the combination of Flettner rotors and route optimisation (van der Kolk et al., 2019).

An interesting overlap between operational measures and the role of charter parties emerges given the implications of vessel behaviour. Thus the inclusion of clauses that consider these measures is essential to maximise the potential benefit and avoid incentivising the wrong behaviour. Adland and Jia
(2018) and Kontovas and Psaraftis (2013) show how, speed optimisation for just-in-time and virtual arrival are not only more energy efficient but also reduce demurrage payments.

An exhaustive list of references for the above technologies and operational measures can be found in Bouman et al. (2017), Hüffmeier and Johanson (2021), Xing et al. (2020).

2.3 Information barriers

The following sections present a critical analysis of research on information quality, availability and asymmetry, as these are particularly relevant to energy performance, as discussed in the previous section.

The term "information" in the subsequent sections refers to different pieces of data depending on the stakeholder in question and the decision at hand. Table 2.2 gathers the main items of information that will be discussed in this section and throughout this research. Some of the information is uncertain due to variation that is difficult to model such as performance of technologies under different metocean conditions and bounded rationality. However, elements such as the charterer not having an accurate idea of vessel performance, result from information asymmetry.

2.3.1 Imperfect information

Data collection and data quality

In ship performance literature, information barriers related to data availability, quality and accessibility are reported to result in a lack of transparency, thus
Table 2.2: Stakeholder decisions and required information

<table>
<thead>
<tr>
<th>Decision</th>
<th>Information required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charterer</td>
<td>Vessel selection • Vessel performance under range of conditions • Fuel savings from energy efficiency measure</td>
</tr>
<tr>
<td>Owner</td>
<td>Energy efficiency measure selection • Technology performance under different conditions • Fuel savings in operation • Capital investment • Payback period</td>
</tr>
</tbody>
</table>

Reducing confidence in technologies. Wang et al. (2010) find that decision-makers fear a real or perceived risk of technology failure due to lack of performance information. Through their survey, Rojon and Smith (2014) documented the demand for in-service performance guarantees provided by technology providers however, less than half of the participants were willing to pay the transaction costs associated with gathering in-service data. This often results in savings claims being based on simulations that cannot be replicated in operation (Johnson and Andersson, 2016, Wang et al., 2010). This is also experienced in the built environment where the theoretical and actual thermal insulating properties of walls are found to be significantly divergent (Li et al., 2015, Lowe et al., 2007).

The lack of standardised, verifiable vessel and technology energy performance information introduces uncertainty when creating a business case to raise capital for more efficient newbuilds and EET. Determining a payback using period-based appraisal becomes a problem (Faber et al., 2012, Rehmatulla and Smith, 2015a, Stulgis et al., 2014, Wang et al., 2010). This is especially significant for small ship owners that seek external financing, who struggle to present a strong business case due to the above as well as the added uncertainty related to freight and bunker rates (Faber et al., 2012, Rickard et al.)
(1998) note the necessity of better defining investment risks via long term measurement of performance. This would help mitigate the uncertainty caused by weather conditions for example.

This lack of validation of performance claims also has an adverse effect on the development and uptake of technologies. This is especially of concern to novel technologies that must build trust in their technology through proven performance. For solutions such as wind assist and air lubrication systems (Faber et al., 2012, Nelissen et al., 2016, Rehmatulla and Smith, 2015a, Silberschmidt et al., 2016), the onus is on the technology provider to collect, process and present data to inspire confidence in prospective clients despite no standardised methods for data collection and performance assessment.

The rigour of the methodology used is always up for discussion and, given the vested interest of the technology provider, may be perceived as biased. In an effort to mitigate this, independent third parties are introduced to verify claims, adding to cost and opacity (NAPA and Norsepower, 2016). A first effort towards transparency through standardisation was the development of ISO 19030 that specifies the collection, processing and interpretation of in-service data for monitoring hull and propeller performance (BSI, 2016a). However this has not had good uptake in general in the industry largely due to the baseline performance definition and considerations for the effect of metocean conditions on bunker consumption (Tsarsitalidis and Rossopoulos, 2018).

Vessel performance modelling and uncertainty

Performance modelling has seen much academic research and commercial development in recent years. Conventionally, vessel performance is based on the Noon Report (NR); a manually compiled report that contains a set of basic
measurements taken by the crew on board to document the ship’s progress, consumption and metocean conditions encountered daily. These reports are used for the technical performance evaluation, commercial chartering and economic performance evaluation of vessels as well as to compare vessels to their peers. DNV-GL (2015) found that half of respondents (N=80) to a survey relied on manual daily readings of data, ranging from fuel consumption to metocean conditions. This has been shown to lead to significant uncertainty when assessing vessel performance (Aldous et al., 2015, Meng et al., 2016). The low frequency data collection also limits the performance modelling that can be undertaken and increases the associated underlying uncertainty built into the model.

Aldous et al. (2013) discuss the implications of uncertainties related to using NR data to run a performance model (Figure 2.3). For example, measurements such as weather condition are instantaneous and may not be representative of the weather over the whole reporting period. This introduces human error along with instrumentation and averaging errors for each of the variables measured.

Continuous Monitoring (CM) high frequency systems can be an alternative but these come at a higher cost to install and maintain (especially if a retrofit) and create vast amounts of data that needs to be collected, stored, processed and analysed in order to get a return on the investment. However, this solution eliminates human error related to taking readings and misreporting, reduces measurement errors and allows for real time alerts to be implemented to assist the crew in decision-making and troubleshooting. CM has paved the way for the development of performance models that require large datasets, such as those using machine learning.
Figure 2.3: Sources of uncertainty in in-service data-based vessel performance models (Aldous et al., 2015)
The potential of high frequency in-service data used together with computational methods such as multivariate regression (Bocchetti et al., 2015; Yoo and Kim, 2019), Artificial Neural Network (ANN) (Bal Beşikçi, Arslan, Turan and Ölçer, 2016; Jeon et al., 2018; Petersen et al., 2012), analytic hierarchy process (Bal Beşikçi, Kececi, Arslan and Turan, 2016) and other machine learning applications has been widely recognised but not embraced by industry.

Haranen et al. (2016) give a good summary of the three approaches to performance modelling: white, black and grey box. Most of the above examples are black box models as they are designed to ingest a training dataset, usually consisting of in-service measured data, and build the model based on the relationship between the explanatory and predicted variable (usually fuel consumption or resistance). The robustness of these models comes from the quantity of data and the statistical rigour that is applied to characterise the variables.

White box models are based on physical relationships that based on the theory from first principles such as the resistance model by Höltrop and Mennen (1982). Grey box models try to exploit the benefits of both types of modelling in order to make modelling more accurate and efficient by defining some relationships (such as the Admiralty Law), while leaving other relations to be described computationally. Each of these methods has specific merits and disadvantages however a common weakness is the risk of overfitting data which requires specific strategies to mitigate against (Yoo and Kim, 2019).

These computational vessel performance models can also be adapted to estimate the effect of both EE technologies and measures. Bal Beşikçi, Kececi, Arslan and Turan (2016) apply their performance model based on an analytic hierarchy process to identify the most influential EE measures ranging from
maintenance to speed optimisation with the purpose of creating a decision-support system for selection by owners. Similarly, Kidd (2016) and Adland, Cariou, Jia and Wolff (2018) look at modelling the effect of hull fouling and cleaning aiming to optimise the timing of interventions and evaluate impact.

On the technology front, van der Kolk et al. (2019) combine hydrodynamic, aerodynamic, engine modelling and route optimisation to evaluating the potential fuel savings of Flettner rotors. While these mathematical models are increasing in accuracy, there is still some difficulty in verifying that the performance of these technologies can be replicated and measured in practice to validate effectiveness. Operational measures such as virtual arrival (Jia et al., 2017) and trim optimisation (Coraddu et al., 2017) also benefit from modelling in order to illustrate their potential operating in the field.

Despite the potential for computational grey and black-box models (Haranen et al., 2016, Paulescu et al., 2017) for vessel performance, most of the industry relies on speed-consumption curves. In these speed-consumption models, data collection, filtering criteria, curve fitting and accounting for measurement error are decided ad-hoc by the vessel owner or operator (Adland et al., 2020, Bialystocki and Konovessis, 2016).

While technical departments within shipping companies may be well adjusted to work with more accurate performance models, Karaminas and Shen (2016) identify a gap between the technical and commercial desks due to the reliance on speed-consumption curves by the latter. A potential charterer may be able to reverse engineer performance curves from a single operating point provided by the owner however, this requires making several assumptions which may lead to high uncertainty. It is also dependant on there being trust between the owner and charterer as to the veracity of the warranted performance point.
This information asymmetry makes bunker estimates on the charterer side difficult, creating uncertainty around potential operating costs when fixing a vessel.

### 2.3.2 Asymmetric information

In addition to low-quality data and lack of performance modelling standards, uncertainties arising from information asymmetries are common. This is because the commercial shipping system landscape has a lot of stakeholders (Figure 2.4). These stakeholders involved in a transaction or relationship have access to different information when compared to the other parties and do not share it. The concept of information asymmetry is usually framed by the Principal-Agent (PA) problem which has already been investigated in shipping ([Bergantino and Veenstra 2002](#), [Kontovas and Psaraftis 2013](#), [Rehmatulla and Smith 2015a](#)). A common example is ship-to-shore communication related to fuel consumption misreporting leading to inaccurate performance judgement ([Faber et al. 2012](#)). A more relevant example is the reliance of charterers on performance information from owners ([Bergantino and Veenstra 2002](#)).

Chartering practice introduces information asymmetries and split incentives due to the cost structures and stunted information flows. Three types of chartering are generally used in industry namely the **Voyage Charter (VC)**, **Time Charter (TC)** and bareboat. The difference lies in who bares the cost of different elements of owning and operating a vessel commercially (Table 2.3). More granular details regarding costs can be found in [Stopford (2009)](#).

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1 May also be referred to as tramp or spot charter.
Table 2.3: Stakeholder cost allocation associated with charter markets

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Bareboat</th>
<th>Time Charter (TC)</th>
<th>Voyage Charter (VC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo handling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voyage expenses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating expenses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital cost</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Owner revenue

<table>
<thead>
<tr>
<th>Owner revenue</th>
<th>Day rate ($/day)</th>
<th>Day rate ($/day)</th>
<th>Freight rate ($/t)</th>
</tr>
</thead>
</table>

Key: Charterer cost: [Red] Owner cost: [Gray]
Figure 2.4: Stakeholder relationship diagram for shipping (Rehmatulla, 2014)
In bareboat charter, the charterer bares all the operating costs and pays a lump sum to the owner for a usually long fixture. On TC, the owner bares all the costs except voyage and cargo handling costs against a fixed day rate. The charterer will issue orders to the vessel’s master in order to transport cargos. On VC the charterer pays a rate based on the amount of cargo that needs to be transported on a particular voyage and the owner is exposed to all of the operating and voyage costs.

These cost structures and revenue streams, combined with the state of different markets make certain vessels and trades more or less attractive to operate on a particular charter market. As an example, wet bulk vessels are much more likely to be operating on VC due to well defined trade patterns and charterers having less exposure to costs of delays. This is seen in the oil and product sector where freight rates are very dynamic thus the flexibility of VC is seen to be more advantageous to both parties. Dry bulk vessels are more typically associated with TC as they may engage on a variety of routes and cargos over the period.

Other factors such as uncertainty around bunker price may push owners towards one market over the other as was the case in early 2020 when the effects of the IMO sulphur cap could not predicted. Another operational factor that can have significant a significant effect on voyage costs are demurrage payments related to the arrival of vessels at port. Other shocks to the market such as the IMO 2020 sulphur regulation and the 2020 oil price crash can see chartering strategies react very quickly to be used to mitigate risk or react to market conditions. Late 2019 saw a shift towards storage of low sulphur fuel floating storage as a hedging strategy while in 2020 vessels were used to store crude oil as the price crashed into negative territory.

2_shocks to the market such as the IMO 2020 sulphur regulation and the 2020 oil price crash can see chartering strategies react very quickly to be used to mitigate risk or react to market conditions. Late 2019 saw a shift towards storage of low sulphur fuel floating storage as a hedging strategy while in 2020 vessels were used to store crude oil as the price crashed into negative territory.
ent factors can affect the value significantly while creating a contractual barrier to energy efficiency. One observation is that, in some markets, demurrage payments can be higher than freight rates thus owners have a perverse incentive to get to port ahead of time and wait as demurrage costs increase. Mazioli et al. (2019) explores how operational factors such as available quay-side length and dockside operation time have a significant effect on demurrage costs. The demurrage clauses in conventional charter parties do not account for this behaviour and thus make disputes administratively cumbersome. For this purpose, Jia and Adland (2019) propose a fairer alternative using blockchain smart contracting in order to determine the size of demurrage payments that accounts for operational factors such as vessel speed.

The transactional payment model in VC is opaque and does not give exposure to the charterer as to what the actual voyage costs are. While this is more straightforward as owners benefit directly from efficient vessels and operation, charterers who are concerned with the carbon intensity of the transport work used to move their cargo do not have access to this information. Whilst the market dictates charterers will pick the lowest rate, this behaviour assumes there is no demand for more efficient transport work, leading to a logical disconnecting of charter rates from vessel performance. While this is an interesting dynamic to explore, several interdependent factors make the decision-making process for charterers increasingly complex to model. Under TC, the cost structures are more transparent and provide a good base case to develop modelling capability.

The TC cost structure sets up a clear split incentive problem as the performance of the vessel is influenced by actions of the owner, but it is the charterer who is responsible for paying for bunker. Figure 2.5 represents the expected cash flows on different charter markets. Under most TC parties, any invest-
ment or costs related to maintaining or improving vessel performance are born by the owner but benefited from by the charterer. This creates a textbook example of a principal-agent problem.

The Principal-Agent problem Several economic studies have considered the principal-agent problem due to chartering practice (IEA, 2007; Kontovas and Psaraftis, 2013; Rehmatulla, 2014). The fundamentals of agency theory lie in two basic concepts; namely that all parties (or agents) are autonomous and want to maximise their own outcomes and that there is some element of information asymmetry between them (IEA, 2007). As Rehmatulla (2014) explains, the principal-agent problem found in time charter agreements is based on the fact that, while the owner (Agent) has knowledge and control over the performance of the vessel it is the charterer (Principal) who incurs the cost of bunker throughout the fixture. This is found to lead to problems identified within the theory as moral hazard and adverse selection which have been modelled by Rasmusen (2007). Most principal-agent problems can be categorised as moral hazard with hidden action, moral hazard with hidden information and adverse selection. The difference between these is in the order in which players take key actions (Figure 2.6). The uncertainty caused by unknown information is represented by the inclusion of an
In moral hazard, both parties have complete information however, the agent acts in a different way than expected by the principal after a contract has been signed. The principal is then exposed to risk due to the actions of the agent that were not exposed ante. An example would be an agent taking out life insurance with a premium based on a certain lifestyle only for the Agent to then take up skydiving as a hobby without advising the broker (Principal). *Nature* in this case would be a random variable representing the Agent’s disposition towards extreme sports ranging from high to low.

Looking at instances of this related to energy efficiency, Han et al. (2009) note moral hazard when the Chinese government (Principal) issued economic incentives for *Energy Efficiency Retrofits (EER)* without knowing if property owners (Agents) will change their behaviour once the incentives were issued.
In the case of shipping, brokers (Principals) are constantly exposed to moral hazard as they fix vessels with no knowledge of vessel operation during the fixture (Zhiming 2012).

In adverse selection, there is incomplete information as uncertainty is introduced by Nature moving first. A canonical example is Akerlof (1970) and his work based on used car sales. The quality of the used car lies at some point on a spectrum between bad and good. The car salesman (agent) has more information regarding this and thus can sell a bad quality car for a higher-than-market value to the buyer (principal). This causes a market failure where better cars do not get rewarded for higher quality by attracting higher prices.

It is within an equivalent context of uncertainty, stemming from information asymmetry, that ship owners are expected to make decisions regarding EE investments and charterers are expected to make decisions on fixing vessels based on performance. The next section will be dedicated to a review of decision-making theory within the energy performance context to understand the processes involved and the importance of information use.

### 2.4 Decision-making and energy efficiency in shipping

When referring to decision-making regarding EE and vessel performance in this study, there are two distinct decisions that need to be made. On the charterer side, a decision needs to be made on which vessel to fix on TC. For the owner, the main concern is the procurement of more efficient vessels or undertaking an EE intervention on existing tonnage (Smith et al., 2013). DNV-GL (2015) identify the main driver in EE decision-making in shipping to be the
pay-back period. Yet, almost half of respondents (N=80) mentioned the lack of information available is a major concern although no further detail was given as to what the term *information* meant.

In general, decision-making can be considered a special form of problem solving characterised by novelty, complexity and an element of open-endedness. In most cases, there is little understanding of the situation at the outset and a vague idea of the solution (Mintzberg et al., 1976).

Various approaches have been developed in different fields to tackle decision-making. These can be broadly divided into normative and descriptive models. Normative models describe how a decision should rationally be made while descriptive theory aims to describe how decisions are actually taken (Howard, 1988; Jennings and Wattam, 1998; Wang et al., 2017).

Normative theory assumes well-structured decision-making, based on perfect rationality with a preference for the ordered and known leading to the best possible choice. Utility theory in economics is a good example of this where, a decision with a higher utility will be consistently preferred to others with lower utility (Wilson and Dowlatabadi, 2007). Common methods applied in this field include multi-criteria decision analysis, analytic hierarchy process, ranking, cost-benefit analysis and pay-back period analysis. These are methods that work towards optimising the outcome of an objective function to a particular parameter or set of parameters. In work related to the EE of buildings, Wang et al. (2017) points out how a normative approach can be misleading due to uncertainties in the accuracy of building models and modelling the physical characteristics of building materials and operational scenarios.

Simon (1955, 1956) contributed significantly to the field of human decision-making, looking specifically at the applicability of rationality and the conse-
quences of it being bounded. His work examines how the economic assumption of rational maximisation does not hold as even in simple problem spaces, *satisficing* is more efficient than optimising in most situations. Therefore, rather than following the theoretical economic definition of rationality, Simon suggests an outlook that is more based on psychology and cognition to frame observable decision-making.


Most applications in shipping stop at the normative aspect thus limiting potential use in practice. A critical look at literature on performance decision-making in shipping exposes the sparsity of work in this field. Documentation related to how practical EE decision-making is undertaken is virtually non-existent with only one detailed study found related to shipping (*Schøyen and Sow* 2015). The majority of literature focuses exclusively on normative techno-economic optimisation. Subsequently, literature from the built environment sector was reviewed as, among other reasons, there is a similar EE gap (*Gillingham and Palmer* 2013) and a complex relationship between several stakeholders including owners, tenants, technology providers, contractors and local regulatory authorities which is similar to shipping (*Liang et al.* 2016).
A recent trend shows incremental increases in the accuracy of normative techno-economic models through the use of computational methods. This has led to the development of complex decision support models of a normative nature (Bal Beşikçi, Arslan, Turan and Ölçer, 2016, Bal Beşikçi, Kececi, Arslan and Turan, 2016, Baldi and Gabrielli, 2015, Ölçer and Odabaşı, 2005, Schøyen and Sow, 2015, Yuan and Ng, 2017). While technically robust, they are found to suffer from a lack of transparency and detachment from practical descriptive elements and market or policy factors. Thaler (2016) also argues that assuming rational expectations implies the parties involved act with a full understanding of the model being used which is difficult to verify.

Four broad elements were found to characterise performance decision-making scenarios:

- Technical complexity
- Multiple stakeholder interests
- A systematic decision-making structure with a normative discrete ranking or appraisal criterion
- The use of information and data from various stakeholders

The above observations make it very clear that there is a weak link between the technical literature, which focuses on theoretical technology performance, and barrier theory which focuses on difficulties of achieving desired outcomes in practice. This leaves a gap between experts’ and decision-makers’ views as described by Cash et al. (2003).

2.4.1 **Rewarding energy efficiency**

Assuming rationality, an owner is required to recoup the initial investment in more efficient vessels or retrofits. This can be achieved through operating the
vessel or selling the asset; in this study we will consider the former. When operating on TC, this can be done through charging an Energy Efficiency Premium (EEP) to charterers for a more efficient ship (assuming the expected bunker savings outweigh the premium) (Smith et al., 2013). On VC, the owner can decide to undercut competitors and recoup costs by being more successful at fixing the vessel, thus increasing utilisation (possibly by sailing faster). A second option is to operate at the going market rate and retain all the bunker savings (Rehmatulla, 2014, Wang et al., 2010). Despite anecdotal evidence that efficient and newer ships are chartered more often, there is very weak empirical evidence to corroborate this. This creates a barrier to more investment in efficient ships and presents a higher risk to potential financiers as the return on investment is uncertain given they do not sustainably attract higher rates (Adland, Thomassen and Østensen, 2019, Prakash et al., 2016).

Both these studies are based on AIS data, fixtures information and, in the case of Prakash et al. (2016), Rightship’s GHG rating based on the Existing Vessel Design Index (EVDI) which considers design parameters of vessels rather than their actual operational efficiency. While ratings for ship efficiency have increased in popularity, Scott et al. (2017) note that ratings related to GHG, despite their potential to mitigate emissions through industry lead initiatives, are largely neglected. Poulsen et al. (2018) test if eco-ratings drive better environmental performance in shipping and identify several shortcomings that prevent this from happening. These shortcomings are found to be, the lack of universal recognition of any rating due to different interests of stakeholders and, the lack of ability to benchmark vessels on performance due to most ratings being based on design characteristics rather than operational performance.

The authors conclude that ship owners do not use ratings as these lack credibility and third-party verification. Olaussen et al. (2017) find similar prob-
lems with the well established Energy Performance Certification in the Norwegian building sector in their regression based study with a large sample size (N=4674) that allowed the creation of a control group before and after the introduction of energy labelling. The authors note that price premiums are not caused by the energy labels but based on superficial aspects such as aesthetics and visual inspection (for example the presence of double-glazed apertures).

Agnolucci et al. (2014) identify information barriers related to consumption verification and information asymmetry regarding vessel performance leading to poor decisions making as the main reason behind this. They conclude that owners get on average only 40% of the total benefit from more efficient ships. The authors also point out that the bargaining power of efficiency changes according to market conditions, with a tight market giving more bargaining power to owners with more efficient ships based on their analysis of fixtures data.

Adland et al. (2017) find that the benefit can go as low as 14% to 27% when observed over a longer time frame while being penalised when markets are booming as efficiency comes second to speed. This multivariate regression-based study using fixtures data over 15 years (2001 – 2016) for bulkers finds that results vary significantly with vessel size. However in all cases, evidence of rewards was very weak and not seen to attract a premium from charterers. Adland, Cariou and Wolff (2019) also find no clear link between EE and charter rate premiums in the anchor handling tug and offshore service vessel markets.

Faber, Behrends and Nelissen (2011) find that only owner-operators or owners who have long-standing relationships with charterers can recoup investment from fuel efficiency technologies more readily while Wang et al. (2010) cite the heterogeneity of markets and the difficulty in assessing vessel performance as
the main market barriers.

Several authors have noticed that the size of the owner and charterer can cause interesting deviations from the observed norm. Adland et al. (2016) show that on the spot market, certain large charterers have pricing power making it unlikely for them to pay any premium due to the volume of business that comes out of a relationship with an owner. However, interviews conducted by Rehmatulla (2014) and maritime intelligence by Eason (2012) found that large ship owners still invest in EE even if not rewarded and large charterers such as Maersk will not pay higher charterer rates (possibly due to their size as mentioned previously) but will fix more efficient ships first.

In an analysis of wet bulk markets, Tamvakis and Thanopoulou (2000) find a small number of "prime" charterers who are willing to pay a premium for better vessels however this was not found in the dry bulk market. This study was mainly related to vessel quality rather than efficiency and the findings are attributed to the higher value of wet bulk cargo and the higher reputational impact of pollution incidents. The conclusion is that economic conditions will prevail and only regulatory measures will push the creation of a strong two-tier market. This was observed to happen on the pollution front after the passing of the Oil Pollution Act in 1990 following the Exxon Valdez incident (Tamvakis, 1995). In a more recent study of offshore service vessels, Adland, Cariou and Wolff (2019) echoed this finding by concluding that operational efficiency depends largely on the market and operating profile if no regulation is in place.

In all the above studies, the main outcome is that the extent to which owners can charge an EEP is largely curbed by the difficulty in assessing and communicating vessel performance in a salient and robust way which is preventing energy efficient vessels from being rewarded. Policy and regulation requir-
ment based on standardised and mandatory systems for the collection and dissemination of vessel data on energy efficiency (i.e. principally in-service data for fuel consumption as a function of vessel speeds).

This points towards a policy requirement based on standardised and mandatory systems for the collection and dissemination of vessel data on energy efficiency (i.e. principally in-service data for fuel consumption as a function of vessel speeds). Thus far, such initiatives have been voluntary and private such as Rightship [Scott et al. 2017]. Yet, in the broader context of emission monitoring, supranational organizations such as the EU and IMO have the opportunity and incentive to mandate the collection and distribution of such vessel-specific data in international regulations. This would also alleviate the problems related to asymmetric and incomplete information on the real energy efficiency of the global fleet.

2.5 Summary of findings

The presence of an EE gap in shipping related to several market barriers and failures is evident, with studies showing that information barriers play a key role in hindering a general improvement in performance. While vessel performance information is used in operations for performance monitoring, a lack of standardisation leads to poor quality data collection and lack of consistency in use for performance modelling which is echoed in the built environment.

Similar to building efficiency, a host of stakeholders are found to have access to particular information causing information asymmetry which in turn causes opacity in decision-making.

An overview of decision-making theory with regards to performance and EE
was undertaken which brought to light shortcomings in current normative decision-making literature related to chartering and investment in EE interventions. Scant documentation of this decision-making process in practice is found in literature and, while barriers are well defined, most literature is focused on normative techno-economic models as an expression of computational optimisation rather than decision support.

The main findings of interest can be summarised as follows:

- There is very limited use of in-service operational data to inform decision-making.
- There is no opportunity to validate EE performance claims for estimated performance improvement with either in-service data or from previous experience.
- The poor information regime and lack of trust due to information asymmetry is prohibitive to EE uptake and does not allow for rewarding of more efficient vessels making investment a higher risk.
- Transparency as to the provenance or creation of data is limited indicating information asymmetries. Despite this, no acknowledgement of the uncertainties, and their magnitude, that arise from incomplete information are included in quantitative studies. This uncertainty is observed when communicating vessel and EE performance, on-board data collection and performance modelling.
- Due to the lack of standardised data collection methods or open source databases, information is sourced ad-hoc for each study limiting the possibility of comparative analysis.
- The charter parties governing operation may perpetuate information asymmetry barriers that are derived from the contractual relationship or operational factors rather than technological.
• A distinctly normative approach is found when looking at performance
decision making models with very little reference to commercial consid-
erations, stakeholder relationships and economic or policy climate. This
limits their applicability in this complex landscape.
Chapter 3

Methodology and research questions

3.1 Research question design

Following a critical review of literature, a gap has been identified in work exploring the impact of information quality and asymmetry in energy performance decision-making with regards to vessel and EET. These information barriers are shown to create a market barrier that inhibits the improvement of global fleet performance and, efficient vessels not being rewarded. Although information barriers have been identified by several studies, there is a shortcoming in closing the gap between the generation of information regarding vessel performance and the use of said information commercially through more transparent decision-making for all stakeholders.

The principle hypothesis tested by this study is: Better information use and reduced asymmetry regarding vessel performance in shipping can increase
transparency and reduce uncertainty for stakeholders in vessel chartering and 
[EET] appraisal and allow efficiency to be rewarded fairly.

To assess the validity of this hypothesis, the following actions will be undertaken:

- Gaining a better understanding of decision-making practice with regards to vessel performance.
- Identifying and quantifying uncertainty caused by poor information use and asymmetries between different stakeholders.
- Proposing solutions to reduce uncertainty and increase transparency to support better informed decision-making with regards to vessel performance.
- Assessing the effects of the proposed solutions on uncertainty.

To achieve the above, the following research questions are proposed.

**Research question 1 - What is the current practice in decision-making for chartering and [EER] appraisal?**

The poor presence of research into energy performance decision-making practice within shipping hinders an understanding of the process itself. A clear picture of the procedures, data procurement, information use and stakeholder engagement is essential to be able to identify specific shortcomings related to information use and asymmetries. This specifically focuses on the charterer decisions on fixtures and owners decisions on [EET]. This understanding of information barriers will allow for characterisation using decision-making theory which will provide an analytical framework based on experiences.
Research question 2 - How can the effect of the identified information shortcomings on stakeholders be evaluated?

The analysis carried out in RQ 1 identifies specific ways in which data and information are being used as well as stakeholder relation dynamics. Based on this insight, a method for evaluating the effect of uncertainties in vessel performance on financial uncertainty for stakeholders is developed. This will provide a method for quantifying information barriers based on their overall effect on stakeholder outcome.

Research question 3 - How can the effect of identified shortcomings associated with information barriers in chartering and EER appraisal be reduced?

With identification and quantification of the effect of uncertainties in RQ 2, ways of introducing transparency and reducing uncertainty are proposed and tested. The aim is to empower stakeholders through better information use and to apply ideas from other industries facing similar barriers.

Having set the above research questions, the methodological approach to tackle each is discussed in the next section. Multiple options are considered for each question and associated merits leading towards the proposed methodological path for this study.
3.2 Proposed research methodology

Studies exploring information use and asymmetry focus on identifying and characterising the asymmetry and determining the effect on the case at hand. An overview of the methodologies used suggests that qualitative methods are used for the former including surveys, document analysis, expert elicitation, ethnography and in-depth interviews (Collins and Curtis, 2017; Feller et al., 2009; Gallouj, 1997; Garthwaite et al., 2005). While qualitative methods are sometimes used when determining the effect of asymmetries (Feller et al., 2009; Gallouj, 1997), most studies use quantitative methods to evaluate the effect. A mixed methods approach is found used in economics (Amiram et al., 2016; de Faria and da Silva, 2013; Nath and Mukherjee, 2012), governance (Feller et al., 2009) and energy efficiency research (Phillips, 2012; Vernon and Meier, 2012; Waechter et al., 2015) amongst others. The combination of qualitative and quantitative data can contribute to better studies with more insightful conclusions than if both were considered separately (Bryman, 2009).

Thus, the overarching methodological framework for this thesis is a mixed methods study with a sequential approach as described by Creswell et al. (2011). Following the example of multiple other studies in this field, qualitative data gathering and analysis is conducted in RQ 1. This then guides quantitative work to address RQ 2 and RQ 3 (Figure 3.1)

Figure 3.1: Research methodology framework
Research Question 1 Method

When investigating decision-making within a company or by individuals, social scientists use a variety of methods depending on the research question set. Studies looking for generalisation opt for surveys or structured interviews which are scalable and suited for a large sample size (Collins and Curtis, 2017, de Faria and da Silva, 2013, Nath and Mukherjee, 2012, Phillips, 2012, Tran et al., 2020, Waechter et al., 2015). Conversely, studies seeking in-depth understanding focus on a smaller sample size using semi-structured interviews, content analysis, case studies or focus groups (Frishammar, 2003, Mintzberg et al., 1976, Schøyen and Sow, 2015) or dedicate all resources to an ethnographic study (Johnson and Andersson, 2016). All above methods can be resource intensive. The latter group are more focused and establish a rapport with the participants. This can provide a better data and insights when asking how questions (Harrell and Bradley, 2009).

When investigating strategic decision-making across different stakeholders, large sample size based approaches will not give the detail required to truly understand information use, asymmetries and stakeholder relationships. While ethnographic studies give in-depth insight, they are resource intensive and restrictive as stakeholders cannot be investigated concurrently unless in the same location. An effective way of reaping the benefits of the remaining methods is by conducting a case study that includes in-depth interviews, content analysis and quantitative analysis on one event. While it is recognized that generalisation would not be possible, the use of multiple data collection methods from multiple stakeholders would allow for triangulation and rigour to the construct (Bryman and Bell, 2011).

In situations where the data from and relationships between multiple stake-
holders is to be investigated, case studies are particularly well suited as they allow the flexibility to bring together diverse sources of data while working within a defined boundary (Yin and Kim [2009]). This boundary can be temporal, geospatial, organisational or cross-sectional, focused on one event analysed from different perspectives (Stake [1995]).

Qualitative case studies are scarce in shipping however, a small number in the EE field yielded rich insights that would not have been attainable in any other way (Johnson et al. [2014], Poulsen and Johnson [2016], Poulsen and Sampson [2019], Poulsen and Sornn-Friese [2015], Schøyen and Sow [2015]). In other sectors, there are several works regarding information use, strategic decision-making and use of information that are based on multiple case studies with in-depth interviews and document review making up evidence base for subsequent findings (Frishammar [2003], Mintzberg et al. [1976]). Although individual case studies are often criticised by the scientific community as isolated data points, Flyvbjerg (2006) extensively explains why they are an invaluable tool to create and validate theory and make lasting contributions to relevant evidence bases.

In light of the above, a case study has been identified with a ship owner with whom a relationship was established through the industrial partner for this research. This thesis aims to create evidence filling the literature gap around case-studies regarding the implementation of EER as well as identify specific uncertainties related to information use and asymmetries.

A combination of in-depth interviews with various stakeholders in an EER project were carried out along with content analysis of documentation and in-service data collected from on board the vessel. The data obtained from the case study is analysed thematically to:
• Build a narrative of the decision-making process
• Identify information provenance, use and associated challenges
• Explore relationships between different stakeholders
• Identify information asymmetries and shortfalls in transparency

The case study looks at the implementation of an EER to a Multi-purpose vessel (MPP) in 2015 by a ship management company who was responsible for the vessel at the time. The vessel underwent several structural modifications including a bulbous bow redesign, addition of a rudder bulb and a new high-performance hull coating with an agreement in place for a charterer to fix the vessel on a long term TC at a higher charter rate. More importantly, a CM performance monitoring system was installed to assess the impact of the retrofit.

MPPs are a type of general cargo vessel with a flexible platform designed to transport a wide variety of cargos. Most have hatches as well as lifting gear, increasing versatility in being able to call at ports, quaysides or offshore sites with limited or no lifting capabilities. They also tend to have clear decks which allow them to transport large and awkwardly shaped cargos such as heavy machinery and components of offshore installations. Due to this flexibility, they usually operate on a tramp basis. The current global fleet is made up of around 3000 vessels in-service (Clarksons 2018b).

Research Question 2 Method

In past studies, researchers have chosen to apply organisational, actor-network or principal-agent theory (Duncan 1972, IEA 2007, Whittle and Spicer 2008) to characterise relationships between stakeholders. While these approaches are robust, they are better suited for purely social science studies. In eco-
nomics and EE, a combined qualitative and quantitative approach is usually used to characterise information use and asymmetries. Several different methods have been developed using this approach. For example, data gathered through surveys is usually used for statistical hypothesis testing or analytics (Nath and Mukherjee, 2012, Phillips, 2012, Waechter et al., 2015), while expert elicitation (Garthwaite et al., 2005, O'Hagan et al., 2006) and economic utility theory (Amiram et al., 2016) have been used to build mathematical models to quantify effects of uncertainty through information asymmetry.

Decision-making in the shipping industry is affected by the characteristics of the stakeholders involved rather than only rational economic optimisation. To develop a representative quantitative model that evaluates the influence of the parties’ behaviour on each other’s outcome, any method selected is required to:

- model the strategic interaction and behaviour of players
- accommodate the complexity introduced by nuanced industry practices
- express both aleatoric and epistemic uncertainty
- be implemented in a format that is flexible enough to describe different scenarios
- consider technical, economic and commercial aspects of energy performance decision-making
- produce quantitative outputs that can be interpreted comprehensively and used as input for further modelling

This is not a novel problem and has been extensively explored in various disciplines via strategic interaction modelling. Some popular methods include agent-based modelling, Bayesian networks, black box data driven models (grouped generally under the machine learning heading) and techno-economic
probabilistic models. Machine learning methods require extensive amounts of quantitative data that describe the real-world situation being modelled. While this has been shown to be applicable to ship performance modelling, it does not capture the qualitative aspects of stakeholder interaction and is inherently opaque.

Bayesian networks and agent-based modelling offer a much more flexible framework that can be built to account for both qualitative and quantitative inputs for modelling complex interactions and uncertainty (Yang et al., 2018, Zhang et al., 2018). It also provides a visual representation of the network facilitating model programming and communication.

Bayesian networks were found to be limited by the software available for this research as quantitative datasets need to be expressed in probabilistic distributions which need to be determined through other software applications which is more resource intensive. Instead, a compromise between technical complexity and stakeholder interaction representation was found with the use of a probabilistic techno-economic model which allows for the flexibility to use conventional programming languages, in this case MATLAB.

A versatile tool used to frame strategic interactions is Game Theory (GT) which appears in literature frequently to describe PA problems specifically in the context of information asymmetry. The stakeholder interaction framing is then captured by using GT in constructing the input and output information thus reaping the benefit from both methods to maximise model utility and flexibility.

**Game theoretic modelling** The following sections will go through an overview of literature related to GT. This is covered here rather than in Chapter 2 as it is specifically related to the method selection for answering the research ques-
tion which has been proposed above.

GT was originally used as an analytical tool in theoretical mathematics until von Neumann and Morgenstern (1944) applied it to model strategic behaviour between different parties. Their work showed how games can provide a framework for modelling strategic interactions. Although perceived as being a predictive tool, GT is by nature an analytical tool built for generality and mathematical rigour (Camerer 2003). The foundation of GT is that every interaction between two or more parties can be described as a game with players who can choose a set of strategies to interact with each other. For each combination of strategies, a different utility function is compiled for each player that defines their pay-off.

Utility theory underpins GT with each player looking to maximise utility for themselves irrelevant of the outcome for the other players. Various strategies for finding the optimal equilibrium for players to obtain maximum utility have been explored with the Nash equilibrium being the most well known (Nash 1950). GT has also been extensively used to model and analyse decisions outside of economic theory where the players do not necessarily act to maximise utility. To this effect, Camerer (2003) developed a new branch of GT coined as behavioural GT which combines behavioural economics and experimental observations. GT is often used to create a theoretical framework and identify the theoretical optimal solution. This is then compared to empirical observations or modelled outcomes to see where the two diverge and to design solutions to close this gap.

Rysanek and Choudhary (2013) provide an example of the use of three alternative optimisation criteria, Wald, Savage, and Hurwicz.
One of the most important parameters for building a game is players’ access to information. This makes GT especially adapted to describe stakeholder interactions with varying degrees of information asymmetry. A game can be undertaken under imperfect information where players are unaware of the actions chosen by other players or under incomplete information where the possible actions, strategies and subsequent associated pay-offs of other players are not known.

Applications of GT span a vast range of disciplines and have tackled energy related topics including industrial energy management (Aplak and Sogut, 2013), waste-to-energy technology selection (Solonen, 2016) and EE decision making in the built environment (Gu et al., 2009, Li et al., 2011, Liang et al., 2016, Xu et al., 2019). The latter studies are of specific interest to the work being undertaken in this research. A very pertinent example from power consumption is work by Fernandez et al. (2018) who set a game between consumer and energy supplier. In this model, the optimum outcome lies where consumers provide enough information about their usage as to allow the supplier to buy electricity only when needed, thus reducing costs which could be fed back to the consumer through lower energy bills.

A number of examples of GT used in shipping can be found however, they are largely concerned with strategic market competition, especially in the container liner market (Aymelek et al., 2016, Kou and Luo 2016). These are mostly academic economic theory exercises seeking optimisation of routes and analysis of market oversupply. Shi and Voß (2011) provide several examples of GT applications in the shipping industry including asset flows and asymmetric information.

Application of game theory in EE stakeholder modelling Gu et al. (2009)
explore strategies for energy-efficient developments in a case study which look at why Chinese developers are not building energy-efficient residential properties. Although this would make the properties more attractive on the market, the associated CAPEX and risks are greater as less efficient buildings are priced more competitively. This results in the more energy-efficiency assets having a lower return on investment. The authors suggest that regulation through standardisation is a possible solution for this however, they acknowledge the heterogeneity in builders and workmanship as a challenge in introducing any strict policy. If one considers housing development to be a game, the strategies developers take for residential buildings are complex ones which need to take into account energy-efficiency, health and comfort, CAPEX and also increased prices to account for the higher quality. In parallel, significant uncertainty is introduced as to whether the property will sell because of different consumer types, property markets and utility prices.

The authors’ attempt to find a Nash equilibrium leads to the realisation that the problem is rooted in a dominance of asset play in the market with residential properties being built as an investment rather than being built as the best possible structure. In this case, enhanced cooperation is proposed as a solution, with the architect acting as a key actor who reconciles the desires of the developer with the needs of the other stakeholders such as buyers and occupiers.

Focusing on green retrofits, Liang et al. (2016) look at the attitudes of owners and occupiers with regards to these energy saving investments. Three occupancy types are considered (owner-occupier, single and multiple occupier) and a non-cooperative game between owner and occupier is set up for

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4 Very similar to market for lemons concept put forward by Akerlof (1970).
each case with the strategy being that the owner is either reluctant or keen to undertake the retrofit. A list of barrier and incentive factors is drawn up from literature and allows for utility functions to be created with terms that are defined to have direct or indirect and long or short-term effects. The outcome of the analysis identifies issues that require to be tackled to overcome the reluctance of owners to invest, which stems from split incentives, uncertainty on returns and risk aversion.

The paper is largely theoretical and does not attempt to evaluate the actual pay-offs but demonstrates the way GT can be used as a tool for policy advice. Xu et al. (2019) apply the cooperative strategy between designers and contractors to improve EE performance of buildings using evolutionary GT. They show that reducing collaboration costs was the most effective way to achieve a better outcome.

Most pertinent to this thesis is work carried out by Li et al. (2011) which uses games to analyse the effect of information asymmetry in the energy-saving building market and policy implications. An adverse selection PA model is set up to represent a two-player incomplete information, non-cooperative game between developer and consumer where the consumer does not know if the property is energy-saving or not. Through a theoretical analysis, the risks of moral hazard and risk aversion are exposed and the authors propose solutions to reduce the risks of energy-saving buildings not being rewarded. The authors go on to propose solutions including government regulation to introduce legitimacy to information related to energy performance.

Agency theory and information asymmetry games in shipping Psarros (2016) looks at the chartering dynamic in shipping through a GT framework to represent information asymmetry for dry bulk cargos. In his work, the legal
aspect of performance clauses in charter parties is analysed. A probabilistic model is then created to determine the optimal parameters for operating profit maximisation. In the case of TC, a moral hazard with hidden action is used as a model with the unknown effort (Nature) being the premium the charterer is expected to pay for a more efficient vessel in order for the owner to recoup the CAPEX. The author also models VC selecting an adverse selection with screening. Here, Nature is set as the level of environmental stewardship the owner has and on which the charterer has no information. The information that is used for screening after the first period of the negotiation is assumed to be in the form of vetting documents and also publicly available metrics such as Rightship’s Existing Vessel Design Index (EVDI) (Poulsen et al., 2018, Scott et al., 2017). In both cases, the model seeks to optimise the variable parameter to a value that is most beneficial to both parties based on the input assumptions.

Bergantino and Veenstra (2002) match different types of chartering with canonical PA game types. Bareboat charter is analogous to moral hazard as the vessel is chartered out, operated and maintained by the charterer and the owner cannot monitor maintenance on their asset as it is at sea. Conversely, a VC can be described as adverse selection as the owner knows more about the condition of the vessel when negotiating the charter conditions. This is further elaborated by describing it as an adverse selection game with screening as, once the contract is offered, the owner (Agent) provides the vetting data required and the charterer can still choose to reject the contract (Figure 3.2).

From the above sources, it can be seen that the application of GT provides a robust theoretical framework within which the owner-charterer dynamic can
be represented and used as the basis for building a quantitative model. It becomes evident that the choice of PA problem model depends on the missing information and sequence of actions by the respective players. Psarros (2016) shows how the type of game is selected based on the parameter that is of interest such as environmental stewardship or additional premium for a more efficient vessel. Hence it can be argued that the same PA problem can be represented as both an adverse selection and a moral hazard problem depending on the aspect that is of interest and the moment in time that is being considered.

Given this work focuses on the uncertainty around vessel performance, drawing on the examples above, an adverse selection game is proposed to model a TC decision at the pre-fixture stage. The unknown parameter set by nature is vessel performance. The warranted performance provided by the owner is a form of signalling and it is assumed that the owner accepts the contract if the conditions of the contract reach some level of expected utility for both parties. The charterer assesses the contract with some level of trust based on the expectation of transparency with regards to vessel performance. Translating this dynamic to an adverse selection model, Figure 3.3 adapts the canonical PA model to the TC relationship.

Following the above, a qualitative element is introduced and the relationship between key stakeholder decisions and information flows will be defined by
modules in a probabilistic techno-economic model framed by GT. The model design cycle adopted by Refsgaard and Henriksen (2004) (Figure 3.4) is applied. Information barriers characterised from the outcome of RQ 1 are combined with a technical model that represents vessel performance uncertainty through Monte Carlo (MC) simulation (Aviso et al., 2019, Dadashi and Mir-baha, 2019). A GT framework allows for the evaluation of the effect of each stakeholder decision as well as the effect this has on financial outcome. Furthermore, the flexibility of the design allows for sensitivity analysis to be carried out to evaluate the impact information barriers has on different stakeholders.

Figure 3.3: PA model for adverse selection adapted from Rasmusen (2007)

Figure 3.4: Model development cycle (Refsgaard and Henriksen 2004)
**Research Question 3 Method**

With the model developed in RQ2, measures to increase transparency and reduce uncertainty are explored to evaluate their effect on stakeholder outcome.

Akerlof (1970) presents several methods to reduce the impact of information asymmetries such as performance guarantees between stakeholders. He also proposes the establishment of standard practices. This is echoed in more modern studies (Garmston 2017, Johnson and Andersson 2016, Wachnik 2014) with such as energy management standards, Energy Performance Certification (EPC) and various publicly available selection toolboxes available in the built environment (Aydin et al. 2018, Lee et al. 2015). The most direct way to reduce information asymmetries is through the building of relationships between stakeholders. This is especially relevant in shipping which is found to be a highly relational industry (Rehmatulla 2012, Schøyen and Sow 2015). However, this comes at the cost of transparency as the asymmetry is only reduced internally between those directly involved in the relationship.

The above examples assume pro-active willing actors wanting to change the status quo which historically has not been the norm in shipping with regards to emission reductions as well as safety and the environment (Pomeroy and Earthy 2017). Standardisation with regards to performance measurement in shipping is still in its infancy and is driven through the implementation of EE indices (Lister et al. 2015, Scott et al. 2017) and technology selection tool boxes (GloMEEP 2017). While these metrics have good potential, they suffer from limited transparency in terms of the data used to rate vessels and also access to the rating itself. A distinct low emission reduction ambition is also noted by Scott et al. (2017) as metrics are based on mean performance of the peer-group rather than comparison to the top performers. In some cases,
emissions performance accounts for a very small part of the overall information that is used to come up with the rating thus diluting its importance.

To fill this gap, RQ 3 focuses on proposing solutions which make use of existing data sets, performance modelling and contracting. These solutions focus on the reduction of uncertainty especially that raised from information asymmetry between stakeholders. Based on the output form RQ 2, counterfactual scenarios are run through the probabilistic model where the effect of proposed information barrier mitigation strategies can be tested. This demonstrates the effect that increased transparency can have on the individual stakeholders as well as on the efficiency and commercial bottom line.

3.3 Summary

Figure 3.5 represents an overview of the methodology proposed to answer the research questions in order to test the principal hypothesis. The following three chapters answer each of the research questions with a discussion chapter bringing the conclusions from each chapter together with observations on effects on policy, regulation and commercial practice.
Figure 3.5: Research methodology and thesis framework
Chapter 4

Qualitative case study

4.1 Aim and objective

This chapter describes the design, execution and analysis of an exploratory case study into an EER investment to observe the stakeholder interaction, information use and decision-making. Data analysis carried out on various sources will inform the design of a quantitative model to represent the identified dynamic relationship characteristics in the next chapter (Figure 4.1).

4.2 Case study construct design

From the outset, this case study is considered to be representative or typical as defined by Yin and Kim (2009) as it aims to shed light onto an everyday situation which has not been documented in detail. However, in some respects it may also be considered a revelatory case due to several factors. Firstly, access was granted to high frequency in-service data for this study which is difficult to obtain for academic research due to commercial sensitivity concerns.
Figure 4.1: Method framework - Chapter 4
Secondly, the case discussed is one of the first known instances of a savings clause being included in the charter party with the ship operator guaranteeing a degree of bunker savings within a certain operating envelope. Finally, the installation of a high frequency performance measurement system with an EER is in itself significant as the majority of the industry has not embraced automatic logging systems preferring manual logging (DNV-GL, 2015; Poulsen and Johnson, 2016).

Keeping to the classification of case studies proposed by Stake (1995), this is a single event study specifically tackling the complexity and nature of one event; the implementation of a set of EER on one vessel. Case studies are by nature flexible enough to provide robust data collection and analysis for quantitative and qualitative studies allowing for both inductive and deductive approaches to theory (Bryman and Bell, 2011). Another strong characteristic of case studies is the ability to triangulate data from different sources to validate analysis (Patton, 2002).

As Bryman (2009) concluded, the combination of qualitative and quantitative data usually contributes to better studies with more insightful conclusions than if both were considered separately. The design selected for this case study in inspired by Creswell et al. (2011) and their nested design with one type of data taking the lead (qualitative) with another type (quantitative) supporting or informing findings better (Figure 4.2).

![Figure 4.2: Embedded mixed methodology design](image-url)
4.3 Data collection

Access to the implementation project under analysis was obtained through industrial sponsors with whom communication channels were already established thus facilitating engagement with parties involved. The strategy for data collection was based on a hypothesised stakeholder relationship illustrated in Figure 4.3 with the asset owner at the at the centre of a radial network of direct stakeholders as portrayed by Wanger Mainardes et al. (2012) and Schøyen and Sow (2015). A slight variation from the model analysed in their work is the relationship between the technology provider and the shipyard.

Figure 4.3: Hypothesised relationship diagram for EE retrofit implementation

During data gathering, a more complex stakeholder relationship was revealed (Figure 4.4) and thus data sources increased accordingly through snowballing. The names of the companies involved and key informants interviewed have been withheld following University College London ethics guidelines due to the commercially sensitive nature of some of the findings presented, as well as the conditions agreed upon when consent for use of the data was granted.

Following protocol postulated by Yin and Kim (2009) to ensure case study construct validity, multiple data sources are identified and used as listed in Table 4.1.

The case study database is composed of the following:

1. In-depth semi-structured interviews with stakeholder key informants iden-
Figure 4.4: Revealed relationship diagram for EER implementation (parties directly involved in case study highlighted)

Table 4.1: Sources used for case study data collection

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>In-depth interviews</th>
<th>Technical documents</th>
<th>In-service data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ship manager</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Charterer</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consultancy</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classification society</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
identified which in turn lead to further snowballed interviews.

2. Technical documentation regarding vessel and retrofit implementation including the energy savings clause in charter party.

3. Verification documentation from a classification society validating performance improvement post-retrofit.

4. In-service data including:
   - Historic NR data collected from February 2011 to August 2017
   - CM data collected since the implementation of the performance monitoring system and retrofits from February 2016 to August 2017.

Supplementary materials including press releases and corporate literature were provided which provided more background information on the stakeholders involved.

### 4.3.1 Semi-structured interviews

The interviews undertaken were designed to get insight into three themes: company structure, information use and stakeholder involvement in retrofit decision-making. Figure 4.5 illustrates the overarching questions used to inform elicitation for each theme. These overarching questions are used to design an interview guide as per [Bryman and Bell (2011)] to direct the flow of questioning.

![Figure 4.5: Themes and associated overarching questions](image)

Figure 4.5: Themes and associated overarching questions
The overarching questions were developed into an interview with four parts. Each part consists of multiple questions, the answers to which are then used to carry out thematic analysis. Each question can be associated with one of the overarching questions (Table 4.3). In order to ensure robustness and academic ethical standards when collecting qualitative data, data collection protocols and data protection applications were submitted to and approved by the Bartlett School of Energy, Environment and Resources ethics commissioner and the University College London data protection commission.

Key informants were identified through industry sponsors for the research and contacted directly with a proposal for participation and information sheet which provided further details on the project. On acceptance of participation, a consent form was provided for completion. This was also carried out for any snowballed participants to achieve the final key informant list in Table 4.2. The interview guide, consent form and information sheet can be found in Appendix A.1.

Table 4.2: List of key informant interviews

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Job title</th>
<th>Selection</th>
<th>Date</th>
<th>Medium</th>
<th>Duration</th>
<th>Documentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship manager</td>
<td>Investment manager</td>
<td>Direct</td>
<td>16/06/2017</td>
<td>Skype</td>
<td>00:54:26</td>
<td>Notes</td>
</tr>
<tr>
<td>Ship manager</td>
<td>Ship performance</td>
<td>Snowball</td>
<td>16/06/2017</td>
<td>Skype</td>
<td>01:58:49</td>
<td>Recording &amp; transcription</td>
</tr>
<tr>
<td>Charterer</td>
<td>Managing director</td>
<td>Direct</td>
<td>29/06/2017</td>
<td>Phone</td>
<td>01:02:00</td>
<td>Recording &amp; transcription</td>
</tr>
<tr>
<td>Consultancy</td>
<td>Managing director</td>
<td>Snowball</td>
<td>21/08/2017</td>
<td>Skype</td>
<td>00:35:03</td>
<td>Notes</td>
</tr>
</tbody>
</table>

4.3.2 Technical documentation

Extensive technical documentation related to the vessel was provided by the ship performance manager including:

- sea trial reports with reference power curves for ballast and laden con-
### Table 4.3: Four-part interview structure

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Answer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Part 1: Establishing interviewee role and company type</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Could you tell me a little about yourself and your experience in the industry?</td>
<td>Context, A2</td>
</tr>
<tr>
<td>2</td>
<td>How would you describe your role in the organisation?</td>
<td>Context, A2</td>
</tr>
<tr>
<td>3</td>
<td>Could you describe your organisation and its main business?</td>
<td>Context</td>
</tr>
<tr>
<td>4</td>
<td>What is your role in decisions regarding the selection of technological EER? Just to clarify, by EER I mean technological interventions installed to existing tonnage such as new bulbous bows, propeller ducts or WHR to improve energy efficiency</td>
<td>Context, A2</td>
</tr>
<tr>
<td></td>
<td><strong>Part 2: Exploring decision making</strong></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>What were the main motivators that made you consider EER?</td>
<td>A1</td>
</tr>
<tr>
<td>6</td>
<td>Could you tell me a little bit more about the decision-making process taken within the organisation, perhaps with a recent example of an intervention?</td>
<td>A1, B3, B4</td>
</tr>
<tr>
<td></td>
<td>Probes:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. . . how is &quot;insert internal/external stakeholder name&quot; involved?</td>
<td>A2, C5</td>
</tr>
<tr>
<td></td>
<td>b. . . what kind of information would you need/use for that?</td>
<td>B3, B4</td>
</tr>
<tr>
<td></td>
<td>c. . . where would you get that information from?</td>
<td>B3, B4</td>
</tr>
<tr>
<td></td>
<td>d. . . how was this intervention financed?</td>
<td>A1, C5</td>
</tr>
<tr>
<td></td>
<td>e. . . what resources are assigned?</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td>f. . . and how long would that typically take?</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td>g. . . is there a review process in place? (are promised savings checked?)</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td>h. . . would this be done differently for another technology?</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td>i. . . how is the final decision made?</td>
<td>A1, A2</td>
</tr>
<tr>
<td></td>
<td>j. . . are any tools used for that?</td>
<td>A1, B3, B4</td>
</tr>
<tr>
<td>7</td>
<td>Can you tell me more about who or what influences the decision-making process, both internally and externally?</td>
<td>A1, A2, C5</td>
</tr>
<tr>
<td></td>
<td><strong>Part 3: Understand stakeholder experience</strong></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>How and to what extent are the following involved in the process?</td>
<td>C5</td>
</tr>
<tr>
<td></td>
<td>- Technology provider, Charterer, Financier, Retrofit yard</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>From your experience, what other data or information would facilitate or improve this decision?</td>
<td>B1, B2</td>
</tr>
<tr>
<td></td>
<td><strong>Part 4: Wrap up</strong></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>What is the most challenging part of the whole process?</td>
<td>Context</td>
</tr>
<tr>
<td>11</td>
<td>Given the current data and disruption trend, how do you see this decision-making process changing in the future, if at all?</td>
<td>Context</td>
</tr>
<tr>
<td>12</td>
<td>From your experience, are there any lessons learnt your organisation will implement to improve future retrofit selection?</td>
<td>Context</td>
</tr>
</tbody>
</table>
ditions

- model test reports conducted at the hull design phase
- propulsion layout and technical specifications

The ship performance manager also provided a fuel savings verification document prepared by a classification society in order to evaluate the return on investment whilst also building confidence with charterers in the promised savings from EER. This documentation provides insight into the data use and methodology applied by a reputable classification society when it comes to EER analysis. During analysis, this allowed for a comparison to the outcome of ISO 19030 (BSI, 2016a) analysis in this research.

Another piece of data provided was an excerpt of the TC charter party describing an amendment to the conventional performance clause to account for the inclusion of savings expected from the EER intervention. This clause is the bridge that connects the technical to the commercial in the retrofit intervention and provides some insight into the PA dynamic between the stakeholders.

Corporate documentation was only used to provide context and familiarise oneself with the company portfolios and structures. Although very useful, the data from these grey sources provided little input beyond what the interviews provided. Press releases were similarly poor in detail but provided insight into what the companies wanted the industry and public to know about the project.

4.3.3 In-service data

Application of ISO 19030 for long-term performance evaluation

Taking ISO 19030 (BSI, 2016b) as a basis for performance estimation based on in-service data, the methodology can be summarised in Figure 4.6. This
method for estimating the effect that interventions have on vessel performance by using the delta in velocity between a reference and an evaluation dataset as a **Performance Indicator (PI)**. A complete flowchart of the methodology can be found in Appendix A.2.

![Methodology flowchart](image)

**Figure 4.6: Methodology for performance estimation from in-service data**

The method of obtaining the PI is illustrated in Figure 4.7 in terms of speed-power curves for a vessel under assessment. Vessels initially have a speed-power curve based on design data that can be derived from ship trials, model tests or **Computational Fluid Dynamics (CFD)**.

![Power-speed characteristics](image)

**Figure 4.7: Illustrative example of power-speed characteristics for speed loss evaluation**

To determine the effect of interventions or retrofits, in-service data collected over a span of time both before and after the intervention is used to estab-
lish a reference period and an evaluation period between which comparisons can be drawn. With data collected over these two periods, two speed-power curves can be drawn up and compared to the design data curve to establish the difference in velocity at the Main Engine (ME) power $P_{ME}$ for each data point. This speed loss value becomes the $\text{PI}_6$.

If a time series of speed loss is plotted, a figure similar to Figure 4.8 would be expected where a step change can be observed between the reference and evaluation period due to an intervention or retrofit. In this case, the interval between Dry-Docking (DD) is noted on the horizontal axis of the time series. While this methodology offers a starting point for performance estimation, data quality, length of collection period and frequency of data collection will have an impact on the uncertainty associated with the estimation.

Figure 4.8: Typical performance indicator (denoted as H in this case) time series plot showing reference (R) and evaluation (E) periods (BSI, 2016a)

Table 4.4 provides details on the variables collected for performance estimation using ISO 19030 (BSI, 2016a) including dataset length and data collection system. Given the CM dataset is missing metocean conditions and draught, $V_{des}$.

---

6The reference design velocity $V_{des}$ is provided in Figure 4.7 for illustrative purposes.
only NR can be used for performance evaluation.

Table 4.4: Size of dataset (in days) for variables measured

<table>
<thead>
<tr>
<th>Measured parameter</th>
<th>Unit</th>
<th>Data collection system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NR</td>
</tr>
<tr>
<td>SOG</td>
<td>kn</td>
<td>2064</td>
</tr>
<tr>
<td>STW</td>
<td>kn</td>
<td>2066</td>
</tr>
<tr>
<td>Heading</td>
<td>deg</td>
<td>2134</td>
</tr>
<tr>
<td>Wind strength</td>
<td>BF</td>
<td>2070</td>
</tr>
<tr>
<td>Wind direction</td>
<td>deg</td>
<td>980</td>
</tr>
<tr>
<td>Wave height</td>
<td>m</td>
<td>209</td>
</tr>
<tr>
<td>Wave direction</td>
<td>deg</td>
<td>905</td>
</tr>
<tr>
<td>Water depth**</td>
<td>m</td>
<td>984</td>
</tr>
<tr>
<td>Draft</td>
<td>m</td>
<td>2076</td>
</tr>
<tr>
<td>ME power</td>
<td>kW</td>
<td>2078</td>
</tr>
</tbody>
</table>

* Collected at 15 minute resolution due to data consolidation error
** For CM data set, only measured when water depth less than 80m

Together with the above steps, the following data related issues were considered:

- Measurements of ME power or fuel consumption, vessel speed (Speed Over Ground (SOG) and Speed Through Water (STW)), draught, heading, wind speed and wind heading should be recorded for a complete usable data point.
- Data points are filtered to eliminate outliers that are significantly different including those measured during heavy weather and when the vessel is manoeuvring or conducting port operations.

While weather data can be added through a hindcast model given that the AIS data provides a geographical location, the scope is to assess the use of ISO 19030 which only allows measured data to be used.
• ISO 19030 provides methods for corrections to ME power are made to compensate for wind resistance depending on wind direction and speed. This correction was not carried out for this analysis as the transverse projected area exposed to wind loading for this vessel was not available. Although this could have been estimated to reduce some of the variation in the data, the standard does not provide a method to do this thus somewhat defeating the purpose of following the procedure altogether. Moreover, being an MPP, the cargo can have a significantly different impact on the windage for each voyage.

• The selection of the reference period determines whether the performance estimate is an absolute (with respect to the design condition) or relative (with respect to any arbitrary period of choice).

• A clear record of interventions that may have an affect on hydrodynamic efficiency is required to isolate any change in consumption. Table 4.5 lists the record for this vessel. Leaving an appropriate time between interventions in order to isolate the effects of the ones of interest is crucial for the success of such analysis (Adland, Cariou, Jia and Wolff, 2018).

<table>
<thead>
<tr>
<th>Intervention type</th>
<th>Intervention date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull Cleaning and Coating (HC)</td>
<td>02/04/2014</td>
</tr>
<tr>
<td>Propeller Polishing (PP)</td>
<td>03/04/2014</td>
</tr>
<tr>
<td>ME turbocharger overhaul</td>
<td>04/09/2014</td>
</tr>
<tr>
<td>ME overhaul</td>
<td>06/06/2015</td>
</tr>
<tr>
<td>Propeller Polishing (PP)</td>
<td>16/02/2016</td>
</tr>
<tr>
<td>Hull blasting and new coating</td>
<td>29/02/2016</td>
</tr>
<tr>
<td>Dry docking for bulbous bow and rudder bulb</td>
<td>01/03/2016</td>
</tr>
</tbody>
</table>
4.4 Data analysis

The following sections will go through the analysis undertaken for each data source and the insights that are garnered. This allowed for triangulation between the different sources which gave a rich understanding of the case study.

4.4.1 Semi-structured interviews

To analyse the qualitative data collected, the questions set out at the beginning of this chapter are used to characterise decision-making at the critical points identified during the literature review, namely; the decision-making method and appraisal criteria, technical complexity of intervention, information use by stakeholders and stakeholder interaction. This allows for a logic model of the decision-making process to be built (as per Yin and Kim (2009)). A mix of diagrams, tables and charts is used as well as text to better illustrate findings as recommended by Miles and Huberman (1994).

Data from interviews was parsed by transcribing and coding using NVivo 12 which allowed for comprehensive textual analysis of emerging themes within the framework. The nodes that emerged most commonly were gathered into five themes: stakeholder description, narrative, technology selection and motivation, relationships, and information use and decision-making. In the following section, the analysis and findings are presented.

Stakeholder analysis

**Ship Manager** The **Ship Manager** plays a large number of roles and acts as a one-stop-shop for marine asset procurement, financing, management, operation, maintenance and sale. The current portfolio under management is
a mix of different vessels with a small number of MPP vessels out of which one is the subject of this case study. While the management company does not own the vessel, it is responsible for setting up the financial structures and bringing capital together from investors to buy marine assets. The vessel in question is owned by a Special Purpose Vehicle (SPV) which is in turn owned by shareholders. The shareholders entrust the management company with the day to day running of the vessel including chartering and maintenance (Figure 4.9).

This ownership and management structure was part of the reason why an EER was considered. It was the first of its kind undertaken by the SM. The above insight was provided by the Investment Manager (IM) at the SM who is responsible for financial structures, liquidations, insolvency, investor relations and is a managing director for several SPVs set up for vessel ownership. In their description of their role, the IM affirmed that any financial decisions have to go through his department. This led to their involvement in the retrofit project. The current IM has been within the company for 10 years and has worked in vessel finance and asset management for all his career gaining significant experience in this sector.

Moving to the day-to-day management of vessels, the technical department takes over. Teams lead by a technical manager are responsible for daily running, maintenance and dry dock activity planning. Within this structure, the post of Ship Performance Manager (SPM) can be found. As shown in Figure 4.10, SPM is a stand-alone role that reports to the technical manager but receives input from technical teams that are responsible for segments of the fleet and which include a former master mariner and chief engineer each. Support is provided from the IT department that is responsible for ship-board IT but is not dedicated exclusively to performance monitoring.
Figure 4.9: Entity-relationship diagram based around MPP vessel

Figure 4.10: Technical department structure within SM company
This SPM position has only been running for two years and has been occupied by a relatively young professional with mostly academic naval architecture experience. The post was only being carried out on a part time basis by the SPM for a year whilst he continued to pursue his studies. Furthermore, as happens very frequently in such situations, their time was not only dedicated to the task of managing data to measure performance but was also leading projects associated with research, development and implementation of technological assets and operational optimisation.

**Charterer**  The chartering company is a large player in the MPP market and it owns around 50 vessels with other vessels chartered in (almost exclusively on TC). A long chartering relationship with the SM has been established after several years working together and the vessel in question was already under their charter before the EER implementation. The key informant on the charterer side was the Managing Director (MD) responsible for tonnage procurement, overseeing all chartering activity (in and out), sales, purchases, newbuilds, hire payments, market research and client demand studies. The MD is in their mid-40s and has been working at the company for five years with previous experience in ship owning and operating companies. The MD provided a thorough overview of the MPP market which has some specific challenges due to the nature of the client requirements and cargo that is required to be transported.

**Consultancy**  The consultancy company involved in this project is a small but well-established firm that has a wide range of technical design and implementation experience. This comes from the historic close relationship with a shipyard that develops proprietary technologies. The key informant in this
case was a [MD] with a naval architecture background. They explained how the company offered a holistic service package when it comes to [EE] interventions, starting with an energy audit to characterise vessel performance followed by preliminary assessment of solutions to propose to the client. If this initial study is successful, the company has the capability of developing detailed designs, including [CFD] simulations for detailed energy savings estimates. Their expertise lie in hydrodynamic, propulsion and shaft generator retrofits and the company is looking to expand by taking on larger contracts.

Stakeholder relationships

This [EER] intervention campaign was only made possible due to the existing relationship between the [SM] and the charterer. The agreement for the vessel to be fixed for five years at a higher day rate (approximately 22% higher than the market rate at the time) was the crux of the entire process. It was this assurance that secured the financing for the retrofits and thus the sanctioning of the project by the [SM]. In this case, the charterer was not motivated to pay the premium by the savings as over the charter period would be approximately equal to the additional premium being paid. The motivating reason was found to be vessel design which, due to its relatively short length, can access quaysides which would not be accessible to larger vessels giving it a strategic advantage. Additionally, the vessel has a slightly larger beam than vessels in direct competition thus has more stability for a vessel of a similar length making it more versatile and competitive.

Case study narrative

Through interview transcription, an understanding the overall process was obtained allowing critical analysis of decision-making, stakeholder involvement
and information use. This process is described in Table 4.6 which has been compiled by parsing information from the interviews carried out with different stakeholders. The 18 distinct steps were identified that lead from the initial driving motivation to the verification of the effectiveness of the interventions carried out. Two distinct decision-making instances emerge; vessel fixture by the charterer and EER selection. The narrative was found to be consistent from all key informants interviewed however, no one single informant would have been able to provide the complete narrative as they were only privy to discrete parts of the decision-making process due to their expertise. Two of the most striking findings are the insularity of the stakeholders from each other and how the SM is at the centre of all communication leading to clear information asymmetry.

**Motivation for retrofit implementation**

The insight obtained from the IM brought to light the fact that the increase in efficiency expected through the implementation of retrofits was a collateral result of the strategy that was being adopted to ensure the equity tied up in the vessel would still be accessible to the vessel owners (Steps 1-4 in Table 4.6). The vessel was approaching its 10 year mark leaving 5 years of usable lifetime left based on the average lifetime for MPP vessels as confirmed by the charterer. The financing bank was valuing the asset at around $2m less than the value required as collateral thus the implementation of the $2m worth of retrofit interventions was an ideal option as:

- It ensured that the vessel would still be competitive in terms of fuel consumption despite its age when compared to other vessels in the MPP segment
- It increased the equity value of the vessel enough to be able to transfer
### Table 4.6: Steps in the retrofit decision-making process as elicited by the case study

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SPV wants to get out of loan due to vessel age. Bank asking for more than vessel valuation.</td>
<td>Vessel owner</td>
</tr>
<tr>
<td>2</td>
<td>Shareholders in vessel owning SPV do not want to contribute more capital to get out of the loan.</td>
<td>Vessel owner</td>
</tr>
<tr>
<td>3</td>
<td>SPV facing insolvency. Interested institutional investor found.</td>
<td>SPV</td>
</tr>
<tr>
<td>4</td>
<td>Independent of the above, SM discusses with charterer to extend charter agreement. Charterer interested if vessel made more competitive due to considerable age.</td>
<td>SM</td>
</tr>
<tr>
<td>5</td>
<td>SM assessment of viable solutions. Decides on fuel saving options, arbitrary target of 15-25% savings.</td>
<td>SM</td>
</tr>
<tr>
<td>6</td>
<td>Charterer agrees in principle to long term TC if savings are guaranteed.</td>
<td>SM</td>
</tr>
<tr>
<td>7</td>
<td>SPM conducts shortlisting of solutions. Consultancy conducts energy audit, initial scoping, preliminary solution assessment and savings estimates.</td>
<td>SM</td>
</tr>
<tr>
<td>8</td>
<td>SPM contacts yards for implementation estimates through yard agent and network contacts.</td>
<td>SM</td>
</tr>
<tr>
<td>9</td>
<td>Charterer offered CP for 5-year fix at higher than average day rate with savings guarantee clause in CP. Charterer accepts.</td>
<td>SM</td>
</tr>
<tr>
<td>10</td>
<td>Institutional Investor satisfied with IRR based on new charter party. Accepts to acquire vessel.</td>
<td>SM</td>
</tr>
<tr>
<td>11</td>
<td>Financing bank sought for retrofit intervention. Accepts on basis of long term fix at high charter rate.</td>
<td>SM</td>
</tr>
<tr>
<td>12</td>
<td>SM’s IM creates new financial structures for vessel ownership</td>
<td>SM</td>
</tr>
<tr>
<td>13</td>
<td>Consultancy sanctioned to start detailed design of solutions.</td>
<td>SM</td>
</tr>
<tr>
<td>14</td>
<td>Yards scoped and selected on price, availability, expertise and reputation.</td>
<td>SM</td>
</tr>
<tr>
<td>15</td>
<td>Class approval obtained for modifications.</td>
<td>SM</td>
</tr>
<tr>
<td>16</td>
<td>Vessel in for 10-year dry docking, retrofits implemented, performance measurement system installed and commissioned.</td>
<td>Retrofit yard</td>
</tr>
<tr>
<td>17</td>
<td>Vessel leaves dry dock on new charter party and relaying CM performance data.</td>
<td>Charterer</td>
</tr>
<tr>
<td>18</td>
<td>Class verification of savings based on NR</td>
<td>Classification society</td>
</tr>
</tbody>
</table>
This provides a very interesting insight as the retrofits in this case made the vessel less susceptible to environmental obsolescence through a mechanism that also made it more resilient to financial obsolescence. While the decision for paying an EEP in this case is found not to be EE, the data obtained from the stakeholder interaction and decision-making provides a unique insight into the drivers that lead to the investment which cannot be taken at face value.

**Information use and asymmetry in decision-making process**

**In-service data** A shared notion was noted by all the interviewees regarding the essential role that in-service data plays in the future of shipping however this was at odds with the practices that were seen to be upheld.

Although in this case, a CM system was implemented, the SM technical team was not making use of the high frequency measurements except for monthly aggregations. This led to a fault in shaft power measurement being detected several weeks after when it was flagged through a data review for this case study. Performance is assessed using NR-based speed-consumption curves by the charter desk, who use them for performance disputes. No indication of the way the curves are created except that obvious outliers are filtered out. No consideration was given to measurement uncertainty and no distinction was made between uncertainty stemming from NR and CM and its the effect on performance monitoring.

The CM system was implemented to validate performance improvement due to the interventions but no plans were made to develop the supporting data framework and associated software required to do so. The situation remains the same more than two years after the implementation of the CM data col-
lection system with the in-house performance monitoring platform to analyse and visualise the CM data being still under development. One of the reasons this happened was the fact that the SPM dedicated to this task was managing the whole retrofit project as well as developing the software while only working part-time.

The situation is very different on the charterer side where considerable resources are dedicated to use CM in-service data for operational purposes. In this case, the charterer has a second third-party measurement system (independent from the one installed by the SM) installed on board which relays data back to shore every 30 minutes and this information is actively used in day-to-day operations. Vessels are constantly monitored and performance measured against dedicated Key Performance Indicator(s) (KPI).

As soon as vessels stray too far from the bounds set for these KPI actions are triggered to rectify the situation including instant communication with the ship operator to mitigate any problems at the root cause. Triggers are also set to apply slow steaming based on the bunker fuel price, consumption and the commercial importance of timely dispatch. One example where the charterer’s attention to data proved to be important was when the vessel was being operated at a higher draught due to commercial demands which lead to a significant drop in savings. This second system is also a signal that there is a lack of trust between charterer and owner.

The charterer is found to have a prized relationship with the data service provider that built their data collection system. The system uses data from sensors on board the vessel along with AIS and metocean data to provide normalised performance information. At the beginning of the data provision service, representatives of the data collection and processing service spent
some days on board the vessel to better understand how the vessel was operated thus creating good technical and relational foundations.

These two distinctly different attitudes towards the collection and use of in-service data stem from the fact that it is in the charterer’s interest to ensure that the vessel is performing as best as it can due to the costs related to bunkering. However, it is also essential for both parties that enough proof is at hand to make sure that any performance claims, especially in this case where the charter party includes a savings clause can be corroborated.

When commenting on the industry at present, the charterer mentioned the lack of consolidation of data measured by different measurement systems. A wide range of systems available which makes it very confusing and intimidating to approach, resulting in a classic barrier caused by information overload (Mintzberg et al., 1976). Thus, data-provision companies are increasingly driven to provide a one-stop-shop service which includes all the elements of performance monitoring from the instrumentation all the way up to software development and analysis.

**Retrofit performance estimates** At the beginning of the design process for the retrofit interventions, the consultant was contracted to carry out an energy survey and provide a feasibility study comparing different viable solutions. In this case, the SM provided a set of operating profiles that are typical for the vessel to be used as the basis for the feasibility study. This is a standard course of action for most merchant ships as they operate on conventional routes at similar draughts and speeds. However, it is important to note that due to the tramp market in which MPPs operate, a typical operating profile is difficult to establish since the speed and draught may be significantly different on each leg that is carried out. In this particular case, the consultant only used
the operating profiles specified by the SM, even though they had access to NR data which could have been used to draw up operating profiles based on historic operation.

The estimated energy-saving performance of the retrofits was estimated using CFD, as is common practice. Although attention should be given to the uncertainty associated with this computational method (Roache, 1997), this uncertainty was not communicated to the SM. Instead, a conservative value for expected savings was provided.

This conservatism is a common thread; the SM is even more conservative (in this case, quoting 21% savings while actually predicted to be 26%) in the charter party fuel savings clause. A lack of transparency is noted as the charterer was not made privy to the technical reports prepared by the consultants which contain the results from the CFD analysis.

These instances of information asymmetry illustrate clearly how uncertainty is added to what is already a very uncertain environment. In this case, the cost benefit analysis carried out by the charterer when deciding to commit to the long term fixing of the vessel was based on an inaccurate savings estimate. The margins put in place could have had an adverse effect if the charterer refused the deal leading to it falling through and subsequently preventing the retrofit from taking place. In reality, charterer experienced higher savings than the conservative ones communicated by the SM.

While this is a positive impact, another instance of information asymmetry is created as the better performance was not relayed back to the consultant. This feedback would be invaluable to the consultant as it would help build confidence in their design and analysis for savings estimates and possibly reduce their conservative margin in the next project they take up. However, the con-
sultant confirmed that most clients break off contact as soon as the project is complete and nothing is heard of it again unless something goes wrong. The SM would also have benefited significantly from receiving the feedback regarding the high savings to inform the design of future charter agreements which could be made more competitive if the conservatism is removed. Presumably the better than expected savings can be measured by the SM using the installed CM performance monitoring system however, as discussed above, the high frequency data is not being used at the moment with reliance still being on NR.

4.4.2 Technical documentation

While a limited number of documents were provided for this case study by the SM, these gave insight into specific elements that were not raised verbally during the interviews but filled in important knowledge gaps.

Vessel technical documentation

While the documentation for sea trials, model tests and engine commissioning reports were kept by the SM it was unclear which documents held which information. The SPM noted that only scans of the original documents were know to exist for the whole class of vessels (four sister vessels in this case in the SM’s portfolio). The quality of the documents was poor with hand written additions making some parts illegible and no digital versions of the data held. The SM commented that this was commonplace as yards and test tanks largely depended on hard copies when the vessel was built. It was confirmed with the technology consultancy that they also had access to the same documents. Although they described this as not ideal, the documents were used for the
retrofit design and implementation.

**Retrofit performance validation**

The classification society played a small but significant role at an important stage in this retrofit implementation process. The society is one of the leaders in the industry with a rich history of experience in the sector, specifically EE interventions and retrofits. It provides insight into how performance is measured and what class considers to be a robust way to do this. This is very significant as in shipping, classification societies are highly respected and represent a mainstay of sound best-practices and an assurance of safety, quality and transparency (Stopford, 2009).

While the charterer experienced significant fuel savings, it is difficult to attributed this to any single intervention from the basket of EETs applied to the vessel. While the savings target set internally by the SM might be satisfied, it is unclear as to what the actual increase in performance was due to the lack of benchmarking or standardisation for verification.

This was particularly evident when reviewing the verification study by the classification society. Several shortcomings were found mainly related to data quality and methodology rigour. Data from sister vessels was found to have been used to create a larger dataset as, due to low data quality, multiple data points from the original dataset had to be filtered out during the pre-processing stage. This is particularly problematic given that the sister vessels had a different maintenance and efficiency intervention schedule.

There was no attempt at using the data from the CM system and no indication on the uncertainty that was included in the final validated amount of fuel savings. A value of 26% annual fuel savings was presented in this report with-
out indicating that this is an average figure obtained using an extrapolation of
a deterministic assumption. When the ISO 19030 methodology was applied
to assess the retrofit performance, a 14% ± 6% fuel saving was estimated
leading to a significantly different conclusion (see Section 4.4.3).

Special retrofit performance clause

A special clause was added to the standard TC already in use for the fixture
of this vessel with the same charterer. The clause guarantees a minimum
21% fuel savings on the existing performance clause. While a guarantee is
provided, this is contingent on the conditions of the performance clause and
no indication of how this is measured or verified are provided. This factor
added to the typical vagueness of performance clauses which can lead to
performance claims that are difficult to settle.

Some transparency is provided as the expected savings are presented sep-
arately from the normal consumption. This can be attributed to the existing
relationship between the owner and charterer. There is also an explicit note
stating that any savings above the guaranteed 21% will be the charterer’s to
benefit from. Clear shortcomings are identified as the charterer is not given
specific details on how the savings can be evaluated. Moreover, savings are
expressed in terms of bunker savings (rather than power savings) which is
not ideal as additional factors can affect savings including engine wear, part-
load performance, maintenance and fuel calorific value which introduces more
uncertainty.

In the performance clause, another instance of information asymmetry can be

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8 The clause itself is embargoed due to commercial sensitivity thus no specific details can
be disclosed.
seen in the reduction in expected savings by 5% on the quoted value from the consultancy (that had already been conservative in providing the 26% savings figure). While this is done to mitigate risk on the owner side, it creates an environment that fosters adverse selection to the ultimate detriment of both parties. Thus, the performance clause is identified to be a key component that bridges the technical and commercial aspects of an EER project as it informs the charterer of potential savings and establishes a basis for an EEP for the owner to recoup costs given the split incentive in TC.

4.4.3 In-service data

A detailed analysis of the raw in-service data provided was undertaken. This included extensive consolidation, filtering and visualisation which allowed a thorough understanding of quality failures resulting from the data collection. Having access to the raw data provided a good opportunity for triangulation with other primary sources, adding rigour to the findings.

Data collection and quality

The datasets in Table 4.4 show that, while consistent NR data collection has been carried out since 2011, there is a lack of consistency in CM data. This was due to technical problems in instrumentation installation. Since CM data collection was started after major interventions were carried out in February 2016, no reference period can be set up with an equivalent dataset from before the intervention took place. Another problem identified by the SPM was the difficulty in consolidating data from three different systems; the new CM installation, existing weather monitoring (for metocean conditions) and loading computer (for draught). This was due both to a hardware problem with
wiring and onboard instrumentation cabinets and also a software challenge where different data transfer protocols make integration into one system technically challenging. While several service providers offer this service, the SM expressed signs of information overload and bounded rationality in making choices echoing findings by Poulsen et al. (2018).

Table 4.4 gives details regarding the resolution of parameter measurements which are collected at 5 minute, 15 minute or 24 hour intervals. This implies that, while performance can be estimated at a high resolution, normalisation for weather conditions and draught cannot be carried out. On a deeper dive into the data, significant gaps and outliers were identified caused by a lack of monitoring of the data collection system by the SM. Figure 4.11 shows a gap in speed loss from mid-2014 to mid-2015 due to an error in the power meter measurement due to a software update. Similarly, in mid-2016, a set of outlying data points were identified which were found to be due to an error in STW logging. These errors were infilled using extrapolation and SOG respectively for the purposes of this research. Such gaps in data make it increasingly difficult to use the data for long term trend analysis.

Figure 4.11: Speed loss time series following BSI (2016b), before and after corrections denoted by shading
Evaluation of performance

With regards to setting up of reference and evaluation periods, there are several options that can be considered for the application of speed loss analysis as per ISO 19030. Figure 4.12 illustrates the reference and evaluation data sets that were used to determine the affect of the EE interventions that allowed six months’ worth of data before and after without interfering with other interventions. Table 4.7 compares findings for the evaluation of performance using NR data with regards to interventions carried out in February 2016 with different reference periods. The detailed analysis of performance evaluation can be found in Appendix A.3.

In Case 1, the immediate effect relative to the performance before the interventions is determined. As expected a large step change is observed as retrofits (rudder bulb and bulbous bow change), Hull Cleaning and Coating (HC) and Propeller Polishing (PP) was conducted during the Dry-Docking (DD) period. Following the recommendations in BSI (2016c), the uncertainty in the speed
Table 4.7: Comparison of speed loss dependant on reference period

<table>
<thead>
<tr>
<th>Case</th>
<th>Reference period*</th>
<th>Evaluation period*</th>
<th>Speed loss (%)</th>
<th>Uncertainty (%)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pre-Feb 2016 retrofit</td>
<td>post-Feb 2016 retrofit</td>
<td>14.30</td>
<td>±6.47</td>
</tr>
<tr>
<td>2</td>
<td>post-April 2014 intervention</td>
<td>post-Feb 2016 retrofit</td>
<td>16.00</td>
<td>±6.47</td>
</tr>
<tr>
<td>3</td>
<td>pre-April 2014 intervention</td>
<td>post-April 2014 intervention</td>
<td>4.06</td>
<td>±6.47</td>
</tr>
<tr>
<td>4</td>
<td>dataset start (2011)</td>
<td>post-Feb 2016 retrofit</td>
<td>6.65</td>
<td>±6.47</td>
</tr>
</tbody>
</table>

* all reference and evaluation periods 180 days long

** as per BSI (2016)

loss performance indicator is dependent on the frequency of data used and the type of measurement proxies used. For the cases in Table 4.7, the uncertainty in the speed loss performance indicator may be as high as 6.47% (at a 95% confidence interval) due to the relatively low data frequency and short evaluation period.

Further investigations can be carried out to obtain a more accurate estimate of uncertainty but this is a clear indication of the importance of having good quality and high frequency data collected. Translating the observed performance improvement into fuel consumption, the indicated fuel savings related to the intervention are around 20% at reference speed however, savings may be as low as 7% (at a 95% confidence interval) if one carries through the uncertainty that is associated with the speed loss. Therefore, a more accurate quantification of savings may be represented as 14% ± 6% when using the Admiralty formula to convert speed to fuel consumption based on the vessel specifications and engine load.

The reference period for Case 2 is taken just after the April 2014 intervention (HC and PP) while the reference period for Case 3 is taken before the April 2014 intervention. Thus, theoretically, subtracting the speed loss in Case 3 from that in Case 2 will eliminate the effect of the HC and PP and leave only
the improvement due to the retrofits. It should be noted that any overlap in reference or evaluation periods between interventions will not allow for isolation of the effects of the intervention.

While some interventions (such as hull cleaning and propeller polishing) are meant to restore vessel performance to its original state, others such as hydrodynamic retrofits are aimed to improve vessel performance beyond the design performance at the beginning of life. Therefore, having data for a reference period during the start of the life of the vessel would be ideal to determine if performance has improved beyond the designed capability.

Case 4 is the best attempt possible at trying to determine the effect of retrofits relative to the original condition of the vessel. This estimated performance improvement is relative to the ship’s condition at the start of the dataset. It appears from the record of NR data, that the ship had deteriorated significantly before this. The consequence of the intervention was therefore to return the performance of the ship to near to its original performance, rather than to make a significant improvement relative to its original performance (e.g. when first in service).

The quality of data available prevented a meaningful quantification of performance relative to the ship’s original performance. Sea trials data was available however, the performance measured after the 2016 intervention was still underperforming relative to these performance quantifications (Figure 4.13).

4.5 Discussion

The data collected and analysed in this chapter covers a wide swath of topics, some of which were set from the outset of the research and some others
which were identified during the research process. Due to the nature of qualitative analysis, a question around representativeness is raised. As discussed in Section 4.2, the selection of this case study was made as it was a good candidate for investigating the research question posed. The heterogeneity of the industry and lack of literature covering this theme (as discussed in Chapter 2) make generalising any outcomes difficult. However, drawing on Flyvbjerg (2006), the value of case study research should not be undermined by the fear of lack of generalisation as can be seen from several studies that resulted in significant findings based on single case studies such as Lowe et al. (2007). The appropriateness of case selection is further discussed in detail in Chapter 7.

However, the owner-charterer relationship based on a TC and the associated cost distribution structure is at the foundation of what is required to create a suitable quantitative model (Stopford 2009). Although literature in the shipping sector is limited, examples in the building environment for rented commercial
properties show many of the same dynamics with regards to energy performance specifically when retrofits are involved (Charlier, 2015; Liang et al., 2016).

4.5.1 Structure and stakeholder involvement

From the qualitative data gathering, an understanding of the roles of different parties within the structure of their companies and within the project was constructed. Once the stakeholder interaction was determined from the interviews (Figure 4.4), the most important players were identified to be the SM and charterer.

The lack of SM experience in EER, performance modelling and use of data clearly limits the extent of the potential improvement achieved. While Poulsen and Sornn-Friese (2015) have shown the important role that third-party management can have on vessels, in this case this was not observed to be so. This is evidenced by the SM’s lack of resources dedicated to data management past the initial investment in data acquisition. This results in a lost opportunity to get a good return on investment form the instrumentation installation.

While the system was specified to be ISO 19030 compliant, it did so at an entry level. Not all the necessary variables were measured at high frequency leading to high uncertainty when evaluating performance. As Johnson von Knorring (2019) also found, there was no specific targeted efficiency effort but rather an investment with no forward planning as to a strategy to maximise the potential both operationally and commercially.

The corporate structure of ownership is observed to create a segregation of ownership and operation activities. This in part explains how the decision-making for this investment was driven by the addition to vessel value rather
than increase in efficiency. This is typical behaviour seen in asset play which was also identified in Poulsen and Johnson (2016). This is especially relevant given the move to the second-hand market - the MPP sector sees the 10 year mark as a cut off for change in ownership to markets with lower requirements. The owner sees a value in the asset, the manager sees value in the operating profit.

On the charterer side, the decision to commit to a higher charter rate was driven by the market opportunities that the investment would open when considering potential revenue from additional flexibility and opportunity of attracting higher transport rates. This decision was taken for the market situation at the time despite being a long term commitment. This suggesting that a decision support system that accounts for variability of parameters (such as freight rates and bunker price) and takes a probabilistic approach would be better suited for charterers to make such decisions.

The relationship between the SM and charterer is observed to be essential in this retrofit implementation, however the extent of information sharing between parties still signals lack of trust. This is embodied in the conservatism built into the CP performance clause. This leads to uncertainty in projecting accurate operating cash flows by the charterer as seen when the vessel deviated from the defined operating condition resulting in a drop in savings.

4.5.2 Information and data use in decision-making

While considerable effort and expense was invested in increasing the quality and quantity of performance data collected, several shortcomings hindered the potential of the investment. The concerns brought forward by Aldous et al. (2015) with regards to the additional uncertainty due to low frequency data
and measurement uncertainty are both very much present in this case study. Commercial decisions are based on speed-consumption curves are not standardised resulting in an ad-hoc approach which makes comparison with other vessels difficult and leads to increased uncertainty in vessel performance. The use of speed-consumption curves to provide single point estimates for vessel performance in the CP leaves the charterer open to adverse selection given the information asymmetry as defined by Akerlof (1970). Moreover, a gap was noted between the SM’s technical understanding and commercial decision-making as pointed out by Karaminas and Shen (2016).

This information asymmetry also applies to the provision of savings estimates in the performance clause. Following the review of the classification society’s verification, a lack of clarity is observed in how savings are evaluated casting doubt on the robustness of the method. These instances of information asymmetry and poor information are identified and summarised in Table 4.9 and 4.10. These distinct issues within the decision-making and implementation process are a direct result of the market failures identified in barriers literature as discussed in Chapter 2.

### 4.6 Chapter Summary

In Chapter 3, RQ1 was defined as: What is the current practice in decision-making for chartering and EE retrofit appraisal?. The findings from the case study identified that, in the instance observed, information related barriers with regards to vessel performance are not linked exclusively to the inclusion of EER but are intrinsic to the owner-charterer relationship and the conventional technical, operating and commercial behaviours within the industry especially
in the TC market. While generalisation based on the case study only may not be considered robust, the strong evidence base and analysis carried out, together with the literature available gives confidence in the conclusions below.

Table 4.8 captures the most relevant barriers identified in the case study and artefacts that stem from them. This provides a robust foundation for the design of a quantitative model that captures these artefacts and the associated dynamics in stakeholder interaction.

Table 4.8: Information barrier categories and artefacts identified

<table>
<thead>
<tr>
<th>Barrier category</th>
<th>Barrier artefact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data quality and acquisition method</td>
<td>Data collection frequency and dataset size</td>
</tr>
<tr>
<td></td>
<td>Exclusion of measurement error</td>
</tr>
<tr>
<td>Performance modelling</td>
<td>Performance modelling (speed-consumption curve based)</td>
</tr>
<tr>
<td></td>
<td>Single point savings estimate from EET</td>
</tr>
<tr>
<td>Information asymmetry</td>
<td>Communication of vessel performance between owner and charterer</td>
</tr>
<tr>
<td></td>
<td>Communication of expected savings from EET between owner and charterer</td>
</tr>
</tbody>
</table>

This case study covers both the charterer’s decision to fix a vessel and also the owner’s choice of EER. Although quantitative input informed stakeholder’s decisions, information asymmetry dominated the process despite the existing good relationship between the owner and charterer. This informs the design of the quantitative model developed in Chapter 5 which has to capture the behavioural aspect of the interaction along with techno-economic factors.
Table 4.9: Identified shortcomings in data and performance modelling

<table>
<thead>
<tr>
<th>Activity</th>
<th>Stakeholder</th>
<th>Information type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data quality and acquisition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data collection</td>
<td>SM</td>
<td>Performance data</td>
<td>Not all variables required for performance evaluation measured at high frequency. Only NR could be used for this with the associated measurement errors.</td>
</tr>
<tr>
<td>Data management</td>
<td>SM</td>
<td>Performance data</td>
<td>Lack of foresight in providing resources for data management and lack of monitoring during data collection leading to gaps in data.</td>
</tr>
<tr>
<td>Data consolidation</td>
<td>SM</td>
<td>Performance data</td>
<td>Difficulty in consolidating data from three different systems into one output.</td>
</tr>
<tr>
<td>Selection of data collection system</td>
<td>Charterer</td>
<td>Data collection type</td>
<td>Information overload when selecting performance monitoring system due to a large number of options and technical complexity</td>
</tr>
<tr>
<td>Data collection</td>
<td>Charterer</td>
<td>Performance data</td>
<td>Charterer installed own system for data collection due to SM not providing access to existing system and lack of trust in data provided.</td>
</tr>
<tr>
<td><strong>Performance modelling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vessel modelling</td>
<td>SM</td>
<td>Performance model</td>
<td>No standardisation in creating speed-consumption curves used for commercial decision-making</td>
</tr>
<tr>
<td>Technical vs. commercial performance</td>
<td>SM</td>
<td>Performance model</td>
<td>Speed-power curves used in technical evaluation and implementation of ISO 19030 but commercial decision-making based on speed-consumption curves</td>
</tr>
<tr>
<td>EER performance</td>
<td>EER</td>
<td>EER performance</td>
<td>No standardised method of measuring impact of EER and isolating benefits of particular technologies when applied in conjunction with others.</td>
</tr>
</tbody>
</table>
Table 4.10: Identified information asymmetries

<table>
<thead>
<tr>
<th>Activity</th>
<th>Stakeholder 1</th>
<th>Stakeholder 2</th>
<th>Information type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilisation and performance characterisation</td>
<td>SM</td>
<td>Consultant</td>
<td>Operating profile</td>
<td>Manager asked for only a set of specific operating profiles to be evaluated by the technology provider even though NR data was made available to the consultants.</td>
</tr>
<tr>
<td>Solution characterisation</td>
<td>Consultant</td>
<td>SM</td>
<td>CFD results</td>
<td>The consultant did not provide any uncertainty when reporting the estimated gain in performance obtained from CFD analysis that can be expected with the proposed retrofit intervention. Consultants decided to be conservative in their estimates quoting only an average expected saving that was obtained from running several different cases, some of which resulted in efficiency penalties rather than improvements. CFD results were not checked by a third party thus the party providing the performance estimate is seen to be inherently biased in showing their solution is the optimal choice.</td>
</tr>
<tr>
<td>Charter-party design</td>
<td>SM</td>
<td>Charterer</td>
<td>Performance declaration</td>
<td>In CP performance clause, one fixed value of savings was determined strategically by the SM IM. It included a degree of conservatism by reducing promised savings from the estimate provided by the consultancy to mitigate risk of performance claims. The charterer was given no access to the results of CFD analysis.</td>
</tr>
<tr>
<td>Validation</td>
<td>SM</td>
<td>Class society</td>
<td>Performance data</td>
<td>When a class society was asked to validate the savings estimate based on in-service performance data, this was only based on NR data which was found to be of very low quality. The methodology used by the class society was also not found to be robust.</td>
</tr>
<tr>
<td>Design feedback</td>
<td>SM</td>
<td>Consultant</td>
<td>Performance data</td>
<td>Once retrofit was completed, there was no communication or feedback given to the consultant which would help develop better designs based on performance in operation. The only feedback that is received is usually when performance is less than that estimated.</td>
</tr>
</tbody>
</table>
Chapter 5

Quantitative modelling of stakeholder interaction

5.1 Aim and objectives

The previous chapter provided a better understanding of the role which information use, communication and stakeholder interactions play in decision-making based on vessel performance. This chapter develops an analytical framework that represents the nuances of this dynamic relationship and that quantifies the effect of the barrier artefacts identified in Chapter 4 (Figure 5.1). This chapter endeavours to:

- Develop a theoretical framework to represent the strategic interaction between the vessel owner and charterer at the decision-making phase in a TC fixture. The framework will take into consideration the barrier artefacts related to information asymmetry.

- Develop a techno-economic model to incorporate uncertainty with re-
Figure 5.1: Method framework - Chapter 5
gards to vessel performance. This model will deal with the barrier artefacts related to data quality, acquisition and performance modelling starting from in-service data.

- Use the framework and model to simulate a Business-As-Usual (BAU) scenario to illustrate the risk exposure of each party due to the shortcoming in information.

## 5.2 Chartering mechanics

Figure 5.2 is a graphical representation of the TC routine in terms of information flow between stakeholders for the pre-fixture, fixture and charter execution phases. An extensive review of the chartering routine and standard party forms can be found in Appendix A.4.

![Figure 5.2: Typical TC routine showing stakeholders and information flow during pre-fixture and charter execution](image-url)

The most important aspects related to information use and asymmetry related
specifically to vessel performance, that occur within CP agreements, are the performance clause and the associated performance declaration by the owner.

5.2.1 Performance clause analysis

A review of standard TC parties was carried out to determine how vessel performance is communicated to the charterer (Table 5.1). The study revealed several elements of interest; use of the word *about* when declaring performance or weather, weather threshold definition and performance definition under ballast and laden condition. The following paragraphs will go through these observations and discuss the information barriers that are inherent in standard CP.

<table>
<thead>
<tr>
<th>Party name</th>
<th>Year*</th>
<th>Organisation</th>
<th>Vessel Type</th>
<th>Weather Spec</th>
<th>Laden Spec</th>
<th>Ballast Spec</th>
<th>&quot;about&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASBATIME</td>
<td>1981</td>
<td>ASBA</td>
<td>-</td>
<td>Open</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BALTIME 1939</td>
<td>1974</td>
<td>BIMCO</td>
<td>Dry bulk</td>
<td>Good</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BHPBTIME</td>
<td>2003</td>
<td>bhp billion</td>
<td>Dry bulk</td>
<td>BF4</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIMCHEMTIME</td>
<td>1984</td>
<td>BIMCO</td>
<td>Chemical Tanker</td>
<td>BF4</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIMCHEMTIME 2005</td>
<td>2005</td>
<td>BIMCO</td>
<td>Chemical Tanker</td>
<td>BF4</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>BOXTIME</td>
<td>2004</td>
<td>BIMCO</td>
<td>Container</td>
<td>BF4</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOXTIME 2004</td>
<td>2004</td>
<td>BIMCO</td>
<td>Container</td>
<td>BF4</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>EXXONTIME</td>
<td>2005</td>
<td>ExxonMobil</td>
<td>Tanker</td>
<td>BF6 &gt;12hrs</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>GASTIME</td>
<td>1980</td>
<td>BIMCO</td>
<td>Gas carrier</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>GENTIME</td>
<td>1999</td>
<td>BIMCO</td>
<td>Dry bulk</td>
<td>BF4</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTERTANKOTIME 80</td>
<td>1980</td>
<td>INTERTANKO</td>
<td>Tanker</td>
<td>BF7 &gt;12hrs</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>LINERTIME</td>
<td>2015</td>
<td>BIMCO</td>
<td>Container</td>
<td>Good</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LINERTIME 2015</td>
<td>2015</td>
<td>BIMCO</td>
<td>Container</td>
<td>Good</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NYPE2015</td>
<td>2015</td>
<td>BIMCO</td>
<td>General</td>
<td>BF4</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>SHEELLINGTIME 1</td>
<td>2006</td>
<td>Shell</td>
<td>LNG Carrier</td>
<td>BF5 &gt;12hrs</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>SHELLTIME 4</td>
<td>2003</td>
<td>Shell</td>
<td>Tanker</td>
<td>BF8 &gt;12hrs</td>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

*Latest revision.

The *about* legacy term in the clause codifies uncertainty around performance. It allows for a margin of variation when describing the warranted performance
given the inherent uncertainty in weather and operational factors. This adds complexity when speed-performance claims are brought up given that there is no fixed definition of the margin implied. When used in reference to speed in past arbitrations under UK law, it has been used to imply both a margin of 0.5 knots and 5%. In consumption, it has been used to imply 5% margin. There are also contrasting views on whether the margin can be used twice; both on fuel consumption and speed (Maynes, 1998; Williamson, 2012). In some cases, this term is also used in the CP when defining the already ambiguous BF weather threshold, adding another element of uncertainty (Coghlin et al., 2014).

The majority of clauses cover only laden condition performance which accounts for just over half the operating time for most bulk vessels. There is also significant variation in the weather threshold setting with most abiding to BF4 being the upper limit for which performance is guaranteed. In some cases these go up to BF8 while others do not give a specific definition and only state a good weather condition. As far back as 1990, UNCTAD (1990) specifically criticised speed-consumption clauses as being ill-defined with performance boundaries being too vague.

Not much variation was noted across charter parties with regards to performance declaration with the exception of ones by oil majors, Exxon and Shell, which went into significant more detail in their performance clauses. They also included a clause that specified that performance would have to be reviewed every six months and provided detailed explanations of circumstance when the charterer can make a performance claim and the procedure that is to be followed to determine the value of the claim. Another significant difference is the use of a tabular format for presenting consumption data at different speeds for the ballast and laden conditions. Although seemingly trivial, the provision
of physical space on the charter party document itself sets an expectation that this information has to be provided by the ship owner if they expect to be chartered in by these companies. The language used when stating performance indicates that this is a warranty and reinforces the fact that the performance is guaranteed under the conditions set in the contract.

A limited amount of innovation has been observed in recent years with some charterers specifying instrumentation and data collection to be ISO 19030 compliant (BSI 2016a) and others specifying particular weather service providers to be used as third-party verifiers of metocean data in case of weather related performance claims (VPO 2018).

Considering weather specifically, BF4 has been shown to be an effective threshold to allow comparison of performance (Hudson and Daniels Galle 2017) however it leaves the charterer with no indication of vessel performance in rough weather which can make up for a significant amount of the operating profile on certain routes. This is further hampered by the uncertainty related to manual reporting of weather conditions from the bridge and a mixture of BF and Douglas Scale numbers. This lack of standardisation is prohibitive to performance benchmarking.

**Strategic performance declaration in performance clauses**

Veenstra and van Dalen (2011) conduct a statistical study with a large data set (N = 4433) of TC. When comparing the warranted performance with the vessel design data, they identify strategic behaviour by owners who set the warranted daily fuel consumption and speed in a way that benefits them. The study found that warranted speed was systematically lower and warranted consumption systematically higher than the design values. The findings show that
this is strategically planned by owners to reduce their exposure to risk to performance related claims. Although the mean delta between warranted and design values for both speed and fuel consumption are small, the standard deviation is comparatively large.

A more interesting hypothesis confirmed by data was that warranted speed and consumption will vary between different contracts for the same vessel. Little evidence was found that warranted performance changes on a contract-by-contract basis however a cyclic trend was noted that followed market conditions as well as uncertainty in bunker price (increased volatility sees the difference between design and warranted speed decrease). The authors also observed a larger spread of warranted performance for vessels with a high size/consumption ratio (ie. more efficient). This implies that these vessels have more leeway and can be made to look more or less competitive, as required, given their good efficiency. This can be taken advantage of in a situation where there is a surplus of tonnage and an owner could use some of that leeway to undercut the competition and fix the vessel while still not being at risk of underperforming due to the margins applied.

This evidence of strategic behaviour suggests that performance is not negotiated but used by the owner to their advantage as required thus consolidating the [PA] problem in this case. By under-representing speed and over-representing consumption, the owner can build some leeway allows flexibility for operation whilst being technically within the warranted performance envelope. While this is of interest to both parties given performance claims are notoriously burdensome, the problem is that the charterer is not formally in-

---

9It should be noted that this study is based on data between 1997 and 2005 just before bunker prices started to increase thus, vessels were more likely to be operating close to their design speed.
formed that this is done and what the magnitude of the leeway is.

Having described the relevant aspects of the chartering routine, a theoretical framework to capture the interactions described above is designed. It includes the noted information barriers related to chartering practice. From the review of literature and prototyping with various modelling options, a probabilistic techno-economic model is developed framed within a strategic game between charterers and owners. This allows for the creation of a modular design providing flexibility around inputs, outputs and scenario characterisation. The following sections lead through the development of the model followed by a baseline simulation that represents a BAU scenario.

5.3 Theoretical mapping of stakeholder interaction in chartering

5.3.1 Game design

The aim of this section is to model the owner-charterer dynamic in a game which replicates the adverse selection paradigm and provides a framework to illustrate the propagation of uncertainty in energy efficiency decision-making through information related barriers listed in Table 4.8. In order to constrain the problem, a boundary is set around the owner and charterer as the two players that will be represented in the pay-off matrix (Figure 5.310). It should be noted that no third-party brokerage is assumed in designing this game which would add an intermediate layer between the charterer and owner which could add further uncertainty. An assumption is being taken that the owner and charterer have an in-house chartering desk with the same information that would be

10 Where P represents the financial pay-off described as operating profit.
available to a broker.

Player 2

<table>
<thead>
<tr>
<th>Strategy C</th>
<th>Strategy D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{1}^{AC}, p_{2}^{AC}$</td>
<td>$p_{1}^{AD}, p_{2}^{AD}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{1}^{BC}, p_{2}^{BC}$</td>
<td>$p_{1}^{BD}, p_{2}^{BD}$</td>
</tr>
</tbody>
</table>

Figure 5.3: Two-player game framework

Player and pay-off characterisation

Players Luce and Raiffa (1989) define rational players as having well specified outcomes with a consistent pattern of preference and strive for maximum utility. For the purposes of this study and following von Neumann and Morgenstern (1944), it is assumed that both players want to maximise utility in terms of operating profit. The rationality of the actors will be assumed in the first build of the model. For the TC model, the optimal outcome for each player is hypothesised in Table 5.2.

Table 5.2: Player optimum outcome classification

<table>
<thead>
<tr>
<th>Player</th>
<th>Optimal outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimisation</td>
</tr>
<tr>
<td>Owner</td>
<td>Operating costs</td>
</tr>
<tr>
<td></td>
<td>Investment payback period</td>
</tr>
<tr>
<td></td>
<td>Off-hire time</td>
</tr>
<tr>
<td>Charterer</td>
<td>Voyage costs (including bunker)</td>
</tr>
<tr>
<td></td>
<td>Charter cost</td>
</tr>
</tbody>
</table>
Owner characterisation  The owner is the Agent in this PA game and the strategies assigned are designed to represent the effect of an increase in transparency regarding vessel performance. Li et al. (2011) describe the owner’s strategy as providing Adequate Information and Not Adequate Information with regards to a building’s energy performance. This implicitly assumes that the information held by the owner is good and complete, however, this is not the case in vessel chartering decisions where in many cases the owner does not have good performance models. Thus, the strategy for the owner will focus more on investigating the effect of the barrier artefacts related to information asymmetry. The strategy is labelled as having High Transparency (HT) or Low Transparency (LT).

HT implies that the owner provides a higher degree of detail related to vessel performance. This does not imply that they share, for example, all NR during the charter but will share the speed-consumption model as well as the related uncertainty associated with the using the model during pre-fixture. Conversely, the LT case denotes the BAU where the owner sets the vessel performance clause unilaterally with the charterer not having any information as to how accurate it is. In simpler terms, under LT the charterer knows there is uncertainty but cannot quantify it. This information asymmetry may be a strategic move in many cases as Veenstra and van Dalen (2011) found evidence of the same vessel being chartered out at different warranted performance, suggesting active manipulation of inadequate information from the owner.11

Charterer characterisation  From the case study and industry outreach conducted in Chapter 4 trust between owner and charterer related to performance

11The duration of TC was not found to be a significant explanatory variable to the variation thus reducing the change that the difference is related to short term charter variations.
was paramount in conducting the fixture. Thus, the strategy to be explored in this work will be based on Trust and Not Trust. Mistrust usually leads to over estimation of bunker margins leading to difficulties in planning and over bunkering which directly affects cash flow for the charterer especially in tight markets.

Lack of trust has been found to be pervasive in shipping especially relating to EE interventions as Poulsen and Sampson (2019) find in their qualitative in-depth interview study. In this case, the mistrust is related to virtual arrival which, even though governed by a clause in the CP, is not implemented due to trust breakdown between stakeholders. Two levels of mistrust were identified: firstly between ports and shipping companies on the practicalities of implementing virtual arrival and secondly between owners and charterers with regards to the validation of fuel savings due to virtual arrival (despite third party weather service provider confirmation).

**Pay-off matrix**

For every scenario of the game, outcomes are generated based on the different strategies each can have. Adapting the method used by Liang et al. (2016) to analyse different types of building occupancy, the games are developed in a bottom-up approach to allow for the gradual introduction of complexity. This allows for the problem to be decomposed in distinct steps building up towards full model complexity without excluding any of the elements involved. Using the player and character descriptions above, a two-player game describing the strategic decision-making interaction is designed resulting in the pay-off matrix illustrated in Figure 5.4. The subscripts on the pay-offs denote the player while the numbering in the superscript identifies the strategy combination being considered.
Referring back to Table 4.8, the structure of the pay-off matrix represents the information asymmetry while the artefacts related to data quality, acquisition and modelling are considered through the design of the quantitative model in Section 5.4. With the quantitative evaluation of pay-offs, this method allows for comparison of the pay-offs of different strategic decision making by the players. In addition, the effects on the outcome of changes in the dynamic brought about by introduction of new technologies or increased transparency can be tested and qualified, for example.

5.3.2 Utility function definition

In order to determine pay-offs for the players through evaluating utility, similar studies were consulted in the energy performance field, mostly in the built environment, as well as shipping. A robust way to assess utility in a decision-making scenario under uncertainty is by evaluating expected cash flows based on the different decision scenarios. Wang et al. (2017) and Liang et al. (2019) use this method together with GT in order to evaluate the effect of incentives and the valuation of EE investments under uncertainty.
For the purposes of this study, utility shall be defined as described in Table 5.2 in terms of operating profit. This assumption is naive in that it does not consider other factors that charterers and owners assign utility to. Long-term relationships between stakeholders, being associated with particular companies, having a presence in particular markets and the value of having a vessel in the right place at the right time may be some of these factors. In the near future, as more stringent environmental regulation comes in place, this may be another factor that is perceived as having utility although not related to profit. For the purposes of this work, the above are not considered as their intangible value is challenging to model although they are factors that affect decision-making in the charter market.

Various shipping applications also use this approach including [Karslen et al. (2019), Schinas and Metzger (2019) and Psarros (2016)]. Thus, considering a conventional TC agreement simplified from Psarros (2016), the following generalised utility functions can be used to model cash flows and the expected operating profit for owner and charterer respectively over the length of the fixture period:

\[
E(\text{OP}_o^T) = \sum_{t=1}^{T} [R_t - CO_t] \\
E(\text{OP}_c^T) = \sum_{t=1}^{T} [-R_t - CV_t - E(B_t) + E(RF_t)]
\]

Where for a charter period \( T \) days long, \( OP_o^T \) is owner operating profit ($), \( R_t \) is the daily charter rate ($/day), \( CO \) is the average daily operating costs ($), \( OP_c^T \) is charterer operating profit ($), \( RF_t \) is freight revenue from transport work ($/day), \( B_t \) is the cost of bunker ($/day), \( CV_t \) is voyage costs ($/day).
It should be noted that \( B_t \) is normally an integral part of voyage cost however in this case it is being represented separately for clarity as this work focuses on EE. The notation \( E() \) is used to denote an expected term that can only be estimated when the vessel fixture is agreed as used in Karslen et al. (2019) and Liang et al. (2019). It is assumed that both players are rational and will strategically act to maximise their respective operating profit.

Operating profit for the owner can easily be evaluated as a good knowledge of operating costs through experience is assumed and the revenue from the charter is fixed\(^{12}\). The charterer pay-off however carries uncertainty in bunker cost and freight revenue which stems partially from market conditions (future utilisation, freight rates and bunker cost) and factors affecting bunker consumption (vessel performance, hull and propeller condition, weather). In evaluating risk exposure associated with chartering, Plomaritou and Nikolaides (2016) consider bunker cost to be one of the most substantial.

The owner is exposed to some risk stemming from performance claims that the charterer may raise based on the warranted consumption agreed upon in the charter party. However, at the pre-fixture stage neither, the owner nor the charterer can include these payouts in their assessment of costs throughout the fixture.

At the end of the charter period \( T \), the realised operating profit can be determined as:

\[
OP_T^O = \sum_{t=1}^{T} [R_t - CO_t] - PC_T^T
\]

\(^{12}\)There is also an inherent risk of defaulting or renegotiation from the charterer which is not considered.
\[ OP_c^T = \sum_{t=1}^{T} [-R_t - CV_t - B_t + RF_t] + PC^T \]

Where \( PC^T \) is the total value of any performance claims over the charter period \( T \) ($). The total value and probability of occurrence of performance claims is directly related to how conservative the owner is in warranting the vessel.

Following the equations above, the financial risk that the charterer is exposed to upon fixing a vessel can be described as the difference between the expected and the realised operating profit. With the basic generalised utility functions established, the four scenarios described in Figure 5.4 can be evaluated. The above general utility functions (Eq. 5.1 and Eq. 5.2) shall be used to determine the expected player operating profits for the four cases. It should be noted that the following has not been accounted for in order to limit the complexity of the modelling:

- Negotiation on the charter rate is assumed as this is outside the scope of this work. Negotiation specifically within the context of energy savings clauses has been extensively modelled and discussed by Psarros (2016) for the grain trade.
- No brokerage fees are included.
- Commercial and operational aspects of the charter have not been included in order to focus on vessel performance such as demurrage costs.

It is uncertain how these elements would impact the outcome of modelling results and are therefore set as null constants for the purposes of this work. This is not to signal that their importance is negligible but rather that accurate rep-
presentation requires a significant amount of dedicated work to build a strong evidence base to ensure robust mathematical representation. These aspects may be very important for other specific chartering games. Due to the modular nature of the modelling framework, additional pieces of code that cater for these can easily be added. The limitations and areas of further development are discussed in Chapter 7 and Chapter 8.

Having established the theoretical framework within which the owner-charterer decision-making relationship is represented, the next section leads into the quantitative model design to quantify the pay-offs and related uncertainty.

5.4 Quantitative modelling

The focus of this section is to design, build and test a techno-economic model that is able to represent the adverse selection game with the ability of quantifying the effects of uncertainty propagation on player utility, i.e. expected operating profit. Using the input obtained from literature in Chapter 2, the insight into stakeholder relationship dynamics and information use from the case study in Chapter 4 and the chartering mechanics discussion above, a modelling framework is devised as illustrated in Figure 5.5.

The individual modules and data sources will be discussed in the following sections thus developing the complexity of the model by ensuring rigorous and transparent treatment of each part. The simplified schematic also describes the sequence of steps executed in the model which is designed to:

1. Ingest, filter and pre-process on-board vessel data
2. Create performance model (speed-consumption curve)
3. Determine and communicate warranted performance
4. Estimate bunker consumption for fixture
5. Compute owner and charterer operating profit

This model is used to represent the four cases in Figure 5.4 with the purpose of comparing the outcome of a deterministic approach under LT against that of a probabilistic approach under HT which considers the propagation of uncertainty from different sources. MC simulation is used to obtain probability distributions for outputs such as bunker consumption and operating profit estimates.

To build and test the model, a performance dataset from a product tanker operating over three years is used to assess the applicability and robustness of the modelling strategy. Following this, results are compared to other findings in literature and qualitative analysis from Chapter 4. The scope is not to create the most accurate performance model but one that is representative of actual practice.
Given no standardisation or agreement on a method for performance modelling is in place (Adland et al., 2020), the steps in Figure 5.6 describe the in-service data pre-processing, filtering and modelling method adopted in this thesis. This provides a foundation to model uncertainty therefore the specific mathematic expression of the speed-consumption relationship can be altered as required. The following sections will go through the steps undertaken in detail.

**5.4.1 In-service data pre-processing for performance modelling**

This section describes the pre-processing of raw in-service data and definition for associated measurement uncertainty to be used in the creation of speed-consumption based performance models in Section 5.4.2. The primary parameters for performance modelling are the STW, main engine fuel oil consumption, environmental condition (or proxy thereof) and draught. These four
parameters are the minimum common denominator at any attempt at performance modelling.

Pre-processing

The data used in this work is a CM data set (data collected automatically for 1087 days and averaged over 10 minute intervals) for a product tanker with the characteristics in Table 5.3.

Table 5.3: Overall typical vessel characteristics

<table>
<thead>
<tr>
<th>Type</th>
<th>Product tanker</th>
<th>Segment</th>
<th>Handysize</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deadweight</td>
<td>50,000 t</td>
<td>Design speed</td>
<td>14.9 kn</td>
</tr>
<tr>
<td>Year of build</td>
<td>2013</td>
<td>Design draught</td>
<td>13.1 m</td>
</tr>
<tr>
<td>LOA</td>
<td>183 m</td>
<td>Installed power</td>
<td>9.48 MW</td>
</tr>
<tr>
<td>Beam</td>
<td>32.2 m</td>
<td>Fuel type</td>
<td>HFO</td>
</tr>
</tbody>
</table>

This high frequency dataset was averaged or summed over a 24 hour period to create NR. Vessel draught was not included in the dataset provided and derived from AIS data following the method used in Faber et al. (2020). While draught reporting in AIS data may be incomplete, this was not found to affect the findings significantly as the scope is not performance modelling. Loading condition assignment was based on mean draught as indicated in Figure 5.7. This works best with vessels that conduct full-to-empty trade such as bulk carriers (Jia et al., 2019).

Having established loading conditions, the data set can be divided into journeys or legs defined by a change in loading condition. This adds a level of granularity that, if added to information regarding port of departure and arrival

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13While taking draught as a continuous variable rather than a discrete value (ballast or laden), this is done in order to replicate what is conventionally done to produce speed-consumption curves.
Figure 5.7: Draught time series and loading condition allocation from AIS, allows controlling for routes taken when assessing performance. Any gaps in draught data were infilled by extrapolation followed by a smoothing algorithm to reduce noise.

**Filtering**

Filtering is applied to in-service datasets to remove spurious readings and provide a form of basic normalisation. In trying to replicate normal commercial practice, coarse filtering described in Table 5.4 was carried out on the limited amount of data that is collected in NR. An indication of the amount of data lost during the sequential filtering from the entire population (N = 1087 days) is also provided in Table 5.4 to illustrate how much data is lost at each stage resulting in only 34% being used.

Figure 5.8 illustrates why filtering was required to eliminate days with excessive fuel consumption and spurious speed readings including negative values. Having established the loading condition, two data sets were created. When working with the laden dataset, a speed filter was applied to remove outlier
Table 5.4: Sequential data filtering outcome on dataset size

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Condition</th>
<th>Dataset size</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1087</td>
</tr>
<tr>
<td>STW</td>
<td>kn</td>
<td>1STW≤40</td>
<td>790</td>
</tr>
<tr>
<td>TPD</td>
<td>t</td>
<td>5TPD≤40</td>
<td>667</td>
</tr>
<tr>
<td>Weather</td>
<td>BF</td>
<td>≤4</td>
<td>368</td>
</tr>
</tbody>
</table>

days when the vessel was operating at a slow speed (≤6 kn).

![Figure 5.8: Pre (left) and post (right) basic filtering](image)

Outlier filtering based on Chauvenet’s criterion (as per [BSI (2016b)](https://example.com)) is applied to further consolidate the dataset. This method can only be used for a population that follows a normal distribution. A Jarque-Bera test confirmed normality in the TPD population thus the outlier removal by Chauvenet’s criterion holds. In both datasets, no outliers were detected indicating that the sequential logical filtering as outlined in Table 5.4 was effective as illustrated in with Figures 5.9 and 5.10.
Figure 5.9: Histograms showing the primary variables before filtering

Figure 5.10: Histograms showing the primary variables after filtering
Measurement uncertainty

As with all measuring instruments and methods, there is measurement uncertainty associated with both instrumentation and measurement frequency. Aldous (2015) thoroughly explores instrumentation, data acquisition and problems associated with the precision and accuracy in their work. In a speed-consumption model, fuel consumption and speed are the primary variables. Thus the measurement uncertainty associated with these parameters needs to be considered. The uncertainty for these parameters is expressed in terms of a probability distribution in the HT scenarios to provide a more realistic outcome. Conversely, no measurement error is assumed in the LT cases.

Bunker consumption Several studies have investigated the merits of different methods for bunker consumption measurement with broadly similar observations when comparing three most common methods used; Bunker Delivery Note(s) (BDN), tank soundings and fuel flow rate meters. Recently, there has been a renewed interest in methods to measure fuel consumption as it is a widely accepted proxy for emissions measurement without the installation of emission specific instrumentation. Both the EU Monitoring, Reporting and Verification (MRV) and the IMO Data Collection System (DCS) accept fuel consumption measurement using the methods mentioned above by applying emission factors (DNV-GL, 2017).

In-depth studies by Aldous et al. (2015), Faber et al. (2013), Hunsucker et al. (2018) collate a lot of data regarding bunker fuel consumption measurement. This data is used to inform the following paragraphs.

BDN are well regulated and mandatory under Regulation 18 of MARPOL Annex VI for vessels of 400 GT or more and are required to be held on-board for
at least three years. They document the quantity of all fuels types bunkered and details such as supplier and sulphur content, thus making them important documents in case of any disputes regarding fuel quality. Given they are manually complied with no standardised format, they also carry the risk of human error (along with more trivial problems like illegible handwriting and bad carbon copies), physical loss and active changing of records by crew members who stand to gain from misreporting (Faber et al., 2013). BDN provide information as to how much bunker is taken onboard at periodic intervals rather than how much the vessel consumes making them impractical to use for vessel performance monitoring.

Tank soundings are the most common means of measuring bunker on board using knowledge of the tank geometry, depth of fuel oil, floating position, motions of the vessel and physical characteristics such as density (also documented in BDN). Several methods are in place to measure tank levels including electronic, mechanical and manual sounding which are usually used several times a day to determine the average contents of the tanks. The tank level is used as a proxy for fuel consumption which introduces significant uncertainty.

The uncertainty results from the accuracy of trim and heel measurements, accounting for motions while sounding, location of dips for manual soundings, presence of sludge and water in the tank and accuracy of fuel characteristics (mostly density and coefficient of expansion) and tank tables\textsuperscript{14}. However, this is by far the most common method of measuring fuel consumption as it is relatively cheap ($1,000 - $1,500 per tank) to install and run and is stan-

\textsuperscript{14} Tank tables are used to convert bunker level to volume. Conversions and retrofits to tanks are common however tank tables may not be updated accordingly after such changes introducing errors.
standard practice for NR and conventional record keeping. Despite this, there is no standardised method for how and how often to conduct soundings, thus consistency is difficult to achieve.

In recent years, fuel flow meters have gained popularity and come at a significantly higher capital cost to install and maintain ($15,000 - $60,000 per installation). Various types are available on the market which can be interfaced to DAQ systems to establish high frequency monitoring of fuel flow rate. Volume flow meters require measurements of temperature and density to be taken in order to calculate flow which introduces uncertainty. Mass flow (also known as Coriolis) meters are more expensive but do not require temperature and density inputs.

Table 5.5 gathers the associated measurement errors expected for the different methods considered based on literature from suppliers and studies into fuel consumption monitoring. In this study, given that it is assumed that vessel in-service data collection is based on NR tanks soundings are the measurement method. Given the variety of sources of uncertainty that is associated with this method, a conservative 5% error will be associated with TPD data used to compile speed-consumption curves.

Table 5.5: Measurement error associated with fuel consumption monitoring (Aldous, 2015, Faber et al., 2013, Hunsucker et al., 2018)

<table>
<thead>
<tr>
<th>Method</th>
<th>Measurement error</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Soundings</td>
<td>2-5%</td>
<td>Daily</td>
</tr>
<tr>
<td>BDN</td>
<td>1-5%</td>
<td>On bunkering</td>
</tr>
<tr>
<td>Flow meter</td>
<td>0.05-3%</td>
<td>Up to 0.2Hz</td>
</tr>
</tbody>
</table>

**Speed through water** The measurement of STW by a speed log captures the relative speed of the vessel with respect to the surrounding water. What
makes this different to SOG obtained from a Global Positioning System (GPS) device is the presence of currents. The accuracy of measurement is susceptible to wind, waves, sea temperature, shallow water effects and ship motions. Another challenge with speed measurement is periodic calibration of the instrument which, if not maintained, has a tendency to become biased and give inaccurate readings (Bos, 2016). Speed logs were largely considered to be a back-up to SOG up until recently however, with the increased interest in performance monitoring, more attention is being given to this measurement (Antola et al., 2017).

A comparison between SOG and STW (Figure 5.11) values for the NR and CM data shows the effect which averaging over a 24 hour period has on the error between SOG and STW. The high frequency data shows that there may be a dynamic (speed dependent) error in the data as the variation is greater at speeds above 8kn. IMO MSC (2000) stipulates that the error when the ship is operating free from shallow water effect and from the effects of wind, current and tide, should not exceed 2% of the speed of the ship, or 0.2 knots, whichever is greater. In case of speed through water, following Aldous et al. (2015), a 1% error is assumed.

Figure 5.11: SOG and STW comparison for CM (left) and NR (right) data
**Weather conditions** Traditionally, the Beaufort (BF) scale has been used together with the Douglas scale as an indication for sea state. While these give an approximation of the weather conditions, no information is given with regards to relative direction and speed of wind, waves or current which affect performance. Increasingly, weather service providers are being used to provide metocean data which has a high degree of geographical and temporal resolution and avoids problems with visual onboard measurement. The declaration of weather condition can determine whether the vessel is within the warranted performance or not.

Although not directly used to compile speed-consumption curves, weather is used to normalise for rough weather by filtering data points out. With current charter practices, the performance of a vessel beyond the arbitrarily established weather threshold is not communicated in any way to brokers, charterers or anyone outside of the owning company. Any bunker estimates will not account for rough weather and require the application of arbitrary margins to mitigate uncertainty running the risk being too conservative.

**Draught** Draught sensors of the piezo-resistive type suffer from many of the problems that are faced by speed logs due to their sensitivity to environmental factors. Calibration is also challenging along with sensor drift and fouling. Even when installed, sensors are not usually used to report draught but are more commonly used in conjunction with a trim optimisation system. Draught is usually recorded by the crew from the loading computer based on hydrostatics and cargo.

While at port, readings may be taken visually from the quayside (with considerations for water density and temperature) which are significantly accurate however this is not possible while vessels are at sea (Gunkel et al., 2018). It
is common even in CM datasets to find only daily readings for draught that are input manually as in the case of the data used in this research. Given that in speed-consumption curves draught is only used to determine if the vessel is in ballast or laden condition and not enough information is provided for a correction to be applied, the measurement error is not considered in this work. However, Aldous et al. (2015) suggests it might be up to ±1m.

For modelling purposes, measurement uncertainty is introduced using a MC simulation by creating an alternative set of NR data with random errors and fitting speed-consumption curves to each for 1000 distinct runs. The distribution of residuals for each of the runs is used to obtain an average standard deviation to specify the error associated with the model response variable i.e. bunker consumption. Thus, for a higher instrumentation error, a higher standard deviation is expected creating a Probability Density Function (PDF) with higher variation and a larger 95% confidence interval. In order to simulate the measurement errors associated with NR, a random error following a Beta distribution of 5% and 1% is applied to TPD and STW respectively as specified by Aldous et al. (2015).

5.4.2 Performance model

For the purposes of BAU modelling, a quadratic speed-consumption curve is used as a base performance model to determine the warranted performance for the vessel in question (Bialystocki and Konovessis, 2016). Figure 5.12 illustrates STW vs TPD scatters at different loading and weather conditions respectively. For this vessel, a large variation in TPD can be observed between

\[ \text{Using a Beta distribution gives flexibility to add skew or kurtosis through changing the two shape parameters to characterise the measurement error distribution if more information is available regarding the instrumentation.} \]
ballast and laden condition, especially in the 10 to 14 kn range where the vessel operating speed lies. Weather conditions create more variation with heavier weather increasing fuel consumption as expected.

![Figure 5.12: Speed-consumption scatters for different loading (left) and weather conditions (right)](image)

A quadratic relationship is fitted to the data set through iterative curve fitting using Matlab and the associated confidence interval related to the statistical error determined. A quadratic equation was found to be most representative for the TPD and speed as per Bialystocki and Konovessis (2016). A PDF for this error when using the speed-performance curve is applied to establish a probabilistic estimate of $\text{TPD}^{16}$ at a given velocity by running a MC simulation for 1,000 typical annual datasets. Figures 5.13 and 5.14 are the result of the method described above for the dataset at hand.

These curves are usually presented in a simpler format as shown in Figure 5.15 which does away with any indication of uncertainty.

---

$^{16}$It should be noted that this model only accounts for fuel consumed for main engine propulsion and does not account for any auxiliary or boiler consumption.
Figure 5.13: Speed-consumption curve, laden condition. NR data

Figure 5.14: Speed-consumption curve, ballast condition. NR data
Residual analysis

Analysis of residuals is carried out to assess the appropriateness of model design and performance to check for any bias or misrepresentations. Figure 5.16 shows the distribution of residuals lies around a mean of zero for both loading conditions. A t-test was applied to test the normality of residuals and in both cases passed at 5% confidence level.

Further analysis through QQ plots in Figure 5.17 exposes some deviation es-
especially at higher speeds in the ballast loading condition. There are also some
deviations at high and low speed in the laden condition with the model perform-
ing best at daily consumptions that occur the mean operating speed. These
observations corroborate empirical findings by Adland et al. (2020) where
models are found to be sensitive to the vessel speed indicating that modelling
using a conventional speed-performance curve may not be suitable.

Figure 5.17: QQ model residual plots for loading conditions

**Variable independence**  In order to consider the effect of other variables on
residuals and look for homoscedasticity, Figure 5.18 shows residuals plotted
against speed and weather. In the case of speed, an increase in the size of
residuals is noted around the average operating speed (10-14 kn) indicating
that while the vessel is operated within a tight margin of speeds, fuel con-
sumption can vary significantly. Assessing loading and weather conditions in
Figure 5.18, no clear trend in the variation in consumption can be identified. It
should be noted that weather conditions are only described by a BF number
and no indication of relative wind direction is provided, thus the effect of head
or following seas is not accounted for.
5.4.3 Strategic performance declaration

Once the vessel owner or manager has obtained a suitable performance model (Figure 5.15), this operational information must be translated into a commercial tool by determining the warranted performance at an agreed speed (Figure 5.19). In this section, the performance model created will be used to determine the warranted performance for the LT and HT scenarios.

A warranted daily consumption figure, $TPD_w$, is determined from the speed-consumption curve for the laden condition at the warranted speed, $V_w$, which is equated as:

$$TPD_{w_{modelled}} = x_1 V_w^2 + x_2 V_w + x_3$$  \hspace{1cm} (5.5)

Where $x_1$, $x_2$ and $x_3$ are coefficients from the quadratic model fit. The decision of which speed to pick as the warranted speed is affected by several factors. Determining factors might be the region that the vessel is expected to be operating in given the significant impact that metocean conditions can have on vessel speed and consumption. Similarly, if the vessel is operating in a booming market, it will likely be steaming at high speed in order to capitalise
on high cargo value and to compete with peer vessels. Another factor may be the condition of the vessel in terms of hull fouling or general maintenance which may have an affect on speed.

Following findings by Veenstra and van Dalen (2011), the strategic variation that owners apply when assigning the warranted consumption, an additional term is included:

$$TPD_{wLT} = TPD_{w\text{modelled}} \cdot (1 + M_o)$$ (5.6)

Where $M_o$ is the strategic variation applied by the owner to the warranted fuel consumption (%) which is used in the LT scenario. This has the same affect as transposing the speed-consumption curve upwards to increase consumption while keeping the same speed.

The owner can choose to understate consumption, say in an attempt to undercut competition or during a lull in the market, thus appearing to be offering a more efficient vessel while being exposed to high performance claim risk. Conversely, in a stronger market or when in a favourable strategic position, the
owner may want to overstate consumption in order to have more flexibility in operation.

**Low Transparency**  Following the analysis carried out in Appendix A.4, in the LT scenario, it is assumed that the BAU standard CP performance clause will be used in order to communicate the vessel performance to the charterer specifying a warranted speed and associated daily consumption at the laden condition within a BF4 weather threshold caveated by the *about* clause. It is assumed that the “about” clause establishes a range of 5% for consumption and 0.5kn on speed. The owner is also assumed to add a margin \( M_o \) that is unknown to the charterer. Measurement uncertainty is not accounted for.

Looking at the HT case, it is assumed the model and associated uncertainty is shared with the charterer, thus the warranted performance is a probability distribution where distinct daily consumption values are denoted as:

\[
TPD_{wHT} = x_1 V_w^2 + x_2 V_w + x_3 + \eta \tag{5.7}
\]

Where \( \eta \) is an error term generated at random through a MC simulation based on a Gaussian probability distribution form the model residual analysis. The term represents an increase in transparency between owner and charterer as the consumption estimate at \( V_w \) accounts for measurement error and model uncertainty (Figure 5.20).

**High Transparency**  In the HT the charterer is provided with the speed-consumption models for both ballast and laden obtained for all weather conditions with the associated confidence bounds (95% CI). Measurement uncertainty is accounted for though the introduction of the model uncertainty term.
5.4.4 Charterer estimate of bunker

In the VC market, operators will estimate fuel consumption to work out a TC equivalent rate based on standard voyage tables and historic records for the vessel and add an additional arbitrary percentage based as a rule of thumb to account for weather and metocean conditions (Gorton et al., 2009). It is widely assumed that charterers undergo a similar procedure in order to estimate the expected fuel consumption over the length of the TC fixture, using existing knowledge of the operating profile the vessel is expected to undertake.

Low Transparency Taking a conservative approach for the charterer’s bunker cost estimation, the upper bound cost that the charterer expects based on the warranted performance assumes maximum operation throughout the fixture period with some margin for rough weather operation. This method would represent an extremely risk averse charterer or one with no previous experience. In this case, the bunker cost estimation, $B_t$, can be represented as:
\[ E(B_t)_{LT} = T.\alpha.T PD_w.(1 + \beta).B_p \] (5.8)

Where \( \alpha \) is the expected utilisation factor (%) used to establish number of sailing days during the fixture, \( \beta \) is an assumed weather margin (%) and \( B_p \) is bunker cost in $/t.

In Equation (5.8) consumption is not sensitive to loading condition and assumes all sailing is conducted at the warranted speed. Assuming a charterer with some previous experience, a more realistic bunker estimate may be represented as follows:

\[ E(B_t)_{LT} = T.\alpha.\left[ (T PD_w.\gamma) + (\zeta.T PD_w.(1 - \gamma)) \right].(1 + \beta).B_p \] (5.9)

Where \( \gamma \) is the laden time as a proportion of sailing time and \( \zeta \) is the ratio of bunker consumption when vessel is in ballast condition compared to laden (always \(< 1\)). This relation accounts for expected utilisation, time spent in ballast and laden condition and decreased consumption for the ballast condition.

**High Transparency** In the HT case, given that both the speed-consumption curves and associated uncertainty are shared, the charterer can use the historic knowledge and expected operating profile to create a probability distribution of velocities that the vessel will be expected to sail at during the fixture. This can be done by using a MC simulation to create a PDF of expected bunker consumption over the fixture period. It also serves to provide an indication of the associated uncertainty. Given that the curves provided include heavy weather, there is no need to include a heavy weather margin when estimating consumption.
Trust Scenarios

As is common practice, in order to characterise the lack of trust expressed by the charterer in the LT case, an additional margin is included in order to get a conservative estimate of bunker cost. This lack of trust stems from the uncertainty around the performance clause information presented due to the information asymmetry and the single point performance provided. This was found through the case study in Chapter 4 and is documented by Faber, Behrends and Nelissen (2011), Rojon and Dieperink (2014) and Wang et al. (2017). The estimated bunker cost \( E(B_t)_{LT} \) can be expressed as:

\[
E(B_t)_{LT} = T.\alpha.[(TPD_w.\gamma) + (\zeta.TPD_w.(1 - \gamma))].(1 + \beta + \theta).B_p
\]  

(5.10)

Where \( \theta \) is the additional trust margin (as a %) and serves to push up bunker cost. It should be noted that no provision for increased consumption due to fouling or lack of maintenance is included as these fall under the responsibility of the owner as per standard time charter party conditions.

5.4.5 Expected operating profit estimate

Following the development of the model in the previous sections, the expected bunker consumption, \( E(B_t) \), can be estimated for the two transparency and two trust cases. All of the other terms in Equation 5.2 can be used to test the outcome of different economic, operational and temporal factors.

The revenue from transport work for the charterer (\( RF_t \)) is evaluated as:

\[
RF_t = f_r.f_q.n_v^T
\]  

(5.11)
Where $f_r$ is the freight rate associated with the cargo being transported in $$/t$, $f_q$ is the parcel size of the cargo in t and $n^T_v$ is the number of voyages undertaken in period $T$. Average values from historic data will be used for the benchmark case. An assumption is made that there will be constant operation over a similar route over the charter period.

Voyage cost $CV_t$ excluding bunker is difficult to estimate since it is dependent on specific voyages, ports, decisions taken by the master and other factors. As a rule of thumb based on Stopford (2009), voyage costs are assumed to be set at half of the fuel cost. Other variables are based on data from Clarksons (2018b) for Handymaxes operating in the product market including charter rate ($R_t$) and operating cost ($CO_t$).

**Performance claim determination**

In order to get to a more accurate estimation of the expected operating profit, it is important to take into consideration any potential claims that may be raised. Estimating the frequency, value and nature of performance claims is not possible at the fixture stage. Some knowledge based on historic performance or broker information may give an indication of the expected degree of deviation from performance that the vessel manifests during the length of the fixture. The total value of claims can only be assessed at the end of the fixture, therefore, although in some cases significant, they are omitted in the expected operating profit estimates.

In this project, methods to estimate the potential value of performance claims are analysed. The determination of the value of performance claims $PCT^T$ is challenging due to the several factors including:

- the loose definition of fair weather windows
• a single point performance definition provided in the CP
• the lack of publicly available sources that discuss how performance claims are handled and quantified

Grey literature, mostly provided by Protection and Indemnity (P&I) clubs give some information as to how claims are tackled (Furmston and Hosking, 2015; Maynes, 1998; Rabeux, 2019). Those that do provide practical examples, continue to reinforce the notion that a case-by-case approach is observed during any arbitration which makes it more challenging to estimate the cost of claims. Maynes (1998) provides a list of cases that give an insight into the nuances that are observed in each case. They also describe methods to evaluate claims that are considered over a voyage. One of these methods focuses on the vessel’s good weather performance and another considers the performance over the whole voyage and accounts for adverse weather conditions.

Under the LT regime, a simplistic approach illustrated in Figure 5.21 was used. An estimate for the potential value of a performance claim over a fixture based on historic performance can be evaluated as follows:

\[ PC^T = \Delta_B B_p k T \]  

(5.12)

Where \( \Delta_B \) is the mean difference between measured and modelled consumption (from the speed-consumption curve) for days that fall outside the warranted performance (t), \( k \) is the ratio of days liable to performance claims to the size of the dataset, \( B_p \) is the bunker price ($/t) and \( T \) is the fixture length in days.

Under a HT situation, a more comprehensive understanding of overconsumption is possible due to the charterer’s visibility of the speed-consumption curve
used to warrant performance. With this information at hand, charts such as Figure 5.22 can be created to determine how many days and to what extent the vessel is underperforming (measured daily consumption higher than the speed-consumption curve) and obtain more representative values for $\Delta_B$ and $k$. Laden and ballast days are compared to the respective speed-consumption curve to find the variation from modelled bunker consumption.

### 5.4.6 Baseline scenario

**Benchmark performance assumptions**

In order to validate and compare the results from the modelling of the four cases, a benchmark performance was initially established by analysing the historic data set. Table 5.6 provides annual aggregate operating characteristics of this historic dataset. These can be considered in the context of market conditions for Handysize product tankers at the time in Figure 5.23.
Figure 5.22: Scatter plot of measured data set for determination of days liable to performance claims based on the speed-consumption curve

Having characterised the modelling strategy in detail, in-service data will be used to create four counterfactual fixture scenarios and evaluating the results. A baseline scenario is set to test the applicability of the model, analyse results and understand the modelling framework better.

Table 5.6: Annual operating profile data

<table>
<thead>
<tr>
<th>Year</th>
<th>Days</th>
<th>AIS coverage (%)</th>
<th>Sailing days</th>
<th>Voyages</th>
<th>Mean voyage duration (days)</th>
<th>Utilisation (%)</th>
<th>Laden/ballast time ratio</th>
<th>Total FOC (t)</th>
<th>Mean speed (kn)</th>
<th>TPD ratio**</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>237</td>
<td>0.78</td>
<td>197</td>
<td>6</td>
<td>55</td>
<td>0.83</td>
<td>0.73</td>
<td>3508.18</td>
<td>12.0</td>
<td>0.89</td>
</tr>
<tr>
<td>2014</td>
<td>266</td>
<td>0.73</td>
<td>228</td>
<td>7</td>
<td>48</td>
<td>0.86</td>
<td>0.60</td>
<td>3936.51</td>
<td>11.5</td>
<td>0.89</td>
</tr>
<tr>
<td>2015</td>
<td>254</td>
<td>0.69</td>
<td>180</td>
<td>7</td>
<td>54</td>
<td>0.71</td>
<td>0.64</td>
<td>3021.94</td>
<td>11.9</td>
<td>0.93</td>
</tr>
<tr>
<td>2016</td>
<td>35</td>
<td>0.72</td>
<td>27</td>
<td>1</td>
<td>24</td>
<td>0.77</td>
<td>0.22</td>
<td>567.08</td>
<td>12.1</td>
<td>0.97</td>
</tr>
</tbody>
</table>

* Fuel Oil Consumption
** Ballast/laden mean FOC ratio

The spike in earnings and charter rates in 2015 corresponds with a drop in utilisation and no change in mean speed for the vessel under consideration.
which is counter-intuitive as it coincided with a drop in bunker fuel price. This may be due to the increased competition in the market and the necessity of being optimally placed geographically to be considered for certain cargos. This vessel was particularly active in 2014 which cannot be clearly attributed to any of the market conditions being considered.

The historic annual data for the number of sailing days and consumption was plotted as seen in Figure 5.24 and a linear regression was fitted. This relation is used to determine a benchmark consumption for any assumed operating profile. Assumptions related to market conditions are also included obtained from Clarksons (2018b) over the 2013-2016 period.

Thus, as an example, for an expected utilisation of 0.85, 310 sailing days, leads to an estimated consumption of 5319.6t based on the linear relationship in Figure 5.24. All of the terms in Equations 5.1 and 5.2 can now be populated with the benchmark operating profile described in Table 5.7 being created.

Through the analysis of the historic operating profile for the vessel, data indicated that on average 45% of operating days had weather conditions which
Figure 5.24: Annual consumption in relation to sailing days (dashed line showing 95% CI)

Table 5.7: Benchmark operating profile and market assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyages (pa)</td>
<td>$n_v$</td>
<td>6</td>
<td>Number of voyages undertaken per annum</td>
<td>Historic data</td>
</tr>
<tr>
<td>Fixture length</td>
<td>$T$</td>
<td>12</td>
<td>Length of charter period in months</td>
<td>Clarksons 2018b</td>
</tr>
<tr>
<td>Load utilisation</td>
<td>$\alpha$</td>
<td>0.6</td>
<td>Ratio of laden to total sailing time</td>
<td>Historic data</td>
</tr>
<tr>
<td>Time utilisation</td>
<td>$\zeta$</td>
<td>0.85</td>
<td>Utilisation of vessel, sailing days per annum</td>
<td>Historic data</td>
</tr>
<tr>
<td>Bunker price</td>
<td>$B_p$</td>
<td>450</td>
<td>Bunker cost for IFO 380 at Port of Rotterdam (Q1 2018) in $/t</td>
<td>Clarksons 2018b</td>
</tr>
<tr>
<td>TPD ratio</td>
<td>$\gamma$</td>
<td>0.9</td>
<td>Ratio of mean bunker consumption for ballast condition compared to laden conditions</td>
<td>Historic data</td>
</tr>
<tr>
<td>Charter rate</td>
<td>$R_t$</td>
<td>13,500</td>
<td>Peer group charter rate, one-year fixture in $/day</td>
<td>Clarksons 2018b</td>
</tr>
<tr>
<td>Freight rate</td>
<td>$f_r$</td>
<td>50</td>
<td>Freight rate for Easychem cargo in $/t</td>
<td>Clarksons 2018b</td>
</tr>
<tr>
<td>Parcel size</td>
<td>$f_q$</td>
<td>38,000</td>
<td>Typical cargo parcel size from previous voyages in t</td>
<td>Clarksons 2018b</td>
</tr>
<tr>
<td>OPEX</td>
<td>$CO_t$</td>
<td>6,300</td>
<td>Daily operating cost based on OPEX index in $</td>
<td>Clarksons 2018b</td>
</tr>
</tbody>
</table>
went over the BF threshold. This accounts for approximately 45% fuel consumption (Figure 5.25). Thus the widely accepted weather threshold on the CP is not representative of actual operation in this case. Vessels will still sail in weather above BF4 thus implying that, in this case, the performance clause would only be applicable slightly more than half the length of fixture.

Considering this and the lack of correlation between weather conditions as reported by the BF scale, fuel consumption and speed seen in Figure 5.12, it follows that the BF scale may not be well suited to describe weather conditions for performance purposes. This in itself may be a large source of uncertainty that can be reduced with the use of high frequency on-board instrumentation as part of a CM system and the inclusion of a provision in the charter party that specifies a particular weather provider shall be used in the case of any claims brought forward by the charterer.

Figure 5.25: Proportion of time and annual bunker consumption consumed on days above BF4
Bunker consumption estimate

**Low Transparency** Using the baseline scenario based on historic vessel performance, the warranted TPD and speed set by the owner was determined. A warranted speed, \( V_w \), of 12kn is strategically used which is 0.4kn less than the mean observed in speed distribution (Figure 5.26).

![Figure 5.26: Speed distribution for laden condition (CM data)](image)

The laden performance model provides a consumption of 17.8 \( \pm \) 3.4 TPD (at a 95% confident interval) based on Equation 5.5. Assuming a conservative owner, the warranted consumption \( TPD_{wLT} \), is quoted to be 18.5 TPD (a strategic variation of \( M_o = 4\% \) as per Equation 5.6 to round it up to 18.5t) at 12kn laden for fair weather up to BF4. On the charterer side, a weather margin of \( \beta = 5\% \) will be added to account for heavy weather operation by the charterer as per Equation 5.10 as well as a trust margin, \( \theta \), of another 5%.

**High Transparency** To simulate charterer knowledge of the expected operating profile of the vessel, a speed distribution based on the historic data was fitted to be used in the model. Figure 5.27 illustrates the actual and modelled
speed distributions that were (found to be represented best by a Stable distribution based on the MATLAB distribution fitting toolbox). At lower speeds, the ballast distribution was not representative of the historic dataset. Thus the range of speeds for ballast days was split at 10 kn and distributions refitted\footnote{Only 3\% of ballast sailing days in the historic data set were below a speed of <10 kn.}

![Figure 5.27: Measured and fitted speed distributions used as input to the model in HT cases](image)

The 1,000 random speed distributions for a year were sampled to simulate typical annual operations as specified in Table\ref{tab:annual_operations}. A MC simulation was then used to propagate the uncertainty (as per Figure\ref{fig:uncertainty_propagation}) and calculate a probability distribution of annual consumption using Equation\ref{eq:annual_consumption}.

In summary, Table\ref{tab:modelling_assumptions} describes the assumptions made in modelling fuel consumption and operating profit for the four cases under analysis.
Figure 5.28: Modelling schematic for HT bunker estimate

Table 5.8: Description of modelling scenario assumptions

<table>
<thead>
<tr>
<th></th>
<th>Case 1.1</th>
<th>Case 1.2</th>
<th>Case 2.1 (BAU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trust</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Transparency</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Performance modelling</td>
<td>Speed-consumption curves based on noon report data with no weather threshold</td>
<td>Speed-consumption curves based on noon report data up to BF4 weather threshold</td>
<td></td>
</tr>
<tr>
<td>Measurement uncertainty</td>
<td>Considered</td>
<td>Not considered</td>
<td></td>
</tr>
<tr>
<td>Warranted performance</td>
<td>Based on historic experience</td>
<td>Strategically compiled</td>
<td></td>
</tr>
<tr>
<td>Performance communica-</td>
<td>Provision of speed-con curve including associated confidence interval</td>
<td>Provision of warranted speed-consumption at laden condition</td>
<td></td>
</tr>
<tr>
<td>tion method</td>
<td>Probabilistic: Based on speed-consumption curve and expected probability distribution of speeds</td>
<td>Deterministic: Based on warranted performance communication and expected operational profile during fixture</td>
<td></td>
</tr>
<tr>
<td>Charterer bunker estimate method</td>
<td>Probabilistic</td>
<td>Deterministic</td>
<td></td>
</tr>
<tr>
<td>Weather margin</td>
<td>None</td>
<td>None</td>
<td>Applied, $\beta = 5%$</td>
</tr>
<tr>
<td>Charterer trust margin</td>
<td>None</td>
<td>$\theta = 5%$</td>
<td>None</td>
</tr>
</tbody>
</table>
5.5 Results

Linking back to the start of Section 5.4 and more specifically Figure 5.5, this section presents results and observations culminating in a discussion of the overall model performance. In an effort to establish rigour through transparency, a critical analysis of each module is presented with respect to the barrier artefacts they are proposed to represent.

5.5.1 Performance modelling

Table 5.9 presents the characteristics of speed-consumption curves compiled with and without weather filtering and measurement errors for the ballast and laden condition. The \( R^2 \) and confidence intervals for models with weather filtering are higher indicating a better fit and a lower mean error when compared to the models with no weather filtering. Looking at \( R^2 \) and CI for the larger datasets (N=416), it is clear that with polynomial modelling, a larger data set does not imply a more representative model unlike other data-driven or regression methods. This is due to the fact that only three variables are used (speed, weather and loading condition) to model a fuel consumption without controlling other variables that affect it.

Table 5.9: Performance model statistics

<table>
<thead>
<tr>
<th>Loading condition</th>
<th>Measurement Error</th>
<th>Weather Threshold</th>
<th>SSE</th>
<th>( R^2 )</th>
<th>( R^2_{adj} )</th>
<th>RMSE</th>
<th>COV*1E14</th>
<th>Coefficients</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast x</td>
<td>BF</td>
<td>714.94</td>
<td>0.80</td>
<td>0.80</td>
<td>2.21</td>
<td>9.84</td>
<td>0.11</td>
<td>-0.59</td>
<td>7.21</td>
</tr>
<tr>
<td>Ballast</td>
<td>BF</td>
<td>725.21</td>
<td>0.80</td>
<td>0.79</td>
<td>2.22</td>
<td>247.58</td>
<td>0.11</td>
<td>-0.58</td>
<td>7.18</td>
</tr>
<tr>
<td>Ballast x</td>
<td>n/a</td>
<td>1564.37</td>
<td>0.74</td>
<td>0.74</td>
<td>2.51</td>
<td>883.66</td>
<td>0.12</td>
<td>-0.67</td>
<td>7.54</td>
</tr>
<tr>
<td>Ballast</td>
<td>n/a</td>
<td>1582.53</td>
<td>0.74</td>
<td>0.74</td>
<td>2.53</td>
<td>164.42</td>
<td>0.12</td>
<td>-0.65</td>
<td>7.49</td>
</tr>
<tr>
<td>Laden x</td>
<td>BF</td>
<td>604.98</td>
<td>0.79</td>
<td>0.79</td>
<td>1.69</td>
<td>4.03</td>
<td>0.15</td>
<td>-1.20</td>
<td>10.39</td>
</tr>
<tr>
<td>Laden</td>
<td>BF</td>
<td>624.02</td>
<td>0.79</td>
<td>0.78</td>
<td>1.72</td>
<td>110.72</td>
<td>0.15</td>
<td>-1.17</td>
<td>10.26</td>
</tr>
<tr>
<td>Laden x</td>
<td>n/a</td>
<td>3136.49</td>
<td>0.41</td>
<td>0.41</td>
<td>2.79</td>
<td>7.99</td>
<td>0.07</td>
<td>0.07</td>
<td>7.30</td>
</tr>
<tr>
<td>Laden</td>
<td>n/a</td>
<td>3175.28</td>
<td>0.41</td>
<td>0.41</td>
<td>2.80</td>
<td>215.08</td>
<td>0.07</td>
<td>0.07</td>
<td>7.22</td>
</tr>
</tbody>
</table>
The addition of measurement uncertainty is not observed to affect the goodness-of-fit statistics however the Coefficient of Variation (CoV) increases significantly which implies a reduction in precision with a higher dispersion of the probability distribution\textsuperscript{18}. The reason the goodness-of-fit does not change is that the Beta distribution used to sample measurement errors lies around a mean of zero thus this only affects precision and not accuracy. The models with no weather filtering were used to assess the effect on consumption of using a non-filtered dataset. The difference in annual consumption was found to have a difference of 3% when compared to the weather filtered model (up to BF4) which implies that the application of a legacy 5% weather margin is reasonable.

The data quality in this dataset was observed to be reasonable and, despite the reduction in size due to outlier filtering, still provided a suitable amount of data to create a performance model. This is due to the original length of the dataset and the fact that it was averaged from a high frequency data acquisition system. One aspect which affected quality was the lack of draught measurements in the CM dataset (similar to findings in Chapter 4) which introduces some uncertainty as the loading condition was reliant on AIS-based estimates in this case. On a separate note, the lack of correlation between the weather condition and consumption is indicative of an issue with the lack of granularity which may be caused by the daily averaging and the lack of indication of heading and wind direction.

Although a high measurement uncertainty was assumed, this was not seen to affect the speed-consumption curve performance as the model uncertainty had a higher influence on the fuel consumption estimate. Therefore, as long

\textsuperscript{18} CoV is the ratio of the standard deviation and mean of errors.
as speed-consumption curves are used, consumption measurement by tank soundings rather than more expensive flow meters is not detrimental to the model output. In order to assess the effect of some of these phenomena further, a sensitivity analysis will be carried out in Chapter 6 to test the effect of using high frequency data rather than NR and also consider the influence of the length of the dataset on model performance.

The use of a speed-consumption curve is shown to be adequate for estimating annual bunker consumption providing that the associated uncertainty is also accounted for. An estimate within 2% as achieved in this case would be considered highly accurate by industry standards. While getting daily fuel consumption estimates are invaluable when operating a vessel, for charterers fixing a vessel on a long TC, understanding daily variation may be less important than having an overall estimate. More granular performance estimates become more important when the fixture is underway for operational decision-making such as determining bunkering stops, operating speeds and which cargos to pursue.

However, the lack of standardisation is counter-productive as it leads to conservative estimates through lack of trust as discussed and modelled. The performance of the model is tightly linked to the quality of the data and a good data collection regime ensures better performance as stated by Dückert et al. (2016). A higher amount of data is not analogous to a better performance model. This is tested in the next chapter along with a proposal for further parametrisation of the speed-consumption curve by creating weather based curves to provide a basis for more transparent communication of performance.
5.5.2 Charterer perspective

Figure 5.29 and Table 5.10 present the outcome of the game model for the four different scenarios derived from the player strategies. In the HT cases, the consumption and operating profit is expressed as a PDF while the LT results are deterministic thus represented by a line. For clarity, the second distribution for the high transparency, low trust case is not included in the charts however is represented in Table 5.10.

![Figure 5.29: Bunker consumption and charterer operating profit estimates under different transparency regimes](image)

Table 5.10: Baseline results showing estimated bunker consumption and expected operating profit for owner and charterer

<table>
<thead>
<tr>
<th>Case</th>
<th>$E(OPT^T)$ ($\text{mil}$)</th>
<th>% of historic</th>
<th>$E(B^T)$ (t)</th>
<th>% of historic</th>
<th>$E(OPT^T)$ ($\text{mil}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>1.74</td>
<td>1.00</td>
<td>5320</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>1.1</td>
<td>1.65(0.04)*</td>
<td>0.95</td>
<td>5449(60.5)</td>
<td>1.02</td>
<td>2.63</td>
</tr>
<tr>
<td>1.2</td>
<td>1.53(0.04)*</td>
<td>0.88</td>
<td>5722(60.5)</td>
<td>1.08</td>
<td>2.63</td>
</tr>
<tr>
<td>2.1</td>
<td>1.43</td>
<td>0.82</td>
<td>5781</td>
<td>1.09</td>
<td>2.63</td>
</tr>
<tr>
<td>2.2</td>
<td>1.24</td>
<td>0.71</td>
<td>6070</td>
<td>1.14</td>
<td>2.63</td>
</tr>
</tbody>
</table>

* Mean (standard deviation)

Bunker consumption estimates move further away from the baseline historic performance as transparency and trust decrease as expected. This is also
reflected in expected operating profits. With single point performance communication in the LT cases, only a discrete value can be estimated. This may be a driver for charterers to take a more conservative approach to estimating expected operating profits and take decisions based on the worst perceived outcome due to lack of information. In the HT case, even through only noon reports and simplistic performance modelling was used, a more accurate bunker estimate can be observed with the mean being within 3% of the historic baseline.

5.5.3 Strategic performance declaration

Figure 5.30 illustrates the effect of different strategic warranted TPD on bunker cost estimates under the LT regime. At no change, the warranted TPD is equal to the actual TPD obtained from the speed-consumption model derived from NR. The accompanying parallel lines describe the variation expected by strategic changes in TPD in steps of 0.5t. Given the quadratic nature of the relationship, the bunker speed-consumption estimate increases at a higher rate as warranted speed increases. This brings to light the impact of the about clause as used in performance clauses which allows for a 1kn window around the warranted speed creating a significant amount of uncertainty when attempting to estimate bunker cost over a fixture.

For this baseline, a conservative charter (Case 2.2) estimates that bunker cost of the fixture could be 14% more than the actual attained historic performance. Recalling the assumption that the charterer is a rational actor looking to maximise operating profits, the results show that this is the least optimal option compared to the baseline.

Firstly, it effectively ties up a significant amount of cash that is expected to be
spent on bunker. This will not actually be used, which becomes a significant issue in tight markets when positive cash flows become paramount in day-to-day operations. Alternatively, that money could be put towards better use through other investments or towards chartering a competing vessel with a higher charter rate but better performance.

Secondly, the results in Figure 5.29 show that, as per CP, the owner has a large margin on the warranted performance which can be used strategically in various ways due to the lack of information on the charterer side. This may lead to a reduction in efforts of the master and crew to operate the vessel efficiently as well as reduction in urgency for hull maintenance or other interventions that will have a positive affect on efficiency. There is also an opportunity for the master to misreport fuel consumption to cover deviations from the agreed instructions or bunker skimming, as Poul sen and Johnson (2016) found evidence in their interview-based study, whilst still operating within the warranted performance envelope.
This situation gives rise to another two instances of the PA problem: i) a problem between the owner and the charterer with respect to the provision of fuel consumption information during the charter and ii) one between owner and the master on board with regards to fuel consumption reporting. While not covered in this piece of work, this field offers several opportunities for further work to be developed in order to model the uncertainty that may be brought about by these stakeholder interactions.

<table>
<thead>
<tr>
<th>High Transparency</th>
<th>Low Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Trust</td>
<td></td>
</tr>
<tr>
<td>( P_{c}^{11} = 1.63, P_{o}^{11} = 2.63 )</td>
<td>( P_{c}^{12} = 1.51, P_{o}^{12} = 2.63 )</td>
</tr>
<tr>
<td>Low Trust</td>
<td></td>
</tr>
<tr>
<td>( P_{c}^{21} = 1.32, P_{o}^{21} = 2.63 )</td>
<td>( P_{c}^{22} = 1.12, P_{o}^{22} = 2.63 )</td>
</tr>
</tbody>
</table>

Figure 5.31: GT pay-off matrix - baseline case

Adverse selection has been shown to provide a good theoretic representation of the TC game when considering vessel performance, in line with Bergantino and Veenstra (2002). The use of GT has potential to represent the consequences of behaviour in a strategic and complex interaction model (Figure 5.31). Results show that communication of performance is imperative to greater transparency. The performance clause in current CPs provides a great opportunity for innovation. The technical and commercial gap closure is seen to improve outcome although it is difficult to model the owner’s perspective as it relies on largely exogenous factors that are difficult to integrate. In the next chapter, different methods of communication of performance are discussed.
5.5.4 Performance claim determination

Taking the LT approach proposed in Section 5.4.5 for the baseline scenario, only 1% of days are liable to performance claims. Claims are estimated at $1230 over the fixture which is insignificant and unrepresentative (Figure 5.21). The effect of strategic warranted performance is assessed based on this method and Figure 5.32 illustrates the resulting outcome. As can be seen, even half a knot or half a tonne within the "about" range can have a significant difference on the liability of the owner. This further confirms that owners can significantly mitigate against claims based on their prior knowledge of the vessel and control over operation through their crew. This supports findings by Veenstra and van Dalen (2011).

Figure 5.32: Percentage of days sailing liable to performance claims and prospective claim value

Under the HT regime, the effect of strategic performance warranty is illustrated in Figure 5.33 which shows the additional amount of bunker that would be consumed during a 12 month long fixture. In this case, strategic declarations of TPD are considered which entails shifting the speed-performance curve upwards. The chart on the left uses the laden curve to assess all the days while the one on the right compares the ballast days against the ballast consump-
tion curve which makes a significant difference. Considering this, and including the margins resulting from the about clause, an estimated claim for 154.6t of bunker is apparent for an annual charter of this particular case. Note that this figure is dependent on the operating profile and weather conditions which may vary significantly year to year.

Figure 5.33: Effect of strategic $TPD_{w}$ change on bunker consumption and using only laden warranted performance (left) and laden and ballast (right)

The findings in this case have to be carefully considered given that, with the availability of performance curves including the associated mean error, the over consumption for around 60% of the days was within the model error. While this part of the model needs further work (discussed in Chapter 7), the significant effect of the “about” clause on performance can be seen as even a 0.25t change in warranted consumption results in around 30t of over-consumed bunker being lost with the charterer being unable to claim for it. The relation between the strategic change in warranted $TPD$ and bunker costs is quadratic - the amount of over-consumed bunker is larger for small changes in the warranted $TPD$. 
5.5.5  Owner perspective

If performance claims are included in results from the baseline case (Table 5.11), it becomes clear that the owner is penalised in the HT regime. This is mainly due to the deterministic way in which the performance clause is designed and implemented in operation. Thus, the effect of information asymmetry and poor quality of data are clearly impairing charterers from making decisions based on the best representation of the actual performance.

Table 5.11: Baseline scenario results - including claims

<table>
<thead>
<tr>
<th>Case</th>
<th>$OP^T_T$ (US$)</th>
<th>% of historic</th>
<th>$E(B^T_T)$ (t)</th>
<th>% of historic</th>
<th>$OP_2^T$ (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>1.74</td>
<td>1.00</td>
<td>5320</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>1.1</td>
<td>1.66 (0.04)*</td>
<td>0.95</td>
<td>5449 (60.5)</td>
<td>1.02</td>
<td>2.53</td>
</tr>
<tr>
<td>1.2</td>
<td>1.63 (0.04)*</td>
<td>0.93</td>
<td>5722 (60.5)</td>
<td>1.08</td>
<td>2.53</td>
</tr>
<tr>
<td>2.1</td>
<td>1.43</td>
<td>0.82</td>
<td>5781</td>
<td>1.09</td>
<td>2.63</td>
</tr>
<tr>
<td>2.2</td>
<td>1.24</td>
<td>0.71</td>
<td>6070</td>
<td>1.14</td>
<td>2.63</td>
</tr>
</tbody>
</table>

* Mean (standard deviation)

If we represent the pay-offs for the players in matrix form (Figure 5.34) we find no Nash equilibrium under the specified set of assumptions. The model indicates that under Case 2.2, which is closest to the assumed BAU, the charterer has the worst outcome thus misleading decision-making on vessel selection.

5.6  Chapter Summary

In Chapter 3, RQ2 was defined as follows: How can the effect of the identified information shortcomings on stakeholders be evaluated?

This chapter proposed a novel way of bringing together the technical and commercial information regimes in vessel chartering which are usually treated in isolation both in academic literature and in industry. Following the design and
development of a new model, the effects of the information shortcomings were quantified in terms of operating profits and bunker costs. By breaking down the complex dynamic into distinct model modules, the overall result provides a transparent way of evaluating the effects of information barrier artefacts identified.

The design and inputs to the model were derived from measured data with uncertainty from other sources added to simulate variation observed in in-service data. These variations are associated with measurement uncertainty, performance modelling, performance declaration and information asymmetry which all have a measurable effect on the expected outcome for the stakeholders. While this illustrative example showed the insights that can be generated from just one study, the true value of this model is the flexibility and transparency that it offers making it open to further development to look at other cases or to provide a generalised picture.

The use of GT shows potential as a good framework to build an analytical model that transparently considers the perspective of both charterer and owner and their expected economic outcomes based on their respective strate-
gies. By representing information barriers and asymmetries, this techno-economic model can empower charterers and owners to quantify the effect of these market failures when making chartering decisions. It can also empower policy makers to test the potential outcome of measures regarding transparency and quality of information required by also considering the behaviour of industry players. Due to the flexibility offered by the quantitative modelling, it can be developed to test the outcome for various market scenarios, implementation of standardisation or policy, different performance modelling and data collection approaches and performance-based contracting.

Gathering the findings and comparing them to findings in literature and the case study in Chapter 4, Table 5.12 gives an overview of how the insights fit into the current landscape. The quantitative results compare well to both literature and the case study. Moreover several features and behaviours were identified that are not usually analysed or only done so anecdotally. Shortcomings identified are discussed in Chapter 7.

The results presented lead to the conclusion that, in the current scenario, information barriers and lack of trust regarding vessel performance leave charterers with a large uncertainty when determining the commercial viability of a fixture. The strategy chosen to overcome this is being conservative when estimating operating cost to mitigate against financial risk from unknown uncertainty. This in turn provides owners with little or no incentive to operate vessels more efficiently or, in the long term, to invest in more efficient tonnage as these have not been seen to attract higher charter rates.
Table 5.12: Summary of model insights and comparison to literature and case study findings

<table>
<thead>
<tr>
<th>Features/Inferences</th>
<th>Literature fit</th>
<th>Case study fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-service data processing and performance modelling</td>
<td>Findings agree with outcomes observed by Aldous [2015], Bialystocki and Konovessis [2016] and Duckert et al. [2016] regarding implications of in-service data use for performance modelling. Lack of standardisation problems identified corroborate Adland et al. [2020].</td>
<td>Lack of standardisation in data use, pre-processing and modelling found to be detrimental as high frequency data was not used in daily operations by the SM.</td>
</tr>
<tr>
<td>Performance communication</td>
<td>Gorton et al. [2009] and UNCTAD [1990] point this inadequacy out and allude to the difficulties this causes in practice with legacy charter parties. No instances of performance curves being shared was noted.</td>
<td>The performance clause followed the legacy single-point performance model for TC with an addition of fuel savings as an aside. The single-value savings estimate proved to be very inaccurate when the vessel operated marginally outside the design conditions for the retrofit. The conservatism of the SM with reference to vessel performance misled the charterer into thinking consumption would be higher.</td>
</tr>
<tr>
<td>Strategic performance declaration</td>
<td>This phenomenon was found by Veenstra and van Dalen [2011] although based on warranted vs. design speed rather than operating speed and the effect over a charter was not evaluated in practice.</td>
<td>No further information was given due to commercial sensitivity however, main driver for charterer were the characteristics of the vessel making it specialised for particularly lucrative transport rather than fuel performance.</td>
</tr>
<tr>
<td>Expected operating profit estimation for charterer</td>
<td>No literature directly related to charterer estimates based on performance clauses is known to the author. Similarly, literature describing the magnitude of demurrage costs and brokerage cost found to be limited.</td>
<td>The charterer agreed to the setting of the above average charter rate based on previous experience and expected performance. No further information was given due to commercial sensitivity however, main driver for charter were the characteristics of the vessel making it specialised for particularly lucrative transport rather than fuel performance.</td>
</tr>
<tr>
<td>Expected operating profit for owner and performance claim evaluation</td>
<td>Literature around performance claims is limited and based on a few public cases of arbitration.</td>
<td>At the time the case study was undertaken, the first instance of a performance claim was being discussed with the SM thus could not be documented.</td>
</tr>
</tbody>
</table>
Under a higher transparency regime and increased trust, it is proposed that both parties may stand to make smarter business decisions in the short term whilst also promoting a long-term shift towards more efficient shipping through both technological and operational means. The owner side of the model needs more development due to the difficulties around modelling performance claims based. The findings related to the stakeholder relationship illustrate how the model can identify and elucidate the impact of sub-optimal circumstances for individual actors. Thus, the model shows good potential for development into a tool to empower and inform better technical and commercial decision-making towards improved efficiency.

Having established this robustness, the next stage of research involves testing the impact of proposed transparency measures and the impact on player dynamics and the outcome for charterers and owners respectively. This is followed by the addition of an EET module to the model and a discussion on energy savings clauses and performance contracting to assess the effect of sharing the associated risks and rewards under the uncertainty.
Chapter 6

Uncertainty reduction and transparency measures

6.1 Aims and objectives

This chapter will use the GT application and model developed in Chapter 5 to assess different scenarios which represent technical and commercial tools intended to mitigate uncertainty and information asymmetry (Figure 6.1). As in other GT literature in Section 3.2, the BAU results lead to identifying strategies to improve outcomes for all parties by, in this case, reducing uncertainty and information asymmetry.

6.2 Proposed transparency measures

Throughout this research, solutions to reduce the identified information related problems were sourced from literature in shipping and other sectors. The solutions are applied to increase transparency between stakeholders and make
Figure 6.1: Method framework - Chapter 6
better use of empirical data.

Starting with data quality, several sources discuss the effect that high frequency and long data sets have on performance modelling. Aldous et al. (2015) showed the significant effect of frequency and data set length for performance modelling when applying multivariate linear regression in a greybox model. Adland et al. (2020) find that, despite the low frequency, even NR data, can provide high quality speed-consumption curves if used in a large enough quantity and a power law relation is fitted while not being constrained to the Admiralty formula. Combining the insights from these studies, the first proposition tested uses the high frequency measurements to compile speed-performance curves instead of NR along with the associated reduced uncertainty from automated data collection (Aldous et al., 2015).

With regards to performance modelling, as previously defined, the purpose of this research is not to develop a new method but assess how the existing commercial practice can be changed by setting up a framework that makes communication of performance more transparent. In Section 5.5, the commercial reliance on speed-consumption curve performance models has been discussed at length. Standardisation of models is a powerful tool in instilling trust and transparency however this takes a significant amount of resources and time to develop, leading to stopgap solutions being required for the current commercial landscape.

From an operator’s point of view, Karaminas and Shen (2016) propose solutions to close the chronic information gap between the commercial and technical departments in shipping companies. The authors present several practical examples of charts that can be used to bridge this gap including creating parametrised speed-consumption curves based on loading condition and
The proposed technical changes discussed above require a contractual framework to support any implementation in practice. The shortcomings of performance clauses have been discussed in Section 5.2 and Appendix A.4. Based on this, proposals to improve communication of performance and reduce information uncertainty are presented targeting information asymmetry reduction. These proposals are assessed by running the GT model developed in Chapter 5 and comparing the LT BAU with a proposed HT scenarios.

In Section 5.5, the benefit to the charterer by having access to curves based on NR rather than single-point performance was shown to be significantly advantageous in estimating bunker costs. Based on the outcome of models based on CM data and parametrised performance models, a new HT scenario can be set up to assess the effect of a more transparent performance communication regime. This moves away from a single point performance declaration at a weather threshold to a descriptive performance.

As a final measure to increase transparency, an additional module representing an EER investment is assessed to evaluate the effect of additional complexity within chartering decisions. This is especially of interest as retrofitting is seen as one of the key options for shipowners to extend the commercial lifetime of their vessels as tougher environmental regulation comes into force and charterers expectations of lower carbon transport work increases (Bullock et al., 2020). Additionally, as pointed out in Section 2.4.1, more confidence needs to be instilled in the industry in order to ensure that more efficient performance in rewarded accordingly. This section will discuss how vessel EE in operation is integrated into the contracting regime to share the financial benefit from efficient operation.
Table 6.1 summarises the identifies barriers and proposed solutions that will be tested in this chapter.

Table 6.1: Proposed barrier mitigation strategies to increase transparency and reduce uncertainty

<table>
<thead>
<tr>
<th>Barrier category</th>
<th>Barrier artefact</th>
<th>Mitigation measure</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data quality and acquisition method</td>
<td>Data collection frequency and dataset size</td>
<td>Use of high frequency data and different size datasets</td>
<td>6.3.1, 6.3.2</td>
</tr>
<tr>
<td></td>
<td>Exclusion of measurement error</td>
<td>Apply error margins associated with CM instrumentation</td>
<td>6.3.1</td>
</tr>
<tr>
<td>Performance modelling</td>
<td>Performance modelling (speed-consumption curve based)</td>
<td>Use of standardised parametric performance model</td>
<td>6.4.1</td>
</tr>
<tr>
<td></td>
<td>Single point savings estimate from EET</td>
<td>Probabilistic methodology for assessment</td>
<td>6.6.1</td>
</tr>
<tr>
<td>Information asymmetry</td>
<td>Communication of vessel performance between owner and charterer</td>
<td>Alternative performance disclosure and clause</td>
<td>6.5.1</td>
</tr>
<tr>
<td></td>
<td>Communication of expected savings from EET between owner and charterer</td>
<td>Alternative performance disclosure</td>
<td>6.6.1</td>
</tr>
</tbody>
</table>

6.3 Data quality and acquisition method for improved model quality

6.3.1 Data collection frequency and measurement error

Thus far in this work, on-board CM data was re-sampled as NR and used to compile performance models. In this section, CM data is used and the model performance compared with the one from the lower frequency data. The data collection system installed on this vessel provided TPD values based on the consumption over the 10 minute CM period. Table 6.2 presents the statistical
outputs of the performance modelling technique presented in Section 5.4.2 applied to the CM data set with measurements at 10 minute intervals. As defined by Aldous (2015), measurement uncertainty for speed and bunker consumption under high frequency DAQ is set at 1% for both variables.

Table 6.2: Performance models - CM data

<table>
<thead>
<tr>
<th>Loading condition</th>
<th>Measurement Error</th>
<th>Weather Threshold</th>
<th>SSE</th>
<th>$R^2$</th>
<th>$R^2_{adj}$</th>
<th>RMSE</th>
<th>COV*1e14</th>
<th>Coefficients</th>
<th>CI</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast x BF4</td>
<td>1.28</td>
<td>0.50</td>
<td>0.50</td>
<td>2.72</td>
<td>0.42</td>
<td>0.38</td>
<td>-5.99</td>
<td>31.97</td>
<td>5.33</td>
<td>17478</td>
</tr>
<tr>
<td>Ballast x n/a</td>
<td>3.16</td>
<td>0.41</td>
<td>0.41</td>
<td>3.13</td>
<td>0.78</td>
<td>0.30</td>
<td>-4.47</td>
<td>27.02</td>
<td>6.14</td>
<td>32521</td>
</tr>
<tr>
<td>Laden x BF4</td>
<td>1.32</td>
<td>0.46</td>
<td>0.46</td>
<td>2.11</td>
<td>0.55</td>
<td>0.53</td>
<td>-10.69</td>
<td>68.38</td>
<td>4.14</td>
<td>29849</td>
</tr>
<tr>
<td>Laden x n/a</td>
<td>4.31</td>
<td>0.27</td>
<td>0.27</td>
<td>2.74</td>
<td>0.09</td>
<td>0.49</td>
<td>-9.81</td>
<td>65.83</td>
<td>5.38</td>
<td>57674</td>
</tr>
</tbody>
</table>

Figure 6.2 and 6.3 are the corresponding speed-consumption curves, data points and confidence intervals. Comparing the results to those in Table 5.9, the $R^2$ and RMSE values show a significant drop in performance for the model which can be attributed to the increase in variation despite filtering for outliers as specified by BSI (2016b). These observations imply that the modelling technique may not be suitable to handle the increased data frequency thus questioning the compatibility of speed-consumption curves with the high frequency data collection regime.

The high data collection frequency captures very localised and specific phenomena such as wave and swell effects as well as navigational manoeuvres. In this case, the weather data used is expressed in BF scale which does not account for instantaneous variation which makes a case for different modelling strategies that are better suited to handle high quantities of data. The performance with an intermediate frequency data collection based on hourly resampled measurements was also tested. This mode performed marginally
better than [NR] as shown in Appendix A.5.

Figure 6.2: Speed-consumption curve, ballast condition, CM data

The advantages of [CM] including the elimination of human error and significant reduction in measurement errors as specified in Section 5.4.1 are offset by the inability for speed-performance curves to capture variable dependencies dynamically. Although there has been a rise in academic and commercial research in the last ten years concentrating on using advances in machine learning to build models that can exploit the large quantities of data, these lack transparency.

If a suitable model was found, companies may not have the bandwidth or skill required to analyse and manage performance modelling and monitoring at this level of detail. As has been observed in Chapter 4, they might have funding to acquire and install the system however may not invest in the resources required to make best use of the data collected. Third-party companies can fill this niche, however, a degree of transparency and ability to communicate
the processing clearly has to be ensured in the services they provide to avoid further information asymmetry.

### 6.3.2 Length of dataset

As per the best practice guidelines from [BSI (2016c)] and [Aldous (2015)], the use of larger data sets is recommended to reduce uncertainty in the response variable. This was tested out by creating speed-consumption curves using six and three months’ worth of data in order to compare performance by estimating bunker consumption. The three month dataset, even when using CM data, was not suitable due to poor quadratic fit obtained for the laden model at lower velocities as illustrated in Figure 6.4. Note that the goodness-of-fit statistic was indicative of a good fit in spite of this.

In this case, a power law based model (Equation 6.1) was found to be more representative at lower speeds for this smaller dataset. This highlights the
The importance of model validation beyond the statistical goodness-of-fit. It also demonstrates that different models are better in certain aspects implying more strongly that standardisation in performance modelling is not trivial.

\[ TPD = aV^b \] (6.1)

Figure 6.5 illustrates the outcomes from the three and six-month models. A clear decrease in accuracy can be observed as the data size decreases. The mean value of modelled annual estimates moves further away from the historic mean with the precision also suffering as the standard deviation increases as dataset decreases in size (Table 6.3). Therefore, smaller datasets create less representative models and do not capture long term trends such as performance degradation due to fouling, corroborating Aldous (2015) and BSI (2016c). Statistical performance of all models can be found in Appendix A.5.

The above has shown that the data regime selected by the owner to model performance has a significant impact on the robustness of the outcome and
also on the modelling technique that is most appropriate for the data being used. Given the modularity of the model, it offers flexibility for input from any kind of performance model allowing for the testing of alternatives to speed-performance curves.

Table 6.3: Performance model annual fuel estimate comparison - dataset length

<table>
<thead>
<tr>
<th>Bunker consumption (t)</th>
<th>Full dataset</th>
<th>6 months</th>
<th>3 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5286.40</td>
<td>5540.67</td>
<td>5891.74</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>57.42</td>
<td>65.95</td>
<td>68.43</td>
</tr>
<tr>
<td>Mean error</td>
<td>-33.20</td>
<td>221.07</td>
<td>572.14</td>
</tr>
<tr>
<td>Mean error (%)</td>
<td>-0.62</td>
<td>4.16</td>
<td>10.76</td>
</tr>
</tbody>
</table>
6.4 Performance modelling for supporting transparency

6.4.1 Weather based parametric models

The methodology for creating weather and loading condition-based curves, referred to as parametric, is consistent with that in Section 5.4.2. In this case, since the data will be segmented by BF value, a large data set is required, hence CM data is used. Following the findings in Section 6.3.1, both power law and quadratic fits were tested which resulted in the performance models shown in Figures 6.6 to 6.9.

As seen previously, the quadratic curve provides a more robust model at higher speeds while the power law has better fit over larger speed range especially at lower speeds. This sensitivity of speed-consumption models to vessel speed as also noted by Adland et al. (2020) for a variety of ship types. The better fit raises questions as to the choice of a quadratic fit for models so far in this research. This was dictated by the better fit quadratic curves were found to have with NR data when the MATLAB curve fitting toolbox was used.

For rougher weather, the lack of data points and the large variation implies very weak models as seen in Figure 6.10. This is because the power exponent for the performance models represented by a dashed line are less than or equal to one implying a quasilinear relation. Using these models at heavy weather would introduce substantial uncertainty due to the lack of model robustness.

A probability distribution of measured BF numbers (Figure 6.11) was fitted using the MATLAB probability distribution fitting toolbox. Samples were taken and fed into a MC simulation to get 1,000 annual fuel consumption estimates.
Figure 6.6: Speed-consumption curves, ballast, CM data, power law fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest
Figure 6.7: Speed-consumption curves, laden, CM data, power law fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest.
Figure 6.8: Speed-consumption curves, ballast, CM data, quadratic fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest density.
Figure 6.9: Speed-consumption curves, laden, CM data, quadratic fit, weather parametrisation. Scatter colour denotes density; yellow implies highest density, dark blue implies lowest.
using the parametric models at the baseline case. The distribution shows the low occurrence of heavy sea states in this data set however, more specific regional metocean data would need to be used depending on the expected operating profile.

Looking at the resulting fuel estimates, a robust performance can be observed by both models with the power law fit being more accurate due to a smaller mean error (Figure 6.12 and Table 6.4). Both present a similar standard deviation, thus precision is comparable in both cases.

Table 6.4: Parametric model annual fuel estimate comparison - fit type

<table>
<thead>
<tr>
<th></th>
<th>Quadratic</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption (t) Mean</td>
<td>5422.05</td>
<td>5317.10</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>63.69</td>
<td>61.13</td>
</tr>
<tr>
<td>Mean error</td>
<td>102.45</td>
<td>-2.50</td>
</tr>
<tr>
<td>Mean error (%)</td>
<td>1.93</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

This method that normalises modelling based on loading condition and weather is shown to reduce uncertainty around fuel consumption. It provides a better method of estimating voyage costs for charterers before fixture which dilutes
Figure 6.11: Weather condition probability distribution - CM data

Figure 6.12: Parametric model annual consumption estimation
the effect of daily variability over the charter period. It opens a discussion as to how vessel performance is communicated to charterers leading to different clause design specifying performance at different operating points. This could see the purpose of a performance clause change from being a loose performance baseline to a tool that allows for better decision-making by charterers through information asymmetry reduction.

As seen in Section 6.3.1, assuming that the use of increasing amounts of data for performance modelling leads to higher accuracy may not be correct if this data is not pre-processed effectively and the appropriate modelling technique used. Larger datasets are prone to introduce high margins of error if simply used with the current speed-consumption curve regime. Nonetheless, the additional quantity of data allows for better filtering and segmentation as shown through the weather parametric curve exercise. The compromise between transparency and model performance is difficult to strike and, while academic and commercial endeavours result in highly effective models, the lack of standardisation is a barrier to both uptake and transparency within the industry.

6.5 Information asymmetry reduction

6.5.1 Communication of vessel performance in consumption clauses

A compromise is required between technical complexity and transparency for ease of communication between stakeholders. Whilst sharing of a black box statistical model could be an option (possibly through an independent third party or open-source algorithms), a simpler option to implement with existing resources involves sharing parametrised speed-consumption curves with
associated uncertainty. Changing the performance clause to a more comprehensive template, as presented in Table 6.5 provides a highly transparent solution as a replacement to the performance information provided in the current clauses.

This is similar to the performance clauses in TC parties such as EXXONTIME (ExxonMobil, 2005) and SHELLTIME4 (Shell, 1984) which require consumption to be quoted at several speeds and loading conditions. Providing the speed-consumption curves along with the associated uncertainty increases transparency and gives more agency to the charterer for vessel selection based on performance and for owners to negotiate better charter rates. The effectiveness of this communication approach is tested by running the GT model based on a HT scenario with parametrised curves.

**Modelling an increased transparency scenario**

Keeping to the baseline scenario outlined in Table 5.7 the fixture game for the four trust and transparency regimes is run with the updated parametric performance model and performance communication as specified in Table 6.6. Only the HT cases, Case 1.1 and 1.2 are changing.

The MC simulation in these scenarios includes a randomly generated daily weather condition based on a probability distribution obtained from the CM data (Figure 6.11). In operation, a charterer would select a suitable distribution based on experience or metocean data based on the routes that the vessel would be expected to be used for during the fixture.

Compared to the results in Table 5.10 the results in Table 6.7 shows that the uncertainty (represented by the standard deviation) around operating profit estimates for the charterer is not affected significantly by the changes in mod-
Table 6.5: Example of proposed performance declaration

<table>
<thead>
<tr>
<th>Weather condition</th>
<th>Model type</th>
<th>a</th>
<th>b</th>
<th>Error $\mu$ (1e2)</th>
<th>Error $\sigma$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laden</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF1</td>
<td>Power law fit</td>
<td>0.08</td>
<td>2.18</td>
<td>1.13</td>
<td>2.13</td>
<td>0.54</td>
</tr>
<tr>
<td>BF2</td>
<td>Power law fit</td>
<td>0.19</td>
<td>1.81</td>
<td>1.00</td>
<td>1.99</td>
<td>0.47</td>
</tr>
<tr>
<td>BF3</td>
<td>Power law fit</td>
<td>0.32</td>
<td>1.61</td>
<td>0.96</td>
<td>2.08</td>
<td>0.41</td>
</tr>
<tr>
<td>BF4</td>
<td>Power law fit</td>
<td>0.36</td>
<td>1.56</td>
<td>1.14</td>
<td>2.27</td>
<td>0.37</td>
</tr>
<tr>
<td>BF5</td>
<td>Power law fit</td>
<td>1.07</td>
<td>1.14</td>
<td>0.89</td>
<td>2.53</td>
<td>0.25</td>
</tr>
<tr>
<td>BF6</td>
<td>Power law fit</td>
<td>5.51</td>
<td>0.49</td>
<td>0.18</td>
<td>3.05</td>
<td>0.07</td>
</tr>
<tr>
<td>BF7</td>
<td>Power law fit</td>
<td>8.64</td>
<td>0.34</td>
<td>0.20</td>
<td>4.45</td>
<td>0.05</td>
</tr>
<tr>
<td>BF8</td>
<td>Power law fit</td>
<td>8.76</td>
<td>0.42</td>
<td>-1.03</td>
<td>5.25</td>
<td>0.28</td>
</tr>
<tr>
<td>BF9</td>
<td>Power law fit</td>
<td>7.07</td>
<td>0.55</td>
<td>-3.51</td>
<td>5.54</td>
<td>0.52</td>
</tr>
<tr>
<td><strong>Ballast</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF1</td>
<td>Power law fit</td>
<td>0.04</td>
<td>2.40</td>
<td>0.83</td>
<td>2.50</td>
<td>0.49</td>
</tr>
<tr>
<td>BF2</td>
<td>Power law fit</td>
<td>0.08</td>
<td>2.11</td>
<td>2.50</td>
<td>2.63</td>
<td>0.49</td>
</tr>
<tr>
<td>BF3</td>
<td>Power law fit</td>
<td>0.08</td>
<td>2.11</td>
<td>2.29</td>
<td>2.69</td>
<td>0.49</td>
</tr>
<tr>
<td>BF4</td>
<td>Power law fit</td>
<td>0.04</td>
<td>2.43</td>
<td>2.33</td>
<td>2.89</td>
<td>0.45</td>
</tr>
<tr>
<td>BF5</td>
<td>Power law fit</td>
<td>0.05</td>
<td>2.35</td>
<td>1.79</td>
<td>3.21</td>
<td>0.39</td>
</tr>
<tr>
<td>BF6</td>
<td>Power law fit</td>
<td>0.54</td>
<td>1.39</td>
<td>1.36</td>
<td>3.40</td>
<td>0.36</td>
</tr>
<tr>
<td>BF7</td>
<td>Power law fit</td>
<td>1.71</td>
<td>0.94</td>
<td>1.00</td>
<td>3.47</td>
<td>0.41</td>
</tr>
<tr>
<td>BF8</td>
<td>Power law fit</td>
<td>5.52</td>
<td>0.46</td>
<td>-0.48</td>
<td>3.54</td>
<td>0.44</td>
</tr>
<tr>
<td>BF9</td>
<td>Power law fit</td>
<td>19.26</td>
<td>-0.04</td>
<td>0.00</td>
<td>2.65</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Table 6.6: Description of increased transparency modelling scenario assumptions - parametric models

<table>
<thead>
<tr>
<th>Case</th>
<th>Trust</th>
<th>Transparency</th>
<th>Performance modelling</th>
<th>Measurement uncertainty</th>
<th>Warranted performance</th>
<th>Performance communication</th>
<th>Charterer bunker estimate method</th>
<th>Weather margin</th>
<th>Charterer trust margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>High</td>
<td>High</td>
<td>Parametric speed-consumption curves based on CM data</td>
<td>Considered</td>
<td>Based on historic experience</td>
<td>Provision of parametric speed-consumption curves including associated confidence interval</td>
<td>Probabilistic: Based on speed-consumption curve and expected probability distribution of speeds and weather</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>1.2</td>
<td>High</td>
<td>Low</td>
<td>Parametric speed-consumption curves based on NR data up to BF4 weather threshold</td>
<td>Not considered</td>
<td>Strategically compiled</td>
<td>Provision of warranted speed-consumption at laden condition</td>
<td>Deterministic: Based on warranted performance communication and expected operational profile during fixture</td>
<td>None</td>
<td>Applied, $\theta = 5%$</td>
</tr>
<tr>
<td>2.1</td>
<td>High</td>
<td>Low</td>
<td>Speed-consumption curves based on NR data up to BF4 weather threshold</td>
<td>Not considered</td>
<td>Strategically compiled</td>
<td>Provision of warranted speed-consumption at laden condition</td>
<td>Deterministic: Based on warranted performance communication and expected operational profile during fixture</td>
<td>None</td>
<td>$\theta = 5%$</td>
</tr>
<tr>
<td>2.2</td>
<td>Low</td>
<td>Low</td>
<td>Speed-consumption curves based on NR data up to BF4 weather threshold</td>
<td>Not considered</td>
<td>Strategically compiled</td>
<td>Provision of warranted speed-consumption at laden condition</td>
<td>Deterministic: Based on warranted performance communication and expected operational profile during fixture</td>
<td>None</td>
<td>$\theta = 5%$</td>
</tr>
</tbody>
</table>

Table 6.7: Baseline scenario - parametrised performance model results

<table>
<thead>
<tr>
<th>Case</th>
<th>$OP_T^C$ ($\text{mil}$)</th>
<th>% of historic</th>
<th>$E(B^T)$ (t)</th>
<th>% of historic</th>
<th>$OP_T^C$ ($\text{mil}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>1.74</td>
<td>1.00</td>
<td>5320</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>1.1</td>
<td>1.74(0.04)*</td>
<td>1.00</td>
<td>5318(61.7)</td>
<td>1.00</td>
<td>2.63</td>
</tr>
<tr>
<td>1.2</td>
<td>1.62(0.04)*</td>
<td>0.93</td>
<td>5584(61.7)</td>
<td>1.05</td>
<td>2.63</td>
</tr>
<tr>
<td>2.1</td>
<td>1.43</td>
<td>0.82</td>
<td>5781</td>
<td>1.09</td>
<td>2.63</td>
</tr>
<tr>
<td>2.2</td>
<td>1.24</td>
<td>0.71</td>
<td>6070</td>
<td>1.14</td>
<td>2.63</td>
</tr>
</tbody>
</table>

* Mean (standard deviation)

The results from this HT regime imply that, at the fixture stage, charterers can have a clearer overview of the expected performance over the fixture while while owners can have a more transparent negotiation around the day rate.
Figure 6.13: Bunker and charterer operating profit estimates under different transparency regimes - Parametric model

given the uncertainty around fuel cost is reduced for the charterer.

A 15% difference in annual bunker consumption estimate is observed between Case 1.1 and 2.2 (BAU) which, under any market scenario would be very significant to a charterer in the fixture decision-making process. The results in Table 5.10 and Figure 6.14 do not include any considerations for performance claims as this will be discussed in the following sections. Case 1.1 presents the optimum outcome for both parties and is the Nash equilibrium for this game leading to the conclusion that the high transparency - high trust scenario is expected yield the optimal outcome.

This probabilistic parametric model which requires minimal computational power and technical complexity, achieves high accuracy the potential to change the dynamic in chartering significantly. The three years of historic data used to obtain a mean bunker consumption capture the effects of weather variability. Charterers can use regional weather hindcast data models from areas where they intend to operate to have higher agency in fixtures and strengthen evidence-based decision-making. This applies as well for smaller companies.
that cannot dedicate extensive resources towards these and rely on brokers.

**Performance-based contracting implications**

With a higher level of performance transparency as proposed, a different structure for performance guarantee can be devised to establish liability for over-consumption. Given the more granular modelling that takes into consideration specific weather conditions, an opportunity to better define performance margins arises which is different to that proposed in Section 5.5.4. Figure 6.15 illustrates the amount of days that would be considered to be above the parametric speed-consumption curves if applied to the historic NR data. Based on this analysis, 50% of days would be operating at a higher consumption than the expected value which would lead to a bunker overconsumption of around 400t and a corresponding claim of around $178,000 assuming a bunker price
of 450$/t (based on the average daily consumption on days when vessel was observed to be above warranted consumption).

Figure 6.15: Determination of days liable to performance claims with parametric speed-consumption curve

Taking the lead from the current arrangement with the use of the term *about*, an accepted margin of variation around the parametric performance curve can be agreed upon, providing some flexibility for the owner. Looking at the baseline case, applying a performance variation margin would lead to the outcome outlined in Figure 6.16.

When considering this in terms of the pay-off matrix, the differences between the outcomes in Figure 6.17 convey the difference associated with performance claims with an allowable variation margin of 5%. In Figure 6.16, a quasi-linear relation is noted with a change in gradient at the 5% mark. This implies that the deviation up to that point is significantly larger than that at higher performance variation margins. In this circumstance, Figure 6.17 shows that there is no Nash equilibrium as the charterer maximises utility in Case 1.1 while the owner does so in Case 2.2 (BAU). This highlights the importance of
establishing a robust performance contract given that there is a direct conflict in utility maximisation between the two players.

This probabilistic approach only offers an estimate of the possible value of a performance claim based on historic performance and input assumptions together with higher transparency performance communication. In practice, this change in contracting would contribute to additionally closing the knowledge gap between owners and charterers around performance and, subsequently, the distribution of financial risk.

Although this is a simplification and a significant departure from conventional performance contracting in shipping, charter parties have already started to adapt to the changing environmental landscape. Industry bodies have implemented additional clauses to account for new regulation. A recent example of this is INTERTANKO’s clause to account for the IMO 2020 sulphur regulation (INTERTANKO, 2019). Mazioli et al. (2019) show how alternative CPs can be introduced to improve efficiency with an example based on wood pulp transport.
at a Brazilian terminal. An evidence-based design is proposed as a tool to help decision-making with regards to investments and operational changes. This redesign of leads to a beneficial financial outcome to the ship owner, charterer and terminal. A more comprehensive discussion regarding performance contracting and charter party innovation can be found in Section 7.3.2.

### 6.6 Integration of operational vessel efficiency in contracting - an EET application

The introduction of an EET to the parametric model is represented by an additional module to cater for the impact of different technologies on fuel consumption for propulsion. Drawing on the methodology applied in Liang et al. (2016),
the parameters that influence player utilities are identified through a bottom-up approach from literature and the qualitative findings from Chapter 4. These are grouped as drivers (D) or barriers (B), having a positive or negative effect on utility (Table 6.8). They are used to compose the required utility functions for the different strategy combinations (Table 6.9).

### 6.6.1 Utility function adaptation

The drivers and barriers associated with adoption of an EET are introduced to the utility functions developed in Chapter 5 yielding the following relations:

\[
E(\text{OPT}_o) = \sum_{t=1}^{T} \left[ R_t + \Delta R_{EEP_t} - CO_t + I_{nC_t} \right] - I - C_{co} + I_{nc} + EC \quad (6.2)
\]

\[
E(\text{OPT}_c) = \sum_{t=1}^{T} \left[ -R_t - \Delta R_{EEP_t} - CV_t - E(B_t) + E(\Delta B_t) + E(RF_t) \right] + I_{nc} + EC \quad (6.3)
\]

\[
\text{OPT}_o = \sum_{t=1}^{T} \left[ R_t + \Delta R_{EEP_t} - CO_t + I_{nC_t} \right] - P_{CT} - I - C_{co} + I_{nc} + EC \quad (6.4)
\]

\[
\text{OPT}_c = \sum_{t=1}^{T} \left[ -R_t - \Delta R_{EEP_t} - CV_t - B_t + \Delta B_t + RF_t \right] + P_{CT} + I_{nc} + EC \quad (6.5)
\]

Where \( \Delta R_{EEP_t} \) is the additional EEP on the charter rate applied by the owner in order to recoup \( I \) the cost of initial investment ($).

No term for the change in vessel value \( \Delta V \) is included as there is significant uncertainty as to how efficiency plays in the second-hand market.
Table 6.8: Drivers and barriers related to EET implementation for owners and charterers

<table>
<thead>
<tr>
<th>ID</th>
<th>Stakeholder</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drivers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>Owner</td>
<td>Higher charter rate</td>
</tr>
<tr>
<td>D2</td>
<td>Owner</td>
<td>Discounts and incentives</td>
</tr>
<tr>
<td>D3</td>
<td>Owner</td>
<td>Return on investment</td>
</tr>
<tr>
<td>D4</td>
<td>Owner</td>
<td>Higher utilisation</td>
</tr>
<tr>
<td>D5</td>
<td>Owner</td>
<td>Reduction of obsolescence risk (regulation + competition)</td>
</tr>
<tr>
<td>D6</td>
<td>Owner</td>
<td>Asset value rise</td>
</tr>
<tr>
<td>D7</td>
<td>Owner</td>
<td>Reputation enhancement</td>
</tr>
<tr>
<td>D8</td>
<td>Owner</td>
<td>Social responsibility</td>
</tr>
<tr>
<td>D9</td>
<td>Owner</td>
<td>Pull-factor for charterers</td>
</tr>
<tr>
<td>D10</td>
<td>Owner</td>
<td>Pull-factor for pool points</td>
</tr>
<tr>
<td>D11</td>
<td>Charterer</td>
<td>Lower bunker cost</td>
</tr>
<tr>
<td>D12</td>
<td>Charterer</td>
<td>Social responsibility</td>
</tr>
<tr>
<td>D13</td>
<td>Charterer</td>
<td>Pull-factor for shippers</td>
</tr>
<tr>
<td><strong>Barriers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>Owner</td>
<td>High CAPEX requiring financing</td>
</tr>
<tr>
<td>B2</td>
<td>Owner</td>
<td>Interruption of operation during installation</td>
</tr>
<tr>
<td>B3</td>
<td>Owner</td>
<td>Risk of retrofit not working as designed at different operating conditions</td>
</tr>
<tr>
<td>B4</td>
<td>Owner</td>
<td>Risk of performance claims based on EET savings</td>
</tr>
<tr>
<td>B5</td>
<td>Owner</td>
<td>High complexity and uncertainty of technical feasibility</td>
</tr>
<tr>
<td>B6</td>
<td>Owner</td>
<td>Lack of information on performance</td>
</tr>
<tr>
<td>B7</td>
<td>Owner</td>
<td>Lack of experience</td>
</tr>
<tr>
<td>B8</td>
<td>Charterer</td>
<td>Higher charter rate</td>
</tr>
<tr>
<td>B9</td>
<td>Charterer</td>
<td>Interruption of operation during installation</td>
</tr>
<tr>
<td>B10</td>
<td>Charterer</td>
<td>Risk of not getting promised savings</td>
</tr>
<tr>
<td>B11</td>
<td>Charterer</td>
<td>Lack of certainty on return on investment</td>
</tr>
</tbody>
</table>
Table 6.9: Utility function terms definition

<table>
<thead>
<tr>
<th>Term</th>
<th>Name</th>
<th>Drivers/Barriers captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta V$</td>
<td>Increase in asset value</td>
<td>D5, D6</td>
</tr>
<tr>
<td>$\Delta R$</td>
<td>Increased owner revenue</td>
<td>D1, D3, D4, B8</td>
</tr>
<tr>
<td>$I$</td>
<td>Investment cost</td>
<td>B1</td>
</tr>
<tr>
<td>$\Delta B$</td>
<td>Bunker savings</td>
<td>D10, D11, B3, B6, B7, B9, B11</td>
</tr>
<tr>
<td>$C_{co}$</td>
<td>Coordination cost</td>
<td>B2, B4, B5, B10</td>
</tr>
<tr>
<td>$Inc$</td>
<td>Incentives</td>
<td>D2</td>
</tr>
<tr>
<td>$EC$</td>
<td>Energy credentials and reputation</td>
<td>D7, D8, D9, D12, D13</td>
</tr>
</tbody>
</table>

Cariou and Wolff (2018) show that various considerations regarding the state of the market, age of vessel and plan of ownership make the value difficult to establish. It also is not of great concern to ship operators as they usually are not the owners. The next sections analyse how the additional terms in the quantitative model change the outcome of the chartering game for the two stakeholders.

**Setting of EEP by owner - $\Delta R_{EEP}$** There is weak evidence of more efficient vessels attracting an EEP (see Section 2.4.1) in the charter market. Therefore, a simple proxy is used to approximate the minimum break-even return an owner would require to recoup the cost of investment in performance improving technology. Most techno-economic studies (Psarros (2016) and Faber, Wang, Nelissen, Russell and St Amand (2011)) and finance literature (Schinas and Kewitsch, 2015) looking at EE investments use Net Present Value (NPV) or Internal Rate of Return (IRR) as a proxy. Payback period is not universally accepted as a good metric as, while it is simple to compile and comprehend, it does not give information on the yield or profit from the investment.

**IRR** does consider the yield from the investment however **NPV** provides con-
considerations for both yield and profit through the inclusion of a discount rate that is based on the [Weighted Average Cost of Capital (WACC) for the specific company or industry. Drawing upon this, Eq. 6.6 is solved iteratively for an annual cash flow that is required to break even (when NPV = 0) from the investment cost within the defined payback period assuming a given discount rate.

\[
NPV = -I + \sum_{t=1}^{n} \frac{C_t}{(1 - r)^t}
\] (6.6)

Where \(C_t\) is the annual cash flow due to investment which in this case is equated to the EEP ($pa), \(r\) is the discount rate (%) and \(n\) is the expected payback period (years).

In order to keep the model technology agnostic, the parameters describing the techno-economic performance of the EET are intentionally generic to retain flexibility. The next sections will describe these five parameters and present the assumptions considered. For the purposes of this work, a propeller duct is chosen as an illustrative example of an EER as it has a simple implementation, no crew training required, is relatively commonplace, has been on the market for over 10 years and, most importantly, has published data regarding performance and implementation costs by the leading manufacturer Becker Marine (Svardal and Mewis, 2011a).

**Capital investment - \(I\)** Various studies contain approximate estimates for the implementation of different EET and the corresponding potential savings (Bouman et al., 2017, Faber, Behrends and Nelissen, 2011, Yuan et al. 2016). For the purposes of this study, the implementation cost is estimated at $300,000 assuming it is conducted during a scheduled dry docking and covers the de-
sign and materials, installation and other capital costs as specified by Svardal and Mewis (2011b). No maintenance costs are considered for this retrofit although it is acknowledged that the cost of hull and propeller cleaning may increase. The model does not include interest payable on any external financing through loans however considerations for OPEX and cost of capital can be easily included with relatively small adaptation. Thus it is assumed that the investment cost \( I \) is a lump sum at the beginning of the charter.

**Coordination cost -** \( C_{c,o} \) Coordination cost may be considered to be part of CAPEX however, it is kept as a unique term in this case as different methods of evaluating the cost may require different characterisation. For simplicity, based on input from the retrofit case study covered in Chapter 4 it is assumed that the retrofit takes five days on top of any planned maintenance and dry docking. This is evaluated as five days worth of TC at the charter rate defined.

**Payback period -** \( n \) In a survey of around 60 companies HSH Nordbank (2013) found that 64% of the respondents expect a payback period of between 2 and 5 years for their investment in EET. Vessels usually change ownership after 5 years and undertake additional large scale maintenance intervention when any retrofit interventions are undertaken and surveyed by classification societies. Typically, an owner would want to make sure that any investment is repaid within the drydock cycle. For the purposes of this study 3 years is considered as a base payback period. It should be noted that in the HSH Nordbank (2013), 84% of respondents were from Europe which may present a biased stance towards a lower payback period.

**Discount rate -** \( r \) The discount rate defines the expected rate of return of an investment in the particular industry segment. It is difficult to evaluate
accurately and is usually represented by establishing a WACC as a discount rate. This can be difficult to determine if not all the information regarding the investment is known. Thus, it is usually treated as a parameter that is altered to test sensitivity of the criterion variable. In their work concerning marginal abatement cost curves for EET in shipping, Faber, Behrends and Nelissen (2011) present a method that estimates a discount rate based on WACC for deep sea freight transport and individual shipping companies. They estimate the average discount rate to be at 10%.

**Bunker fuel savings - \( \Delta B \)** Poor information on EET performance is pervasive as discussed in Chapter 2. Technology providers usually quote technical potential rather than actual performance, a behaviour which is also common in building efficiency (Shove, 1998). For example, for most EET that improve hydrodynamic or propulsive efficiency, the reduction in power or resistance is reported at particular operating conditions. The leading ducted propeller manufacturer has presented evidence of tow tank tests undertaken at different facilities which show the wide variation of power reduction that was measured at the design operating point for different vessels (Figure 6.18). The evidence suggests that, in reality, installations in operation see higher power savings than the estimated average from tank tests and CFD simulations (Svardal and Mewis, 2011a). This may be an attempt of the technology provider to be conservative in order to protect themselves from underperformance claims.

In the LT scenario, a single-point power reduction of 6.5% is assumed based on the average from Svardal and Mewis (2011b). The value does not take into account the difference in operational draught or any uncertainty. During interviews performed and from industry observation in Chapter 4, owners expressed reluctance to trust technology manufacturers on the savings quoted;
a characteristic shared by charterers. Therefore, margins are added on the savings quoted by the owner (to the charterer), assuming conservatism by reducing 1% off the expected power reduction. On the charterer side, a conservative 10% bunker savings estimate margin is assumed, therefore reducing their expectation of savings by 10% from what is quoted by the owner.

In the HT cases, to overcome the lack of data regarding the performance of EET over different operating profiles and environmental conditions a probability distribution is designed to represent variation in performance. Lee et al. (2013) and Lee et al. (2018) illustrate the uncertainty that can be introduced through exogenous factors in building energy savings ranging from 2.9% to 10.8% over a given year (at a 90% confidence interval). In this case, the cumulative savings uncertainty is characterised by a Weibull distribution.

In the marine sector, Yuan et al. (2016) assumes a uniform, normal and logarithmic PDF when modelling the uncertainty for abatement potential of EET in the absence of data. No significant differences were observed between out-
puts from the three distributions used. Usher and Strachan (2013) present a second option: to elicit these values through expert advice. This requires significant resources, especially for studies involving several technologies such as this one.

Following the example of Yuan et al. (2016), the uncertainty around EET is modelled as a normal distribution based on the tow tank test data in Svardal and Mewis (2011b) which captures the upper and lower bounds of power reduction within the 95% CI. Figure 6.19 shows the distribution range of power reduction expected along with the LT estimate. The distributions are used to apply a random power reduction via MC simulation however they do not account for performance differences at varying speeds and weather condition.

Figure 6.19: Assumed power reduction distribution characterising performance of EET

Providing a power reduction distribution is a more transparent declaration of performance than bunker savings (which relies heavily on assumptions related to operational and environmental conditions) but is challenging to translate into bunker savings. An estimate can be obtained using the characteristics of the installed engine using Equation 6.7.
\[ \Delta B = \frac{P_s(P_I, \epsilon) \cdot SFOC_\epsilon \cdot 24}{10^6} \]  

(6.7)

Where \( \Delta B \) are daily fuel savings (t), \( P_s \) is the estimated power reduction (%), \( P_I \) is the installed power (kW) and \( SFOC_\epsilon \) is the SFOC of the main engine at the given load \( \epsilon \). The design load is assumed to be 0.75 of \( P_I \). Following [Faber et al. (2020)](Faber et al. 2020), the SFOC for a vessel built from 2001 onwards with a direct drive, slow speed two-stroke diesel is taken as 175g/kWh.

In the LT case, \( SFOC_\epsilon \) is assumed to be constant but in the HT scenarios, the SFOC is defined based on engine load as done by [Faber et al. (2020)](Faber et al. 2020) as follows:

\[ SFOC_\epsilon = SFOC_{0.75}(0.445\epsilon^2 - 0.71\epsilon + 1.28) \]  

(6.8)

Engine load is estimated using the power law relationship in Equation 6.9 at each velocity.

\[ \epsilon = \frac{\lambda V^3}{P_I} \]  

(6.9)

Where \( V \) is the speed and \( \lambda \) is a ship specific constant. This estimate accounts for the change in fuel consumption based on the main engine load variation and allows for a more accurate engine model to be included if available. This adds more versatility to the already modular build of the game.

**Intangible factors**

**Green incentives - Inc** The popularity of green incentives is increasing recently with two distinct types of incentives being one-off benefits and activity-
based ones. The former can take shape of grants, low interest loans or pilot projects. This access to capital or reimbursement from projects or institutions is designed to promote the uptake of technologies which tackle particular issues such as port emissions. The latter incentives include discounts on tonnage taxes, harbour fees and less exposure to possible future carbon taxes for more efficient vessels. While these incentive based mechanisms are increasing in popularity, they face a split incentive market barrier on time chartered vessels. This is because the owner of the vessel does not benefit from the port due discounts and thus investment is less attractive unless the vessel is a spot charter or operated by the owner (Karslen et al., 2019, Rehmatulla et al., 2017). No considerations for such incentives were included in the baseline case.

**Energy credentials and reputational value -** These are intangible and particularly difficult to evaluate. In the long term, as companies seek to introduce cleaner supply chains due to higher customer pressure, there will be an intangible advantage to be gained from having more efficient ships through the increased likelihood of being fixed. Furthermore, good press coverage and first-mover advantage should not be underestimated but is difficult to quantify. Shipping is a highly reputational industry and companies are seen to reap the benefits of disruptive behaviour.

Maersk provides a typical example of an organisation taking big steps towards environmental sustainability. They embarking onto a large retrofitting campaign in the wake of the 2008 economic slow down and the rise in bunker prices which followed. This has been reinforced by their public assertions that they are targeting a zero net emissions fleet by 2050 (A.P. Møller – Mærsk A/S, 2018). This can be seen to extend to other elements of the industry such as
charter party design where Exxon have a reputation of picking better vessels. This is codified through their more stringent CPs.

While it is difficult to account for these factors quantitatively, the industry is clearly signalling the importance of greener assets. One such scheme run by the Global Maritime Forum is the Poseidon Principles which are aimed for financiers to determine the environmental performance of their loan portfolios against the initial IMO GHG reduction ambition and inform their decision-making. Owners may find that financing EER, for example, might attract a higher premium for badly performing vessels, thus putting a tangible cost to energy credentials.

6.6.2 Quantitative modelling

Input variables

The utility function devised in the above section is used to run a modified game in the model with the four cases described in Table 6.10. It should be noted that the baseline performance model is used rather than the parametric ones to allow one-at-a-time sensitivity analysis through isolation of the effects related to the introduction of an EER. Assumptions for operational and market factors were kept consistent and are presented in Table 6.11 with the additional information required for EER inclusion.

Results

The translation of estimated power savings (Figure 6.19) to estimated bunker savings using Equation 6.7 shown in Figure 6.20 where the HT scenario is represented by a distribution while the LT uses a deterministic estimate. While the distributions for laden and ballast condition estimate around 1t of savings
Table 6.10: Description of modelling scenario assumptions - introduction of EER

<table>
<thead>
<tr>
<th>Case 1.1</th>
<th>Case 1.2</th>
<th>Case 2.1 (BAU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trust</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Transparency</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Performance modelling</td>
<td>Speed-consumption curves based on noon report data with no weather threshold</td>
<td>Speed-consumption curves based on NR data up to BF4 weather threshold</td>
</tr>
<tr>
<td>Savings estimate</td>
<td>Based on statistical distribution of power savings for ballast and laden condition</td>
<td>Average fixed power savings</td>
</tr>
<tr>
<td>Owner power savings estimate trust margin</td>
<td>None $\alpha = 1%$</td>
<td>None $\alpha = 1%$</td>
</tr>
<tr>
<td>Charterer savings estimate trust margin</td>
<td>None $\gamma = 10%$</td>
<td>None $\gamma = 10%$</td>
</tr>
<tr>
<td>Measurement uncertainty</td>
<td>Considered</td>
<td>Not considered</td>
</tr>
<tr>
<td>Warranted performance</td>
<td>Based on historic experience</td>
<td>Strategically compiled</td>
</tr>
<tr>
<td>Performance communication</td>
<td>Provision of speed-con curve including associated confidence interval</td>
<td>Provision of warranted speed-consumption at laden condition</td>
</tr>
<tr>
<td>Charterer bunker estimate method</td>
<td>Probabilistic: Based on speed-consumption curve and expected probability distribution of speeds</td>
<td>Deterministic: Based on warranted performance communication and expected operational profile during fixture</td>
</tr>
<tr>
<td>Weather margin</td>
<td>None</td>
<td>Applied, $\beta = 5%$</td>
</tr>
<tr>
<td>Charterer trust margin</td>
<td>None $\theta = 5%$</td>
<td>None $\theta = 5%$</td>
</tr>
</tbody>
</table>

on average, in the LT case a 1.8t daily saving is observed. This discrepancy has a significant negative impact on any attempt by charterers to justify paying an EEP when fixing a vessel which leads to the innate conservatism as found in Chapter 4.

Figure 6.21 compares the LT and HT estimates for savings with daily consumption numbers. The chart clearly illustrates the different magnitude of standard deviation for savings and consumption. The low variation in the savings estimate is a result of the power savings distribution created to model the technology.

No account for variability due to weather conditions and differing operational draughts are included, thus even this probabilistic approach does not account for the complete uncertainty. This is due to lack of data from the technology provider.
Table 6.11: Benchmark operating profile, market and EER assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charter rate</td>
<td>$R_t$</td>
<td>13,500</td>
<td>Charter rate for peer group for a one-year fixture in $/day</td>
<td>Clarksons (2018a)</td>
</tr>
<tr>
<td>Freight rate</td>
<td>$f_r$</td>
<td>50</td>
<td>Freight rate for Easychem cargo in $/t</td>
<td>Clarksons (2018a)</td>
</tr>
<tr>
<td>Parcel size</td>
<td>$f_p$</td>
<td>38,000</td>
<td>Typical parcel size of cargo from previous voyages in t</td>
<td>Clarksons (2018a)</td>
</tr>
<tr>
<td>Voyages (pa)</td>
<td>$n_v$</td>
<td>6</td>
<td>Average number of voyages undertaken per annum since 2014</td>
<td>Historic data</td>
</tr>
<tr>
<td>OPEX</td>
<td>$CO_t$</td>
<td>6300</td>
<td>Operating cost based on OPEX index in $/day</td>
<td>Clarksons (2018a)</td>
</tr>
<tr>
<td>Load utilisation</td>
<td>$\alpha$</td>
<td>0.6</td>
<td>Ratio of laden and ballast time</td>
<td>Historic data</td>
</tr>
<tr>
<td>Time utilisation</td>
<td>$\zeta$</td>
<td>0.85</td>
<td>Utilisation of vessel, sailing days per annum</td>
<td>Historic data</td>
</tr>
<tr>
<td>Bunker price</td>
<td>$B_p$</td>
<td>450</td>
<td>Bunker cost for IFO 380 at Port of Rotterdam (Q1 2018) in $/t</td>
<td>Clarksons (2018a)</td>
</tr>
<tr>
<td>Weather margin</td>
<td>$\beta$</td>
<td>0.05</td>
<td>Additional margin to account for rough weather</td>
<td>Gorton et al. (2009)</td>
</tr>
<tr>
<td>Low trust margin</td>
<td>$\theta$</td>
<td>0.05</td>
<td>Additional bunker margin to represent a conservative approach under low trust scenario</td>
<td>Author assumption</td>
</tr>
<tr>
<td>TPD ratio</td>
<td>$\gamma$</td>
<td>0.9</td>
<td>Ratio of mean bunker consumption for ballast condition compared to laden conditions</td>
<td>Historic data</td>
</tr>
<tr>
<td>Warranted TPD</td>
<td>$TPD_{w}$</td>
<td>18.5</td>
<td>As derived in previous section in t [Based on speed of 12.5kn with an additional 0.5t]</td>
<td>Historic data</td>
</tr>
<tr>
<td>Warranted Speed</td>
<td>$V_{w}$</td>
<td>12</td>
<td>As derived in previous section in kn</td>
<td>Historic data</td>
</tr>
<tr>
<td>Investment CAPEX</td>
<td>$I$</td>
<td>300,000</td>
<td>Cost of complete installation of propeller duct in $</td>
<td>Svardal and Mewis (2011b)</td>
</tr>
<tr>
<td>Coordination cost</td>
<td>$C_{co}$</td>
<td>5</td>
<td>Number of days off hire required for installation</td>
<td>Author findings</td>
</tr>
<tr>
<td>Payback period</td>
<td>$t$</td>
<td>3</td>
<td>Expected time for owner to recoup cost in years</td>
<td>Author assumption</td>
</tr>
<tr>
<td>Discount rate</td>
<td>$r$</td>
<td>10</td>
<td>Rate applied to discount cashflow in %</td>
<td>Faber, Behrends and Nelissen (2011)</td>
</tr>
<tr>
<td>Main engine load</td>
<td>$\omega$</td>
<td>0.8</td>
<td>Main engine load assumption for power-to-consumption calculation in %</td>
<td>Author assumption</td>
</tr>
<tr>
<td>Power reduction</td>
<td>$P_s$</td>
<td>6.53</td>
<td>Fixed power savings for LT scenario in %</td>
<td>Svardal and Mewis (2011b)</td>
</tr>
</tbody>
</table>
Figure 6.20: Estimated daily bunker savings

Figure 6.21: Daily savings and consumption distribution
Looking at the bunker consumption over the length of the charter (Figure 6.22), the difference in standard deviation of savings and consumption for the HT cases is evident again. Moreover, savings in the HT case appear to be 1.5 times lower than in the LT case. In the HT scenario, the variability of emissions estimate is not significantly affected by the addition of uncertainty from the savings distribution. The variance of annual consumption is observed to decrease in this case which occurs due to the consumption and savings datasets not being independent variables therefore the canonical rule for the addition of standard deviations does not hold\textsuperscript{19}.

![Figure 6.22: Annual savings and consumption distribution](image)

Results and payoff matrix from the game simulation with the inclusion of an EER are presented in Table 6.12 and Figure 6.23. The owner expected operating profit $E(\text{OP}_\text{e})$ is constant in this case as performance claims cannot be estimated or assumed in a robust way given the additional uncertainty from the EER.

\textsuperscript{19}The standard deviation of a population ($\sigma_\gamma$) made up of the addition or subtraction of two other independent populations ($\sigma_\alpha$, $\sigma_\beta$) is evaluated as $\sigma_\gamma^2 = \sigma_\alpha^2 + \sigma_\beta^2$. 

220
Table 6.12: Baseline scenario - application of EET implementation

<table>
<thead>
<tr>
<th>Case</th>
<th>$E(\text{OP}_c^T)$ ($\text{mil}$)</th>
<th>% of historic</th>
<th>$E(\text{BT}^T)$ (t)</th>
<th>% of historic</th>
<th>$E(\text{OP}_o^T)$ ($\text{mil}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>1.74</td>
<td>1.00</td>
<td>5320</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>1.1</td>
<td>1.79(0.04)*</td>
<td>1.03</td>
<td>5125(60.1)</td>
<td>0.96</td>
<td>2.37</td>
</tr>
<tr>
<td>1.2</td>
<td>1.65(0.04)*</td>
<td>0.95</td>
<td>5158(60.2)</td>
<td>0.97</td>
<td>2.37</td>
</tr>
<tr>
<td>2.1</td>
<td>1.68</td>
<td>0.96</td>
<td>5296</td>
<td>1.00</td>
<td>2.37</td>
</tr>
<tr>
<td>2.2</td>
<td>1.50</td>
<td>0.86</td>
<td>5561</td>
<td>1.05</td>
<td>2.37</td>
</tr>
</tbody>
</table>

* Mean (standard deviation)

Charterer

<table>
<thead>
<tr>
<th>High Trust</th>
<th>Low Trust</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Transparency</td>
<td>$P_{c1}^{11} = 1.79$, $P_{o1}^{11} = 2.37$</td>
</tr>
<tr>
<td>Owner</td>
<td>$P_{c1}^{21} = 1.65$, $P_{o1}^{21} = 2.37$</td>
</tr>
</tbody>
</table>

Figure 6.23: GT pay-off matrix - with EET
The difference between Case 1.1 and 2.2 (BAU) is around 17% for expected operating profit and 9% in fuel consumption over a 12 month charter (Table 6.12). The Nash equilibrium lies at Case 1.1 which provides the optimum outcome for both parties with the caveat that no performance payouts are considered. Figure 6.24 presents the total cost for charterers under the extreme cases where, in the LT scenario, bunker cost is consistently higher due to information uncertainty and conservatism.

Figure 6.24: Charterer cost comparison for extreme Cases 1.1 and 2.2

Discussion

The results above brought to light several issues related to stakeholder dynamics that go beyond those related to data quality and performance modelling. A pervasive problem in the industry that is seen is the lack of a feedback loop between technology provider and customer. This results in slower uptake and development of technologies. Although standardisation for this has been attempted though the introduction of ISO 19030 (BSI, 2016a), the practical implementation of it has been widely disputed in many spaces with the annual Hull Performance and Insight Conference (HullPIC) being specifically dedi-
cated discussing the ISO standard. This further makes the argument for moving away from single-point EET performance to a model or algorithm based on tank test or CFD. The model should be based on a standardised protocol to establish a baseline for design performance which can then be improved on using measured data in operation.

Similarly, companies that offer guarantees on their products place the onus on the customer to have instrumentation to a certain specification installed. This is prohibitive in many cases thus exempting the technology provider from any compensation related to underperformance. Performance guarantees for EET are not common and have only been found in the hull coatings sector.

Once technologies are installed on a vessel that goes out in operation, this provides the ideal platform for data collection to assess the performance of the EET in off-design conditions and with real-world issues, such as the effects of fouling, that cannot be replicated in a model test or CFD due to technical or financial constraints. This in turn results in performance contracts that are not well suited to use post-hoc performance information to define and rebase performance expectations, making any payback calculations either conservative (leading to a high EEP making the vessel less competitive on the market) or unsustainable. Data collected in operation would ideally be fed back to the technology provider, however, several barriers prevent this including lack of willingness to share data due to commercial sensitivity and, more commonly, a lack of high frequency measurement instrumentation that is required.

Moving to practical operation, the difference between a deterministic performance quantification and a probabilistic one (which is dependent on measured data) becomes more apparent in this scenario and underlines the role measured data has to play in establishing a robust EET payback structure.
Figure 6.25 illustrates the elements that make up charterer costs over the fixture in the two key scenarios, Case 1.1 and 2.2 (BAU). The actual charter rate makes up almost 60% of costs thus dominating the outcome. By comparison, the EEP as obtained through an NPV outlook constitutes a negligible percentage of the total cost. The potential for an additional premium associated with fuel savings is favourable given the small proportion of cost it constitutes. This is especially evident when compared to the baseline obtained from the historic dataset as shown in Figure 6.26.

From the charterer perspective, the justification of paying an EEP above the market rate is based on the potential savings. An assessment to find the break-even point for charterers based on bunker price can be used to inform these decisions (Figure 6.27). The chart shows the difference in the break-even bunker price for the HT and LT scenarios. For both cases, the break-even bunker cost is significantly lower than the baseline cost used ($450/t) used to quantify the EEP in this research which is based on the investment cost rather than the expected savings. This highlights the disconnect between the bunker savings and the EER investment and highlights the needs for a mechanism...
Figure 6.26: Bunker and charterer operating profit estimates under different transparency regimes - with EET.

which sets the \text{EEP} based on varying bunker savings and price.

Figure 6.27: Break-even point based on average annual savings

One solution may be performance contracting structure similar to an \text{Energy Service Company(s)} (ESCO). (Wang et al. 2017), points out that uncertainty quantification is a weakness in the current practice with decisions being taken without full understanding of risk leading to conservative performance clauses and guaranteed savings to minimise payout risk. This reinforces the findings.
above suggesting the need for a more transparent arrangement required that does not let uncertainty create a barrier to investment. In a study, Huimin et al. (2019) finds that a cooperative shared savings energy performance contract yields the optimal outcome for both ESCO and owner leading the building of longer relationships and smaller payouts that distribute financial risk more fairly. Wang and He (2018) shows that information asymmetry makes it more profitable for the agent to give different guarantees of environmental performance based on the Principal when considering carbon reduction efficiency in supply chains which is usually held by the manufacturer.

The results in this section codify several features of chartering that are documented in literature and also captured in the qualitative analysis in Chapter 4. Once again, the value of applying GT to structure concepts that are complex to describe and evaluate is shown. The evaluation of the merits of an EET based on the operational performance instead of theoretical estimates is shown to result in very different conclusions regarding the viability of an investment from both the charterer’s and owner’s perspective. The game shows that the higher the transparency regarding the performance, the more both parties can benefit and the less the risk any one party takes on board.

### 6.7 Chapter summary

In Chapter 3 RQ3 was defined as follows: How can the effect of identified shortcomings associated with information barriers in chartering and EER appraisal be reduced?

This chapter assesses the shortcomings identified in literature and Chapter 4 by characterising representative examples of information barriers and testing
these across a range of known commercial and data arrangements. Consis-
tently, better returns were generated if modifications were made to conven-
tional arrangements in contracting and performance evaluation.

The main improvements that can address chartering and performance barri-
ers start with the dataset used; specifically frequency, size and measurement
uncertainty of performance data sets used for performance evaluation. Sec-
ondly, the type of modelling needs to complement the type of data being used.
With these two elements in place, the communication of performance in CPs
through performance clauses can be greatly improved. If these improved mod-
els are made available to charterers when fixing vessels, this leads to more
with more transparency and more benefit for both parties.

With regards to EER appraisal, the main improvements entail the use of mea-
sured performance of the technologies. This is better than relying on theo-
retical estimates that can be misleading and which foster a lack of trust and
excessive conservativeness from both charterers looking to fix vessels and
owners looking to recoup their investment.

The current situation in the TC market allows information asymmetry to limit
the potential of a gradual increase in efficiency in the global fleet through re-
warding better performing ships. Thus any measures to reduce this asymme-
try will have a long term benefit for stakeholders as well as progress towards
emission reduction.

Two clear strategies are outlined in this chapter reduce the information bar-
riers. Firstly, an improved combination of data and modelling strategy used
needs to be reflected back in contractual arrangements that introduce trans-
parency around performance. Secondly, the scale of potential profit loss due to
the current contracting practices needs to be communicated and alternatives
analysed via [GT] to identify which stakeholder stands to gain from them.
Chapter 7

Discussion

7.1 Research in context

In this section, the outcome of this thesis is compared with literature gaps in Chapter 2 to assess if and how these have been addressed. Other themes that emerged through the inductive nature of the study will also be discussed.

The case study in Chapter 4 fills in a significant literature gap providing insight into specific asymmetries and strategies applied by owners and charterers to mitigate vessel performance uncertainty. Amongst these asymmetries, a strong gap between technical and commercial desks was documented within the same company mirroring comments by Karaminas and Shen (2016). The insights gleaned match the barrier structure suggested by Jafarzadeh and Utne (2014) and Rehmatulla and Smith (2015b) despite concerns around representativeness as only one retrofit project was covered in this thesis. The argument that generalisation is not possible using case studies is highly debated by Flyvbjerg (2006) with several examples of significant findings that
came from single case observations as well as \cite{Lowe2007} which lead to changes in national regulation based on one study.

The deeper look into the quantitative case study data also revealed important aspects that might have been missed if the qualitative analysis had not been undertaken. An example of this was the identification of a gap in power meter data (due to an unknown software update. This was directly identified to be a consequence of a lack of dedicated resource allocation to data analysis by the SPM. This in itself is also a novel contribution as in-depth interviews related to specific retrofit interventions are not well documented with the exception of \cite{Schoyen2015}. Only this thorough understanding of the use of data, organisational structure and decision-making process could allow information barriers to be identified and the extent of their effect be understood and evaluated to be later modelled. The increasing data volumes and computational capability in performance modelling are not necessarily the solution to documenting and rewarding more efficient vessels.

On the quantitative modelling side, this research builds on \cite{Bergantino2002} who set up the adverse selection GT framework to represent a chartering dynamic. \cite{Psarros2016} subsequently approached a similar problem through an economic perspective combining it with a probabilistic economic modelling. It is worth noting that the vessel performance aspect is largely unaddressed with a deterministic consumption value being assumed. Therefore, while the information asymmetry aspect is covered, the extent of the possible uncertainty due to data collection and performance modelling is ignored. The uncertainty is taken into account in this work being one of this thesis’ strongest contributions.

The resulting modelling framework is unique in bringing together the techni-
cal challenges of performance measurement and the commercial scenario in which the stakeholders interact. It provides the possibility of quantifying uncertainty in operating profits depending on stakeholder behaviour. While this was previously done in the built environment for leased commercial buildings and EET investments (Li et al., 2011; Liang et al., 2016; Wang et al., 2017), it is the first instance of such a gap being addressed in shipping.

7.2 Appropriateness of method and theoretical framing

The mixed method approach taken in this work is a novel combination of GT and a probabilistic techno-economic model. They have not been combined for modelling this scenario in shipping previously. The GT framework gives the flexibility to characterise different players and strategies as well as draw. The quantitative part of the model allows for uncertainty representation through MC simulation as done by Lee et al. (2013) and is flexible enough to implement adaptations like appetite for risk of stakeholders as applied by Liang et al. (2019). This can be done by changing or adding parameters in the utility functions associated with operating profit.

GT provides an opportunity to capture the nuances of charter party design. This is important because it is one of the key components in any effort to reward efficiency. The modelling framework can lead to the introduction of performance based clauses. This will enable owners or industry bodies that have historically had ownership of standard charter parties to test the impact of different clauses. Similarly, charterers would be able to assess the effect on their outcome from a novel clause which has not discussed beforehand.
Considering the quantitative aspect, the purpose of this work is not to produce the most accurate performance model but reach a compromise between technical rigour and representativeness of the current practice in industry. Owners that use CM along with computational black-box models or multivariate regression are the exception to the rule and charterers that attempt detailed estimates regarding voyage costs at the pre-fixture stage are uncommon. Thus, usability and applicability is more important than accuracy in this case. This is also reflected in the proposed methods put forward in Chapter 6 on uncertainty mitigation and transparency.

When considering performance clauses including expected savings can be tested with this model. Performance models for representing energy savings probabilistically for different operating conditions can be integrated easily. This model can provide evidence to support business decisions and make a case for financing while also be used to test novel performance clauses that include EER.

It is recognised that in this study, exogenous variables such as bunker price, freight rates and voyage costs are considered deterministically however these can be characterised stochastically (through further MC simulation) or can be based on industry projections. While this may increase uncertainty when estimating the operating profit, it provides flexibility for specific additional dimensions that may be desired by the charterer to evaluate risk. This could also allow owners to make business cases for financing of newbuilds or that are capital intensive by showing the reduced likelihood of assets being stranded due to environmental obsolescence. This flexibility extends to accommodating more complex vessel performance models whose output can still be used as input to the model.
As currently designed, the model is targeted for charterers. However, several aspects of it can be developed further to fill knowledge gaps for owners. With knowledge of charter rate projections and expected consumption, the model can be used to find the optimal charter rate or EEP that is optimal for savings pass-through from better performance. As discussed by Gorton et al. (2009), the nuances of performance claims are very difficult to model given the ambiguous performance clause, opacity around precedents and uncertainty around the arbitration process based on evidence provided.

7.2.1 Limitations of quantitative model

The compromise between complexity and representativeness requires some factors to be omitted from modelling in order to define a realistic problem boundary based on the resource available to model it. A consequence of model simplicity is that the extent of the effect that these factors have on the outcome of any modelling and subsequent conclusions cannot be evaluated. In developing the quantitative model for this research these points were documented for transparency and as they present opportunities for interesting further work.

- Model variables - Some variables have been considered deterministically such as the length of the charter period and number of voyages undertaken in a year. These variables can be added a probabilistic distributions or in a range to evaluate the effect they have on the outcome of the model. Another factor is the consideration of draught as a condition (laden or ballast) rather than as a continuous variable which may have introduced further uncertainty in the performance modelling strategy used. While draught corrections based on the Admiralty formula
and vessel characteristics normalise performance for draught, machine learning based performance models such as neural networks can benefit from using draught as an explanatory variable.

• Demurrage costs and port operations - several studies have shown the effect that these factors can have on the voyage costs faced by charterers. Adland and Jia (2018) and Jia and Adland (2019) describe the complexity of determining the value of demurrage payments due while considering laytime and port activity which is beyond the control of charterer or owner. Mazioli et al. (2019) look at a particular port and how changes in laytime, lay day, operation time and length of usable quayside affect the size of demurrage payments based on clauses in charter party contracts. Based on this, it is evident that the consideration of demurrage costs (or revenue) would be a valuable addition to the modelling framework in order to determine operating costs more realistically.

• Market externalities - apart from the exogenous variables mentioned in Section 7.2 other market complexities are not considered. The most prominent is market competition and the fact that, adding a premium for efficiency, adds a risk of the vessel not being chartered at all. This would result in zero utility and profit for the owner while the charterer can move on to another vessel. One way of considering this in the model framework is by adding a consideration for negotiation at the fixture stage as done by Psarros (2016) or by assigning the charterer a level of willingness to pay for efficiency or risk appetite of both stakeholders.

An understanding of the sensitivity of the model the the factors above would help identify which variables need to be represented most accurately and identify any critical shortcomings.
7.3 Integrated takeaways

7.3.1 Standardisation of performance modelling and benchmarking

The large gap in standardisation in vessel performance modelling is a strong source of opacity in the current practice. Even the attempt by ISO 19030, which uses speed-loss as a performance indicator, is found to be inadequate in many cases [Coraddu et al., 2019]. The creation and adoption of ISO 19030 has led to industry-lead conferences specifically targeted towards the application of the standard. This has now created a significant body of evidence to inform possible revisions of the standard. Although standardisation sets a level playing field, it brings up other problems such as the concept of compliance where one can comply but then go beyond the standard which basically removes the transparency element.

Industry bodies (such as Oil Companies International Marine Forum and the Society of International Gas Tanker and Terminal Operators) have traditionally taken the lead in standardising operational aspects such as the creation of the Tanker Management and Self Assessment (TMSA) programme. This leaves some hope that, if standards are put in place, they will be embraced by industry and set by daily practitioners rather than regulatory bodies. A vetting process similar to TMSA that focuses on efficiency as well as safety can drive a move towards environmental vetting similar to the wet bulk convention.

The safety and oil pollution related standardisation were developed to actively protect stakeholders’ own interest thus, as environmental regulation and market-based measures come into force, similar standardisation may be accelerated. Other sectors such as construction in the UK have already made a
move in this direction. In this industry, buildings that do not have a minimum energy efficiency cannot be leased or sold. Although still in its infancy, this has resulted in significant changes in the behaviour of the market as well as collateral changes in the nature of leases, financing, investment portfolio design and management (French, 2019). Such an impact can only be driven by regulation or consolidated industry action.

This also applies to performance estimates for EET which require standardisation based on a body of measured operational data rather than only relying on model tests or CFD. An interesting crossover can be seen where companies developing EET are also venturing into performance monitoring services in order to establish data ownership and understand the behaviour of their technologies in operation. This helps to close the design feedback loop increasing confidence which is essential for increased technology uptake (Rojon and Smith, 2014).

7.3.2 Performance contracting and charter party innovation

The current regime of performance contracting in the TC market has been identified as a key barrier between parties and therefore can provide an opportunity for improvements towards a fairer consideration of performance and distribution of risk. Rialland et al. (2014) discusses how performance contracting can work in ship management in order to distribute risk between parties and reduce information asymmetry through KPIs. Addressing EET in particular, Schinas and Metzger (2019) propose a pay-as-you-save model which is shown to be mutually beneficial in a split-incentive scenario. Töppel and Tränkle (2019) similarly find that well drafted performance contracting dramatically reduce the risk associated with investments in EE in the built environment.
A significant gap in academic research around charter parties was noted during this work with only a handful of Masters theses tackling the subject identified. Most were based on retrospective document reviews (Chernoshtan, 2016; Lindholm, 2014). Smart contracting, better modelling and experiences in other sectors can be drawn upon to design and test the effects of, for example, changes in the language used in energy performance clauses.

Jia and Adland (2019) explore the possibility of solving the problem of demurrage accounting claims through the use of a smart contracting. The authors propose the use of a blockchain to establish trust between stakeholders in the supply chain and reduce the administrative burden of arbitration through a smart contract. The agreement is an algorithm that ingests data from several sources (including AIS, weather and onboard sensors) and, based on pre-agreed terms by all of the stakeholders, establishes a course of action for demurrage claims. The legal standing of computer algorithms as contracts has been established through precedents in different applications and the barrier is more related to the inertia of industries to change the way they operate. Another limitation is the trust in algorithm design and, while blockchain technology provides a level of security, there are still many questions about the application in daily operations.

In a similar fashion, a smart contract around vessel performance can be developed to automatically ingest relevant data from various sources and, based on the agreement of both parties, establishes the value of any performance claims. Figure 7.1 presents this idea schematically. Such a mechanism would make the charter party a tool that reduces information barriers identified as well as rewarding efficiency. Yang et al. (2019) show how a well designed contract can provide a win-win scenario even under conditions of information asymmetry between shippers and operators.
Figure 7.1: Performance based smart contracting clause

The performance regime described above (as well as current chartering practice) can benefit from other innovations such as agreement on specific data service providers. This includes metocean data, weather routing, AIS and fuel consumption estimates which facilitates the resolution of future disputes on performance. The use of ambiguous terminology such as "good weather" and "about" should also be avoided unless specified in some detail (Rabeux, 2019). While these terms add a level of flexibility that may reduce the burden of performance claims due to variability of weather conditions, a compromise may be able to be found by setting up a contractual framework that opens a channel of communication and negotiation during the charter by sharing data.

It is clear that this would lead to a step change in the potential for charterers to estimate fuel consumption from a more comprehensive performance declaration, thus giving much stronger agency to the charterers. In practice, this allows for owners to be more transparent about their premiums, by showing how the vessel operates more efficiently and economically than its peers in spite of being more expensive to charter. The market at the moment does not put a value on better performance (beyond fuel savings) however, with the advent of schemes such as the Sea Cargo Charter (Sea Cargo Charter, 2021) and the performance-based regulation through the IMO Carbon Intensity Index (CII) (IMO MEPC, 2021), this will change in the future.
The challenge lies in giving a performance guarantee, however, this could be replaced by a performance review and a more open discussion on an ongoing basis rather than at the completion of the fixture. As already discussed, smart contracting may be one of the solutions, with blockchain being a conduit for bringing trust between the stakeholder. However, even simpler arrangements can be set up for the same purpose.

Products specifically designed for charterers attempt to fill in the information asymmetry gap regarding vessel performance by bringing together open source data sets (weather, AIS vessel characteristics) in engineering models. This empowers charterers (at a cost) to make more informed decisions and benchmark against competitors while weakening the powerful position of brokers and exclusive arrangements that preclude competition on the basis of performance.

Owners may see this as a threat, however, it is an ideal scenario for the improvement of global fleet efficiency through information unravelling. No owner wants to be at the bottom of the list thus are driven to improve their operation or technology. If these and other innovations are acknowledged and included in the contracting structure, a legitimate reward structure can be set up for the benefit of both parties, leading to higher vessel efficiency. In late 2020, NYK (2020) lead the way in introducing performance-based contracts for newbuilds in collaboration with the shipyards involved thus moving away from design estimated performance to measured performance whilst in operation.
Chapter 8

Conclusion

8.1 Research outcomes

Reflecting back on the research questions set out in Chapter 3, an assessment can be made as to the extent to which they have been answered and other knowledge obtained in the process. The RQs posed were the following:

1. What is the current practice in decision-making for chartering and EER appraisal?
2. How can the effect of the identified information shortcomings on stakeholders be evaluated?
3. How can the effect of identified shortcomings associated with information barriers in chartering and EER appraisal be reduced?

8.1.1 Key findings

In order to answer RQ 1, a case study was undertaken to better understand the practice of vessel selection and EER appraisal. It provided a broad overview of
the interaction between stakeholders and the information used from the project inception through completion and into operation. The case study aided in the understanding of the motivation and practical implementation of an [EER] and provided the following key findings:

- **EE** may not always be the reason for an **EER** to be applied. This underlines the importance of looking at the whole stakeholder network to understand the drivers for investment. Due to the disconnect in the current scenario between parties profiting from vessel ownership and parties profiting from operation, the drivers may not be clear. This makes regulation, policy and initiative design to increase fleet **EE** more complex.

- While **CAPEX** may be procured for **EE** interventions and data collected for performance monitoring, the resources required for using the data collected for performance monitoring may be overlooked. This may lead to a loss of potentially important insights thus, reducing the gains that could be made. Even if data resources are taken into account, it is often the case that the complexity of data collection is underestimated leading to poor quality performance data collection despite the best equipment and intentions.

- Several stakeholders are involved in the project and no one entity has complete oversight of the information available or generated in the process. The narrative for this case study had to be compiled through in-depth interviews with participants representing several entities as well as document and data analysis. Greater transparency in this process would reduce uncertainty and increase trust, both of which may be fundamental to the overall success. This can be done by bringing all parties to the table.
The above insights from the case study lead to the development of the techno-economic modelling framework to answer RQ 2, which sought to evaluate the effect of the information barriers identified in Chapter 4. Three distinct elements were considered in the building of the framework: data quality, performance modelling and information asymmetry. These were captured in a GT framework that represented the stakeholder interaction. A probabilistic techno-economic model evaluated the uncertainty due to the data quality and modelling strategy. The main analysis of results illustrated that all stakeholders stand to gain from an increase in transparency. This was enhanced by the following key findings:

- Not having a standard or widely accepted method for vessel performance modelling can lead to very different consumption estimates from the same data set. This plays into a conservative approach when declaring or interpreting performance guarantees. The presentation of uncertainty with any performance model would provide a better understanding of the representativeness of consumption estimates leading to more informed decisions around fixtures.

- The role of the charter party, specifically the performance clause, should not be underestimated. Legacy language such as the use of "about" in standard forms creates uncertainty around guaranteed performance making single operating point declarations problematic.

- The determination of performance claims is not trivial. It is made more opaque by the language used in both the performance clause and the arbitration process that is commonplace in the industry. A clearer approach which identified the data to be used when settling any claims would make arbitration simpler. It would also reduce duplication of data collection, which was observed to happen in the case study in Chapter
Having established a robust modelling framework, RQ3 proposed solutions to mitigate the effect on stakeholder uncertainty for fixture and EET interventions were proposed and their impact evaluated. Through the preceding RQs and literature, several solutions were tested with varying degrees of success. While the overarching results implied that, with greater transparency, both owners and charterers stand to gain in reducing uncertainty, the following key findings were noted:

- Different data sets benefit from different modelling strategies. The impact of data set length and frequency were tested. Results showed that speed-consumption curves may not be the best way of expressing vessel performance when there are larger amounts of data. This is an area ripe for development, both within academic endeavours seeking to obtain the highest accuracy, and within standardisation and open-source efforts which seek to move away from the current opacity in the sector.

- Simple solutions such as performance curve parametrisation can provide a compromise for both owners and charters that reduces risks due to uncertainty but also allows for negotiation of better charter rates thus rewarding transparency and efficiency. This could quickly lead to a two-tier TC market where the demand for higher quality tonnage and progressive owners accelerates an increase in global fleet efficiency. While there will always be charterers willing to employ cheaper, low quality tonnage, this will increasingly become less attractive. Higher quality charterers who are not only driven by profits and answer the call for more carbon efficient shipping by cargo owners and shareholders.

- In the case of an EE intervention, the limitation of model test or simulation data should be enhanced and complemented with in-service mea-
sured data that can then be used to inform a fair profit sharing regime between charterers and owners based on performance in operation. A probabilistic approach to savings estimates, rather than a deterministic one, leads to more realistic payback period projections.

8.2 Further work and recommendations

This work provides a starting point for research in this field. It has also identified areas that would benefit from further work and areas of interest that should be explored.

8.2.1 Mixed method extension

Starting with the case study regarding an EER, a follow-up analysis of how the long term relationship between the stakeholders has developed would give insight into which elements of the process worked well and what needs improvement. This could take the form of another data gathering exercise through interviews to assess how the performance clause worked in practice. A more extensive quantitative analysis using a larger in-service dataset may lead to more meaningful conclusions on EER performance given teething problems with the data collection would presumably have been overcome. The five year time charter upon which the retrofit decision was made has now come to an end and the retrospective knowledge gained from the experience would provide rich insight that could be useful to inform similar decisions.

An area identified as offering good potential for further investigation is the supplementary PA problems related to vessel consumption reporting once a fixture is underway. The disclosure of fuel consumption by the vessel owner to
the operator is currently based on trust and cannot be verified unless audited in detail. Several services offering fuel estimations based on AIS data and vessel details are already available to charterers. These services can curtail this problem or, at the very least, empower the charterer to start a discussion about any inconsistencies observed. At a more granular level, the communication of consumption from onboard to the onshore offices is a known problem that Poulson and Johnson (2016) found through qualitative interviews. Although these instances have been documented, the extent and magnitude of this misinformation is not known. This raises an opportunity for data gathering through surveys to get a large sample size which provides a statistically significant representation of the attitudes and behaviour onboard. Subsequently, the data can be used to design and test technologies, initiatives and incentives to increase intracompany transparency and efficiency. There is also the opportunity to carry out expert elicitation via interviews with mariners and onshore staff that can then be used for quantitative modelling for the purpose of reducing uncertainties from assumptions (Usher and Strachan, 2013).

8.2.2 Accuracy improvement in models (data and methods)

On the quantitative modelling side, the scope of this study was not about developing the most accurate performance model. The scope was to represent common operational practices and provide a benchmark to illustrate the effect of uncertainty. One improvement that can be tested is implementing sensitivity of consumption and model uncertainty to vessel speed. This was seen to be a limitation in the performance model, as also identified by Adland et al. (2020). A valuable addition work would be a sensitivity analysis to determine the of input variables to accuracy and uncertainty of the outputs. A one-at-a-time method can help identify which modules are most important to represent
the shipping dynamic rigorously and thus focus efforts on the most relevant elements to improve model performance.

The omission of some factors from the utility function require a larger evidence base to be modelled which may be challenging to collect. Specifically, operational costs such as demurrage and brokerage fees play a significant role in particular trades however documentation in literature is scarce thus limiting the potential for robust representation of these costs. A possible solution would be to collect the data through surveys to understand both the relational aspect between operators, charterers, brokers and ports and the scale of the costs that can be included, as well as their likelihood of being incurred.

8.2.3 Analysis of proposed solutions

When considering potential users of this research, the aspects that affect charterers are more thoroughly modelled than those affecting owners. This is mainly due to limited literature covering these particular issues. This gap is prominent in the estimation of performance claims, which are directly related to the performance declaration on charter parties as well as the estimated operating profit for owners. The complexity in modelling this aspect of the charter comes from the arbitrary nature of performance clauses and opacity in how performance claims are settled. While the magnitude and frequency of performance claims can be estimated based on historic data and performance clause conditions, there is no standardisation of how the latter will be interpreted which relates strongly to the ambiguity that is described by Gorton et al. (2009). This gap could potentially be filled through expert input from owners and P&I clubs based on historic experience. Negotiation of charters is seen to be beyond the direct scope of this work. A
framework based on work by Psarros (2016) could be implemented to cover more of the chartering routine. This would provide a range of charter rates under which a fixture would be profitable under specific conditions and uncertainty. Additionally, values such as freight rate, bunker price and utilisation that were defined deterministically in this study can be characterised as probabilistic distributions (through a more onerous MC simulation) to quantify the compounding of uncertainties. This may be especially important in trades where accounting for the volatility of parameters (such as freight rates) may provide a significant value add to the scenario modelling.

This research has also shown the inadequacy of the current performance clauses in charter parties and the potential of novel performance-based contracts to be employed in shipping. An effort in bridging the gap between technical, commercial and legal aspects through a comprehensive contracting structure is required. Performance data transparency between stakeholders can simplify the claims process. However, a legal framework is required to instill trust and legitimacy which can be obtained through several means such as smart contracting. Research into more intuitive and informative performance clauses could be undertaken in conjunction with industry bodies, as these currently hold the legacy standard charter parties. This partnership will facilitate uptake and studies to understand the implications of this model. A similar exercise would be useful to undertake in cases where EER are introduced (such as the case study in Chapter 4) given the additional uncertainty of the technology performance introduced.

The inclusion of EET and the introduction of an EEP is another area that can be further developed given the current lack of empirical data on whether more efficient vessels attract higher premiums. If the currently proposed method of establishing EEP in this study is considered, the NPV-based model can be
improved by including considerations for the cost of capital. It can also be improved by including changes in vessel value on the second-hand market resulting from the inclusion of EET. It should be noted that the evidence base for this is limited and would need to be expanded through analysis of vessel sales.

As more data regarding performance is made available through schemes such as the EU MRV, the reliance on AIS-based estimates is reduced. A study looking into fixtures data and carbon intensity can be undertaken to update literature (Adland et al. (2017), Agnolucci et al. (2014), Prakash et al. (2016), Smith et al. (2013)) which covers the relation between efficiency and charter rate.

8.2.4 Extension into other areas: financing and regulation

The importance of vessel efficiency has been elevated with the rise of carbon intensity as a benchmarking metric. Initiatives such as the Poseidon Principles (Poseidon Principles Association, 2021) led by the Global Maritime Forum and the Climate Bonds Initiative (CBI, 2020) are setting the course, ahead of expected IMO emission reduction measures to be announced in 2023. Transparency of performance is key to both these schemes. Influence Map (2017) exposed how influential industry players have interests in keeping the status quo at the discussion table. Therefore it is all the more important for these initiatives from the financing side to put pressure on the industry to move towards increasing performance transparency and rewarding. This model can be used to build an evidence base for designing measures and illustrate the effects on stakeholders under different scenarios.
8.3 Concluding remarks

This research has explored the information barrier paradigm related to vessel performance that exists in shipping and proposed a model that captures the technical, operational and relational impact on the information available for decision-making with regards to vessel fixtures and technology selection. In the current scenario, information barriers and lack of trust regarding vessel performance leave charterers with a lot of uncertainty when determining the commercial viability of a fixture or EET. The conventional strategy to overcome this is conservativism which in turn provides owners with little or no incentive to operate vessels more efficiently or, invest in more efficient tonnage especially as these have not attracted higher charter rates. Under a higher transparency regime and increased trust, both parties stand to make smarter business decisions in the short term whilst also promoting a long-term shift towards more efficient shipping through both technological and operational means.

This work put forward a novel way of bringing together the technical and commercial regimes in vessel chartering which are usually treated in isolation both in academic literature and in industry. The use of GT has been shown to have potential as a good framework to build an analytical model that transparently considers the perspective of both charterer and owner and their expected economic outcomes based on their respective strategies. By tackling information barriers and asymmetries, this techno-economic model can empower charterers and owners to quantify the effect of these market failures when making chartering decisions. It can also enable policy makers to test the potential outcome of new measures while accounting for behaviour and interactions of industry players. Due to the flexibility offered by the quantitative model, it can be developed to test the outcome for various market scenarios, implementa-
tion of new standards and policies, different performance modelling and data collection approaches and performance-based contracting.
Appendix A

Appendix

A.1 Qualitative data collection materials

Participant information sheet
Decision-Making for Energy Efficiency Retrofits in Shipping

Information sheet for prospective interviewees

Who is conducting the research?
My name is Jean-Marc Bonello and I am inviting you to take part in my research project entitled “Decision-Making for Energy Efficiency Retrofits in Shipping”. I am currently a doctoral researcher at the UCL Energy Institute within the transport group working with Dr Tristan Smith and The Carbon War Room. You may have come across our work in this field including the Third IMO Greenhouse Gas (GHG) Study, contributions to Low Carbon Shipping and Shipping in Changing Climates initiatives and participation in industry conferences.

As the title of my research indicates, I am hoping to find out how ship owners and managers take decisions with regards to energy efficiency retrofits in the current landscape of every increasing regulation, more data collection and disruption.

I very much hope that you would like to take part. This information sheet will try and answer any questions you might have about the project, but please don’t hesitate to contact me if there is anything else you would like to know.

Why is this research being done?
In view of the outcome of the Paris Agreement and both IMO and EU strategies with respect to GHG emissions, every owner is looking at solutions to futureproof their fleet and ensure they remain competitive in tough economic environments. Ship owners and managers are presented with a multitude of solutions for fuel saving and emission reduction amongst which are retrofits that can be applied to existing tonnage. This is all happening within the context of the information age where more data is being created everyday which can be exploited to help decisions in operation but also in planning and implementation. While we know there are barriers to technology uptake, further insight is required into how decisions are taken in practice regarding selection of retrofit technologies.

My research is intended to look at this retrofit decision making process and see how it can be improved for different stakeholders using data and information from various sources. To do this, the current way in which this decision is made is required to be understood to design any future support systems to ensure they target the actual needs of the decision maker.

Why am I being invited to take part?
You have been selected due to your experience with implementation of energy efficiency technologies to your fleet or tonnage that you are responsible for thus you have been highlighted as an active adopter of technological energy efficiency retrofits. Your insight is valuable to create a better picture of the decision-making process carried out in your case in practice while also pointing out challenges and opportunities for better execution.
What will happen if I choose to take part?
Following your acceptance to take part in this research, we will move on to find a convenient time and place to conduct an interview discussing the theme described above. You will be provided with a consent form with detailed statements that will need to be accepted and returned to myself before the interview can take place. As I am conscious of your limited availability and geographical separation, the interviews will take around an hour and may be held in a location of your convenience (such as your offices, conferences or industry events, allowing for logistic plausibility), our London offices or remotely (via Skype). The interview will be recorded for the data to be analysed at a later stage. As described above, questions will be around the decision making related to energy efficiency retrofits drawing upon your experience with this matter.

Participation is entirely voluntary.

Will anyone know I have been involved?
Anonymity and confidentiality are ensured throughout the data collection, analysis, interpretation and publication process. You will be identified by a unique identifier that will not be able to be traced back to yourself or the company you represent. Data will be aggregated, by fleet size, operating region and type, to ensure no participants can be identified individually. The information will be treated as strictly confidential and handled in accordance with the provisions of the UK Data Protection Act 1998. Data Protection Ref for this project: Z6364106/2017/07/37.

What will happen to the results of the research?
Once data is gathered, the analysis carried out will be used as part of my doctoral research as well as other academic papers and publications authored by the research group while retaining anonymity. All raw data (recordings and transcripts) will be encrypted and stored on a password protected location with access restricted to myself. The outcome of the interviews may be published in an academic report and may be submitted to a peer-reviewed journal. You will be granted first access to the paper and, depending on the outcome, will be invited to participate in a workshop or public lecture related to the findings.

Thank you very much for taking the time to read this information sheet.

If you would like to be involved, please complete the following consent form and return to ____________________ by within two weeks of receiving this.

If you have any further questions before you decide whether to take part, you can reach me at ____________________ or on ____________________. Alternatively, if you are concerned with any part of this research and your participation, please feel free to contact the primary investigator, Dr Tristan Smith at ____________________.

UCL Energy Institute
Bartlett School of Environment, Energy & Resources
University College London | Central House | 14 Upper Woburn Place | WC1H 0NN
UCL-Energy Shipping
Participant consent form
Decision-Making for Energy Efficiency Retrofits in Shipping

Consent form for interviewees

If you are happy to participate, please complete this consent form and return by within two weeks of receipt.

☐ I have read and understood the information sheet about the research
☐ I agree to be interviewed as outlined on the information sheet
☐ I am happy for my interview to be audio recorded and stored
☐ I understand that if any of my words are used in reports or presentations they will not be attributed to me or the company I represent
☐ I understand that I can withdraw from the project at any time, and that if I choose to do this, any data I have contributed will not be used
☐ I understand that I can contact the researcher at any time (details below)
☐ I understand that the results will be shared within the research group

Name _______________________
Signed ______________________ Date __________________

Researcher’s name ______________ Signed __________________

Researcher’s contact details:
Email: ________________________
Phone: ________________________

UCL Energy Institute
Bartlett School of Environment, Energy & Resources
University College London | Central House | 14 Upper Woburn Place | WC1H 0NN

UCL-Energy Shipping

Ver. 01_0517
Decision-Making for Energy Efficiency Retrofits in Shipping

Interview topic guide

**Aim:** To get insight into decision making process in shipping companies regarding energy efficiency (EE) retrofits with a focus on structure, data/information use and stakeholder involvement.

**Purpose:** Although there has been work considering barriers to EE retrofit uptake, there is only anecdotal evidence on the process that shipping companies go through to make decisions. This knowledge gap limits insight into what a typical decision making timeline involves, what and how information is used in practice and the stakeholder relationships involved.

In-depth interviews with decision makers that have undertaken this process are expected to offer a better insight when compared to surveys or questionnaires as the interviewees will have the opportunity to discuss themes without being bounded by the nature of the interview.

**Research method:** semi-structured interviews

**Expected length:** around 60 – 90 minutes

**Interviewees:** energy managers, ship owners, ship managers who have implemented retrofits

**Research questions to be answered from interviews:**

| A. Structure | 1. What is the structure of the decision making process?  
| B. Information/ Data | 2. Who are the key players/roles?  
| C. Stakeholder involvement | 3. What information/knowledge is used?  
| | 4. How is this information used?  
| | 5. How are external stakeholders involved? (when, to what extent) |

Question guide:

**Part 1: Establishing interviewee role and company type**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Could you tell me a little about yourself and your experience in the industry?</td>
<td>Context, A2</td>
</tr>
<tr>
<td>2. How would you describe your role in the organisation?</td>
<td>Context, A2</td>
</tr>
<tr>
<td>3. Could you describe your organisation and its main business?</td>
<td>Context</td>
</tr>
<tr>
<td>4. What is your role in decisions regarding the selection of technological energy efficiency retrofits? Just to clarify, by EE retrofits, I mean technological interventions installed to existing tonnage such as new bulbous bows, propeller ducts or WHR† to improve energy efficiency.</td>
<td>Context, A2</td>
</tr>
</tbody>
</table>

†Have diagram at hand to facilitate definition
Part 2: Exploring decision making

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving on to the decision-making process within your organisation:</td>
<td>Lead</td>
</tr>
<tr>
<td>5. What were the main motivators that made you consider EE retrofits?</td>
<td>A1</td>
</tr>
<tr>
<td>6. Could you tell me a little bit more about the decision-making process taken within the organisation, perhaps with a recent example of an intervention?</td>
<td>A1, B3, B4</td>
</tr>
<tr>
<td>Probes:</td>
<td></td>
</tr>
<tr>
<td>a. … how is &quot;insert internal/external stakeholder name&quot; involved?</td>
<td>A2, C5</td>
</tr>
<tr>
<td>b. … what kind of information would you need/use for that?</td>
<td>B3, B4</td>
</tr>
<tr>
<td>c. … where would you get that information from?</td>
<td>B3, B4</td>
</tr>
<tr>
<td>d. … how was this intervention financed?</td>
<td>A1, C5</td>
</tr>
<tr>
<td>e. … what resources are assigned?</td>
<td>A1</td>
</tr>
<tr>
<td>f. … and how long would that typically take?</td>
<td>A1</td>
</tr>
<tr>
<td>g. … is there a review process in place? (are promised savings checked?)</td>
<td>A1</td>
</tr>
<tr>
<td>h. … would this be done differently for another technology?</td>
<td>A1</td>
</tr>
<tr>
<td>i. … how is the final decision made?</td>
<td>A1, A2</td>
</tr>
<tr>
<td>j. … are any tools used for that?</td>
<td>A1, B3, B4</td>
</tr>
<tr>
<td>7. Can you tell me more about who or what influence the decision-making process, both internally and externally?</td>
<td>A1, A2, C5</td>
</tr>
</tbody>
</table>

Part 3: Information/Stakeholder

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only ask Q. 8 if this is not covered satisfactorily by probes in Q. 6</td>
<td>C5</td>
</tr>
<tr>
<td>8. How and to what extent are the following involved in the process?</td>
<td></td>
</tr>
<tr>
<td>- Technology provider</td>
<td></td>
</tr>
<tr>
<td>- Charterer</td>
<td></td>
</tr>
<tr>
<td>- Financier</td>
<td></td>
</tr>
<tr>
<td>- Retrofit yard</td>
<td></td>
</tr>
<tr>
<td>9. From your experience, what other data or information would facilitate or improve this decision?</td>
<td>B1, B2</td>
</tr>
</tbody>
</table>
## Part 4: Wrap up

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. What is the most challenging part of the whole process?</td>
<td>Context</td>
</tr>
<tr>
<td>11. Given the current data and disruption trend, how do you see this decision-making process changing in the future, if at all?</td>
<td>Context</td>
</tr>
<tr>
<td>12. From your experience, are there any lessons learnt your organisation will implement to improve future retrofit selection?</td>
<td>Context</td>
</tr>
</tbody>
</table>
A.2 **ISO** 19030 methodology

![Flowchart for application of ISO 19030 to vessel in-service data](image)

Figure A.1: Flowchart for application of ISO 19030 to vessel in-service data (BSI, 2016b)

260
A.3 Case study in-service data analysis - supplementary material

This section provides graphical representations of data and analysis. Throughout this section:

- the intervention carried out in 2014 will be referred to as \textit{Int1} while the those carried out in 2016 will be called \textit{Int2}
- the first six months are used as an overall reference period for the vessel being the closest to the trial conditions
- reference and evaluation periods are of a six month length (180 days)
- all the time axes are labelled in mm/yy format

Table A.1: Data retention statistics (after filtering and normalisation as per \cite{BSI2016})

<table>
<thead>
<tr>
<th>Period</th>
<th>Raw dataset size</th>
<th>Retained data points</th>
<th>Retained data points (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>1387</td>
<td>621</td>
<td>44.8</td>
</tr>
<tr>
<td>Int1 Reference</td>
<td>180</td>
<td>43</td>
<td>23.9</td>
</tr>
<tr>
<td>Int1 Evaluation</td>
<td>180</td>
<td>59</td>
<td>32.8</td>
</tr>
<tr>
<td>Int2 Reference</td>
<td>180</td>
<td>59</td>
<td>32.8</td>
</tr>
<tr>
<td>Int2 Evaluation</td>
<td>180</td>
<td>68</td>
<td>37.8</td>
</tr>
<tr>
<td>Start</td>
<td>180</td>
<td>62</td>
<td>34.4</td>
</tr>
</tbody>
</table>
Figure A.2: Speed loss time series with 6 month reference and evaluation periods for interventions including dataset start.

Figure A.3: NR power-speed scatter for filtered dataset including trial characteristic.
Figure A.4: NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic

Figure A.5: Case 1 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic
Figure A.6: Case 2 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic

Figure A.7: Case 3 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic
Figure A.8: Case 4 NR power-speed scatters for 6 month reference and evaluation periods including trial characteristic.
A.4 Charting routine and performance clause analysis

The chartering routine

There are several definitions for the stages in the chartering routine which can be described in five sequential steps: pre-fixture, fixture, execution of charter, post-fixture, claims handling. Various authors categorise these in different ways however the general structure and main milestones are similar. In this work, the above naming convention set out by Plomaritou and Nikolaides (2016) will be used. The following paragraphs include a short description of the first three phases being most relevant to this work. The focus is on the behaviour and interaction between stakeholders and use of information throughout the process.

Pre-fixture

Charterers enter the market by making an order known on the market that a requirement for the supply of transport work has arisen. Details include cargo description, port of collection and dispatch and an associated time frame in the case of VC. For TC these are more general and include location of delivery, intended trade, length of charter which are discussed in private between brokers and charterers rather than made public. Owners who receive orders they think are worth considering, contact the broker who circulated the order with an offer which is not binding but a basis for negotiation.

Upon initial matching of an order with ships having matching positions, brokers start several rounds of negotiations on the terms to be agreed upon in the binding charter party. The initial offer entails the main terms of the agreement
which are provided by the owner and negotiated. Upon agreement, confirmation and reconfirmation, a recapitulation of all the negotiation is compiled by the brokers including all the terms agreed upon which is confirmed by both parties. Gorton et al. (2009) highlights the speed at which negotiations take place making the industry inherently reliant on standard charter parties and the importance on good documentation as most of this negotiation may be undertaken by phone and involve several stages of back and forth.

Elements within the standard agreements can be negotiated upon and these vary by market, trade and type of charter. The biggest elements to be negotiated are usually the charter day or voyage rate and specifics regarding the availability (and return in case of TC) of the vessel. One of the clauses that is of significant importance in TC is the performance clause (in some cases referred to as the speed-consumption clause) where the owner declares the expected vessel performance over the period of the fixture. Despite the evident importance, this is not usually negotiated upon unless the warranted performance is significantly different to its peers or the charterer has previous experience with the vessel (or sister vessels).

**Fixture**

The negotiated terms are formalised in a charter party which contractual outlines the terms and conditions to which both the shipowner and charterer agree for a fixed amount of time. The document sets out the rights and responsibilities of the different parties and will be the basis of any future disputes with regards to deviations from what is set out at the start of the fixture (Gorton et al., 2009).
Performance clause analysis  Industry bodies provide practical advice to owners and charterers (BIMCO, 2017) to ensure that common mistakes are avoided as it is apparent that in many cases, standard charter parties are used with no attention given to the specific clauses. This is mainly attributed to the dynamic and fast-paced nature of shipping which leaves little time for the scrutineering of documents that are considered to be conventional in standard practise. This results in difficulties after the charter party has been signed leading to litigation for various reasons. A fundamental element that is commonly omitted are the physical signatures on charter parties which reduces the charter party to a gentlemen’s agreement (Gorton et al., 2009). In an extensive agent-based analysis of charter parties, Rehmatulla (2014) points out the conflicting nature of the requirements of owners and charterers especially during sea passage. One of these is embodied in the utmost dispatch clause that may in many cases work against the interest of charterers if slow steaming or weather routing results in being more economical or allows for virtual arrival.

The performance clause in a TC sets out the expected operational potential of a vessel in terms of a speed and associated fuel consumption within a defined weather threshold and loading condition. The typical performance clause on a TC would be as follows:

“. . . capable of steaming, fully laden, under good weather conditions about _____ knots on a consumption of about _____ tons of _____” - ASBA (1981)

It is expected that the master will operate the vessel as close to the specified velocity as possible with utmost dispatch during the fixture unless otherwise instructed by the charterer. Any deviations from the clause (increased consumption or loss of time) based on the warranted performance are liable to a
performance claim by the charterer. If a claim is filed, a mediator is brought in to lead the discussion between the two parties and assess any evidence provided to substantiate the claim. If this is not resolved, the case may go to arbitration. According to Gorton et al. (2009), under English Law, the performance clause is not understood to be a warranty for speed and consumption over the charter period. It warrants that, during the negotiations and at the time of the fixture, the vessel is capable of the performance. The onus of rough weather risk can also be increasingly put on the owner by drafting increasingly detailed clauses (ASBA et al., 2015, Shell, 1984) which specify a detailed description of orders to be executed by the master under different circumstances including details for different loading conditions.

In most conventional charter parties, any time lost or increased consumption due to heavy weather is borne by the charterer. Speed and consumption should be scrutinised by the charterer together in order to make speed claims based on low speed or high consumption. These are complicated to negotiate but may amount to significant sums emphasising the importance of clauses related to consumption. Considerations for fouling are sometimes included in order to protect the owner against reduced performance claims due to operation in tropical waters for example. ASBA et al. (2015) accounts for this by including a clause whereby agreeing that the charterer and captain can take a decision to undertake hull cleaning "at least once every six months" with hire being suspended during the time the vessel is in dock.20

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20It should be noted that any bunker consumed while in port is also a cost that is borne by the charterer which should not be underestimated as it may be significant due to the higher cost of marine diesel oil used. Consumption in port is specified in some charter parties as it is in the interest of the charterer to have a good idea of the expected cost. In this work, only bunker consumer for propulsion is considered.
Vessels may be ordered to go at "economical" or "low" speed due to commercial or operational reasons and only recently have slow steaming clauses been added to standard TC parties. ExxonMobil (2005) particularly lays out different types of claims that can be brought forward by the charterer under the pretext of breach of performance warranty namely speed warranty and fuel performance warranty compensation. Both of the above are considered for each passage (ballast or laden leg) during the charter period thus, for a speed warranty claim, the average speed over the journey is considering by dividing the distance over the time taken. This is similarly done in the fuel performance warranty case.

**Strategic performance declaration** A similar exercise to Veenstra and van Dalen (2011) is conducted for this research with a small sample of Suezmax vessels on voyage charter were found to be on a TC equivalent (in Q2 2018) at an average of 2kn less than their design speed. The warranted velocity was also compared to the mean laden speed from NR and found to be very similar. Figure A.9 and A.10 present resulting charts echoing Veenstra and van Dalen (2011) when comparing design and warranted speed. From experience in the tanker bareboat market, Devanney (2011) observes shipowners overstating vessel performance to fix a long term charter as the revenues will outweigh any penalties for under-performance if any are brought forward at all and assuming they are lost. This can also be attributed to temporal distortion as losses in the future are heuristically perceived to be of less importance than current ones, in this case, fixing at a lower rate. While these three instances might seem to contradict the previous examples, the authors make a note that the market in which the charter is fixed is a strong driver of the attitude owners take when specifying performance however the bottom line is that strategic performance
declaration is an operational reality stemming from the lack of transparency inherent to the system.

**Execution of charter**

Once the fixture starts, the charterer provides instructions to the master on board who is obliged to operate within the boundaries set out in the charter party and sail with utmost dispatch to the next destination. Deviations from speed and routing are still at his discretion as he is responsible for the vessel and the safety of the crew on board. The master has a challenging position on a TC as he has to answer to the orders of the charterer while also following the operational instructions from the owner. They are also responsible to maintain all shipboard logs including log-books, port sheets, weather reports, bills of laden, NR and Bunker Delivery Note(s) (BDN). These essential documents for daily operations building trust between the owner, charterer and any sub-charterers (Assimenos, 2017). It is important to note that the crew on board is responsible for bunkering operations and tank soundings to estimate daily consumption. It is known that there are several incentives for misreporting bunkering amounts and also bunker consumption in order to have more liberty in the way the vessel is operated or selling bunker on the black market (Poulsen and Sornn-Friese, 2015).

The charterer is usually expected to make a hire payment every 15 days and deductions for any claims can be reduced from the amount of payment. Whilst there are a variety of claims that can be brought by the charterer, performance claims can take the form of speed or consumption claims. Speed claims are based on the vessel being operated too slowly and the charterer claiming for lost time. Consumption claims are considered over the length of a voyage where the bunker consumed is higher than expected for the warranted velocity
Figure A.9: Speed analysis for Suezmax vessels and warranted speed deviation from design speed

Figure A.10: Delta speed and consumption for Suezmax sample fleet
during good weather periods \cite{Makkar2016}. Claims have to be backed by evidence which takes the form of weather service providers supplying high resolution weather reports and in some cases link this with AIS and other data to build a case for the charterer \cite{VPO2018}.

Claims can go through a cycle of escalation starting from mediation through to arbitration and litigation. This is a very opaque part of the industry and only a handful of cases are publicly available to use as examples at the arbitration stage. These available examples shed light on to the complexities of practical implementation of warranties due to the difficulties in assessing weather conditions, the master’s judgement and also the legal wording of the performance clause. Claims and other payment disputes may spill over past the end of the fixture therefore there may be some follow-on post-fixture and claims handling to be undertaken. Recent examples in \cite{Mann2019} show the both technical and legal factors make the process of adjudication difficult and brought down to a case-by-case basis including:

- the interpretation of the "about" with reference to warranted speed and consumption
- establishing a baseline of "normal" operation based on good weather
- conflicting ship logs, weather service provider data and AIS provided by both parties
- no warranty of economical or slow steaming speed
- the reliance on the owner’s "good faith" rather than historic data to establish warranties
A.4.1 Role of the broker

The role of brokering in shipping cannot be underestimated even in this era of data and digital transformation. These intermediaries are considered to be an essential part of the industry due to their knowledge of the market through relationships built over the years. Although they constitute an added expense to both owners and charterers (paid as a percentage of the value of the charter), they may have the connections to optimise matching cargos and vessels adding value especially when having high expertise in particular markets. Pisanias and Willcocks (1999) describe their role as including information acquisition and dissemination, an advisory role through knowledge of the market, negotiation and representation of clients and informal arbitration or facilitation. It is essential that they are continuously informed through formal and informal channels, not withhold any information from their employer and also always act in their interest.

Exclusivity is another privilege that some brokers enjoy implying that to work with particular companies, one would have to go through specific brokers which have the required contacts and information. This is a clear example of how opacity in the market relating to both vessel availability, rates and performance reduces transparency which makes the role of the broker inevitable (Gorton et al. 2009). One of the pieces of information that is vital to the charterer is the vessel performance or consumption at a given service speed which is usually provided by the owner to the broker. Thus, while being privy to the information, the broker has no indication of how representative that figure is however, charterers will rationally prefer brokers who give them more accurate indications of performance in order for them to better assess fixture costs. Brokers with experience on particular routes will gain experience and will be
able to fine tune their predictions which will make a difference in a tight market where competition from other brokers is high.
A.5 Model performance statistics

### Table A.2: Performance models - NR Data - 3 months

<table>
<thead>
<tr>
<th>Loading condition</th>
<th>Measurement Error</th>
<th>Weather Threshold</th>
<th>$R^2$</th>
<th>$R^2_{adj}$</th>
<th>SSE</th>
<th>RMSE</th>
<th>COV*1e14</th>
<th>Coefficients CI N</th>
<th>$x_0^2$</th>
<th>$x_1^2$</th>
<th>$x_0^0$</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast x</td>
<td>BF4</td>
<td></td>
<td>0.89</td>
<td>0.88</td>
<td>2.51</td>
<td>3.19</td>
<td>0.25</td>
<td>-2.70</td>
<td>15.09</td>
<td>5.53</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Ballast ✓</td>
<td>BF4</td>
<td></td>
<td>0.89</td>
<td>0.88</td>
<td>2.53</td>
<td>285.66</td>
<td>0.25</td>
<td>-2.69</td>
<td>15.03</td>
<td>5.58</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Ballast x</td>
<td>n/a</td>
<td></td>
<td>0.88</td>
<td>0.88</td>
<td>2.62</td>
<td>2.99</td>
<td>0.23</td>
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<td>12.52</td>
<td>5.61</td>
<td>31</td>
<td></td>
</tr>
<tr>
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### Table A.3: Performance models - HR Data - 3 months

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Table A.4: Performance models - CM Data - 3 months

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Table A.5: Performance models - NR Data - 6 months

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Table A.6: Performance models - HR Data - 6 months

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### Table A.7: Performance models - CM Data - 6 months

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### Table A.8: Performance models - HR data - all dataset

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