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The value of timecharter optionality in the drybulk market

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ABSTRACT

Using an optimization model on a network with stochastic travel times we estimate the value of flexible worldwide redelivery compared to the more constrained Atlantic ocean option. We evaluate the value of the redelivery option for two types of ship operators: The "oracle operator" with full knowledge about the future and the "FFA operator" who bases his predictions about future freight rates on freight forward prices. Our numerical analysis suggests that the worldwide redelivery option can add around $500,000 to the cumulative profit from a 9 to 12 month timecharter for a mid-size bulk vessel. Our findings are important for the understanding of the value of optionality in chartering contracts.

1. Introduction

It is a common perception among practitioners in the shipping industry that optionality in contracts is not priced correctly. Indeed, many ship operators, particularly in the drybulk segment, have this as part of their business model: Take in tonnage on timecharters (TC) with optional extension periods and redelivery options and make money off the fact that the options are seemingly given away for free (Yun et al., 2018). As an illustration, Jørgensen and De Giovanni (2010) report that 53% of the reported net asset value of shipowner D/S Norden in their 2007 annual report consisted of ship purchase options embedded in timecharter contracts.

There are typically two main sources of optionality embedded in a timecharter contract: the extension option and the redelivery area option.[1] The former option allows the charterer to redeliver the vessel at any point in time within the stated redelivery period. For instance, a typical contract may stipulate a timecharter duration of 9 months plus an optional 3 months. If the spot market drops substantially below the agreed timecharter rate, the charterer will then have an incentive to redeliver the vessel to the owner as soon as possible (i.e. after the minimum period of 9 months has passed). Conversely, a very strong market means the charterer should operate the vessel as long as possible and fully utilize the extension period. The redelivery area option outlines where the ship is to be redelivered to the owner at the end of the timecharter. For period timecharters beyond a duration of a few months this is typically not limited to a particular port, but provides for redelivery within a large geographic area, usually Atlantic, Pacific or simply 'worldwide'. The final place of redelivery is important because it enables the charterer to potentially take advantage of persistent differences in regional rates due to the well-known fronthaul–backhaul dynamic in this market. Due to asymmetric cargo flows, with China being by far the largest importer of drybulk commodities for over a decade, freight rates for vessels going from the Atlantic to the Pacific basin are almost always higher than those for the return voyage (Chen et al., 2014). It follows that redelivery worldwide or in the Pacific should be more valuable than Atlantic delivery, as the charterer/operator may take one final fronthaul voyage to complete the charter.

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[1] We ignore the aforementioned ship purchase options in this paper as they are typically only embedded in long-term TCs with duration of 5–8 years.

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Recent research in maritime economics suggests that the claim of mispriced embedded TC options has some validity. Adland et al. (2017a) investigate the micro-level drivers of timecharter rates in the drybulk market, using a sample of over 10,000 individual fixtures, and find that the presence of an extension option actually has a negative impact on the agreed daily hire, when market conditions, vessel specifications and contract terms are accounted for. According to this research, then, options are not only given away for free, but charterers may even get paid to accept them. The explanation set forth for this apparent anomaly has included that of owner quality or negotiating power. That is, the inclusion of options and acceptance of a discount in the rate is either an attempt by the owner to "sugar-coat" the deal, or a signal of imbalance in the negotiating power in the charterer's favour, or both. The inclusion of options may also signal a perceived credit risk premium. Since charterers with good credit quality are less likely to default or renegotiate the payments of charter hire, shipowners may rationally award contractual flexibility to their counterpart rather than agree to a lower charter hire (see, for instance, Alizadeh and Nomikos, 2009, for a comprehensive discussion on embedded options and their pricing).

It is also true that such optionality is embedded in the physical operation of a ship – they are effectively real options – and therefore cannot be easily monetized. Indeed, Yun et al. (2018) find that embedded TC options have different properties from its financial counterparts, and that the straightforward adoption of theoretical models borrowed from finance therefore does not produce promising results. Even if an operator or charterer has a 'long' position in a TC extension option, this position does not equate to that of a freight option that can be sold short in the financial derivatives market. There are two main reasons for this: basis risk and the joint temporal and spatial aspect of the optimal redelivery of the ship. Basis risk includes (i) deviation in the technical specifications and operation of a ship compared to the reference vessel in the freight derivatives market, (ii) differences in the start and end date of the physical and financial option and (iii) differences in cashflow from the sequential chartering of a vessel at fixed tripcharter rates versus the spot freight rate index underlying the derivatives. See Adland and Jia (2017) for a detailed discussion of such physical basis risks. More importantly, the exercise of the redelivery option (i.e. redelivering the ship to the owner) can only occur at discrete points in time when the ship is both free of cargo and located in a port within the agreed redelivery region. At the start of the timecharter contract, the effective end date of the charter is therefore unknown. The importance of the spatial dimension is not considered at all in the literature and our main contribution is to fill this gap. We note that the use of a floating-rate (index-linked) timecharter removes most basis risks but not the difficulty in matching the duration of the physical and financial option in the time dimension. Consequently, as there is no easy way to take advantage of the perceived arbitrage opportunity, any mispricing would be difficult to remove.

It could also be that the value of options in such physical contracts are so complex to assess that most agents are simply unaware of their true value. The contribution of this paper is to develop and empirically test a methodology to jointly value the extension and spatial redelivery options. Our work is important for the understanding of the value of optionality for charterers, operators and owners alike.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature, Section 3 contains the theory and methodology of our stochastic programming approach, Section 4 presents some empirical results, and Section 5 concludes.

2. Literature review

There exists little research on the value of options embedded in timecharters. Rygaard (2009) describes the technical basis for valuation of timecharter contracts with two types of optionality: the extension of charter duration and an embedded buy option on the underlying ship, where the ship can be bought at predefined time points (Bermudan option) at predefined prices (which may be in non-base currency, introducing additional exchange rate risk). The proposed one-factor stochastic model for forward freight rates is similar to that of Koekebakker and Adland (2004) except that it is extended with mean reversion and the ability to produce volatility smiles. Jørgensen and De Giovanni (2010) similarly adopt the single-factor continuous time model for the dynamic evolution of freight rates of Bjerksund and Ekern (1995) that they use for the closed-form and numerical valuation of various embedded ship purchase options, noting that some combined option structures can be highly complex. Yun et al. (2018) interpret the extension option as a regular European option and value it using both a standard Black & Scholes framework and an artificial neural network approach. Relevant to our work is also the research on freight derivatives valuation and appropriate stochastic processes for either the spot or forward freight rates. Notable examples here are Tvedt (1998), Koekebakker et al. (2007), Nomikos et al. (2013), Kyriakou et al. (2017) and Kyriakou et al. (2018). Default risk in timecharter contracts, as investigated in Adland and Jia (2008), also plays a role here, with Yun et al. (2018) pointing out that extension options should only be given to charterers with low perceived default risk.

Importantly, all the above studies disregard the flexibility in geographical redelivery, instead focusing on the option valuation given the dynamics of some global average spot rate or the dynamics of the term structure of forward freight agreements (FFAs) settled on such a single market measure. This is generally done for the purpose of simplification (Yun et al., 2018). An important question is whether such a simplification will significantly affect the estimated value of the extension option. In our view it is not possible to disentangle the two dimensions – time and space – of ship operation. While a voyage is of comparatively short duration (in the order of weeks), the final voyage still needs to be completed prior to redelivery and remain within the maximum agreed duration of the timecharter, and this limits the operator (in time) in terms of when redelivery can take place. Related to this point is the observation that the final voyage under the timecharter (and therefore its duration) will be determined by the agreed area of redelivery. Once again this imposes a limit on when (in addition to where) redelivery can take place. The effect of this constraint will then percolate back in time to determine optimal behaviour, and ultimately the value of the combined redelivery and extension option, at the start of the timecharter.

To support the importance of the spatial dimension in the valuation of embedded options in timecharters, recent empirical research suggests that the spatial dynamics of freight rates are an important source of both physical basis risk (vs. the freight rate time series used in the literature) and, potentially, an increase in average vessel earnings through optimization. Adland and Jia (2017) show that the true earnings of a ship or fleet of ships will never equal the global averages represented by the Baltic indices, even for a geographically diversified large fleet of Baltic-type vessels. The two main reasons are (i) the moving-average effect imposed on earnings by the sequence of fixed-rate trip durations and (ii) the fact that geographical diversification (regional weightings) cannot remain constant over time due to vessel movements. Adland et al. (2017b) model the Atlantic–Pacific freight rate differential in the Capesize drybulk market and apply a closed-form entry-exit model for the optimal switching of a vessel between the two ocean basins to investigate spatial efficiency. They find that the market is spatially efficient, in the sense that it is not possible to obtain excess earnings through active switching. Prochazka et al. (2019) evaluate the upper bound for the value of having perfect foresight of regional freight rates, and investigate how much of this theoretical maximum can be captured by having limited foresight (in time), using a neural network approach in combination with optimization. They show empirically that the upper bound for large drybulk vessels can be as high as 25% cumulative outperformance, and that a significant portion of this theoretical value can be captured with limited foresight of several weeks.

In this paper we build on the methodology of Prochazka et al. (2019) to investigate the value of the (joint) redelivery and extension option embedded in a timecharter.

3. Methodology

3.1. Background

Without loss of generality we will consider the value of optionality in a timecharter from the viewpoint of an operator. In maritime industry terminology, a ship operator is a company that typically does not own vessels, but charters them in and out on various contracts to take advantage of perceived mispricing between contracts, or simply to take a position on the direction of the market. In addition to the chartering of vessels, a ship operator may also take on contractual obligations to carry cargo through Contracts of Affreightment without having secured the transportation capacity, effectively a way to go ‘short’ the physical freight market in the expectation of a downturn.

The contract structure of interest for our purpose is the simple “TC-in-trip-out”, where the operator charters in a vessel on a period timecharter with a degree of flexible redelivery. The operator (in the capacity of charterer) pays a fixed, predetermined TC rate for the duration of the charter to the owner of the vessel. In an effort to generate a positive profit, the operator then charters the vessel that he now controls commercially out on a sequence of tripcharters, where the vessel sails on any of the main global trading routes until it is to be redelivered under the terms of the TC contract. The charter rate obtained for each trip is equivalent to the prevailing tripcharter rate in the spot market on the day it is fixed. The overall position of the operator can be likened to a freight rate swap, exchanging a fixed payment out for a variable payment in, where the latter is dependent on the ability of the operator to maximize the value of simultaneously optimizing the spatial trading pattern of the vessel and the timing of the redelivery. The objective is to maximize cumulative profits over the planning horizon (the duration of the timecharter). By considering the difference in cumulative profits subject to different constraints on the redelivery location we can estimate the value of the various options. Importantly, our model does not address whether such a naive TC-in-trip-out chartering strategy is the right choice at each point in time. That is, we do not consider the value of optimizing the net exposure to the freight market by allowing the operator to go dynamically “long” or “short”, even though this is an order of magnitude more important than the value of spatial optimization.

We define two types of operators and simulate their performance in the market. The first is an *oracle operator*. As the name suggests, the oracle operator has perfect knowledge of future freight rates and optimizes the decisions accordingly. Thus, he obtains the maximum (expected) profit over the planning period. The expected profit achieved by the oracle operator therefore forms an upper bound for any other strategy. The second type is an *FFA operator*. This operator does not rely on any future information but base his decisions on the market expectations implied by the prevailing prices of Forward Freight Agreements (FFAs) for the planning period. The *FFA operator* models the commercial behaviour of a real ship operator, taking cues from observable forward prices in the market (Section 4).

3.2. Model setting

Let us assume $\mathcal{T} = \{1, 2, \dots, T^F, \dots, T^L\}$ is a finite planning period (in days) with two significant days: T^F is the first day a vessel can be redelivered back to the shipowner, T^L is the last day it can be done. $\mathcal{I}$ is a set of regions between which a ship operates. Similarly let us denote $i^D \in \mathcal{I}$ the region where the ship from the shipowner is delivered to the operator in the beginning of the planning period and $\mathcal{I}^L$ is the set of regions where the ship has to be redelivered back to the shipowner between the days T^F and T^L. If not stated otherwise we use indices $i, j \in \mathcal{I}$ and $t \in \mathcal{T}$.

The operator pays a fixed timecharter rate c (\$/day) for every day the vessel is on charter. The tripcharter rate for a single trip[2] on a route from origin i to destination j at time t is r_{ijt} for every day of the duration of the trip. The objective of the operator is to

[2] A single trip usually comprises one ballast leg to the origin of a cargo, loading the cargo and then a laden leg to a destination port, where it is discharged.

maximize the expected profit over the period $\mathcal{T}$ by reallocating the vessel through the regions on consecutive tripcharters with the obligation to redeliver the vessel to $\mathcal{I}^L$ between T^F and T^L.

We assume each trip takes from $\tau_{ij}^{\min}$ to $\tau_{ij}^{\max}$ days. We assume that the trade duration is unknown before the commencement of the trip (due to weather, port queues, etc.), but is observed at the moment of arrival, and, thus, the consecutive decision (i.e. choosing a destination for the next trip) can differ for different arrival days. We assume that the fixture for the next trip takes place only upon discharging and completion of the previous trip. We assume a discrete uniform distribution $\mathcal{U}\{\tau_{ij}^{\min}, \tau_{ij}^{\max}\}$ of trip duration as in Adland and Jia (2017) and Prochazka et al. (2019). The uncertainty in trip duration reflects the real situation (weather, port queues, etc. are not artificial constructs) and the assumed minimum and maximum durations are industry standards (Baltic Exchange, 2019). While we do not know how realistic the assumption of a perfect uniform distribution is, the true empirical distribution can only be obtained by comprehensive analysis of ship tracking data, which is beyond the scope of our paper. Moreover, our aim is not to build a perfect model of the trading pattern (optimal decision-making is not our primary interest). Instead, the simplified uniform distribution is used to decrease the capability of exact planning the further we go into the future by cumulating the impact of the stochasticity of travel times. This is a desired feature of the model that reflects the real nature of the planning problem. If we did not include it and assumed deterministic trip duration, the decisions would be basically driven by a random few-days spike in rates that happens in a distant future.

At any point i, t in this region–time–space, the operator has essentially $\mathcal{I}+1$ possible decisions (actions): to choose the next region or to decide to redeliver the ship. However, not all of the actions are feasible at any i, t point. For example redelivery is possible only between T^F and T^L, while on the last day of the planning period, there is no other option than to redeliver the ship to the shipowner. Let us denote $\mathcal{A}$ a set of actions, $\mathcal{A} \subset \mathcal{I} \cup \{g\}$, where g is the decision to redeliver the ship. We use an index $a \in \mathcal{A}$ for denoting an action.

Let us introduce an indicator of feasibility f_{iat} for every action, taking the value 1 if the action a is feasible for a vessel positioned at i, t point, 0 otherwise.

The feasibility of actions can be determined by the procedure described in Algorithm 1. We start with assigning feasibility to the redeliver action at every appropriate i, t point. Every i, t point that can reach another feasible point when iterating backwards and considering the maximal trip duration (the worst case), is also marked as a feasible one. By this iterative process, we make sure that the vessel can meet the deadline for redelivery.

Algorithm 1 Determination of feasibility of actions

inputs: $\mathcal{I}, \mathcal{I}^F, T^F, T^L, \tau_{ij}^{\max}$
output: f_{iat}

set initially $f_{iat} = 0 \quad \forall i, a, t$
for $t = T^F$ to T^L **do**
  for $i \in \mathcal{I}^F$ **do**
    $f_{iat} = 1$
for $t = T^L$ to 1 (step $= -1$) **do**
  for $i \in \mathcal{I}$ **do**
    for $j \in \mathcal{I}$ **do**
      $t' = t - \tau_{ij}^{\max}$
      if $t' \geq 1$ **then**
        if $\exists a : f_{iat} = 1$ **then**
          $f_{iat'} = 1$

Although vessels are inherently indivisible assets, we work (conceptually) with "fractions of the vessel" since, for every possible trip duration, the vessel arrives to the destination at different time point. This can be treated by assuming the vessel can be divided into several fractions (as many as there are scenarios of a particular trip duration) and each fraction arrives at different time point. From that point, the fraction of the vessel can continue in trading (independently of other fractions) and is further divided into smaller fractions.

Another interpretation is that the fractions represent the expected capacity of the vessel at a specific i, t point. In the case of the unit vessel, this number equals to the probability that the vessel is allocated at that i, t point.

By making a decision to reallocate a vessel (1 unit) from i to j at time t, the operator's expected profit from such a move is

$$e_{ijt} = \sum_{s=\tau_{ij}^{\min}}^{\tau_{ij}^{\max}} \pi_{ij} (r_{ijt} - c) s \tag{1}$$

where $\pi_{ij} = \frac{1}{\tau_{ij}^{\max} - \tau_{ij}^{\min} + 1}$ is the probability that the trip takes s days given a uniform distribution.

Note that Eq. (1) represents the expected profit if the decision is actually implemented. When we later use estimates of future freight rates r_{ijt}, Eq. (1) expresses the estimated expected profit in the future. The latter is necessary to generate a plan for the vessel movement through space and time, albeit one where only the first decision is implemented and subsequent decisions can be adjusted based on the development of the market.

To formulate the optimization model that leads to maximization of the expected profit, we define decision variables x_{iat} for denoting a fraction of the vessel in region i at time t performing the action a. Further let us denote R_{it} the fraction of the vessel located in region i at time t.

3.3. Oracle operator

Let us consider first the case where the freight rates are presumed known for the entire planning period. The optimization problem to solve is

$$\max_{x} \sum_{ijt} e_{ijt} x_{ijt} \tag{2}$$

$$\text{s.t.} \qquad R_{it} = \sum_{a} x_{iat} \qquad \forall i, t \tag{3}$$

$$R_{jt} = R^{C}_{jt} + \sum_{i} \sum_{s=t-\tau^{\max}_{ij}}^{t-\tau^{\min}_{ij}} \pi_{ij} x_{ijs} \qquad \forall j, t \tag{4}$$

$$x_{iat} \leq f_{iat} \qquad \forall i, a, t \tag{5}$$

The objective (2) is to maximize the expected profit. The constraints (3) and (4) ensure proper flow balance at i, t points. The sum $\sum_{s=t-\tau^{\min}_{ij}}^{\tau^{\max}_{ij}}$ is, naturally, meaningful only for positive s. The variable R^{C}_{it} serves the purpose of storing the distribution of the vessel's fractions over i, t points (which is utilized later when future rates are dynamically updated). On the first day of trading, $R^{C}_{it} = 1$ for $i = i^{D}$ and $t = 1$; 0 otherwise. The constraint (5) ensures that only feasible actions are allowed.

The model (2)–(5) is essentially a network flow problem. It is possible to solve it by a standard linear programming framework or to reformulate it into a dynamic programming setting (and avoid the need for an optimization solver). This is shown in Appendix A.

We note that it is naturally not possible to mimic the performance of the oracle operator in real life due to the assumption of perfect knowledge of future freight rates. We use the concept of the oracle operator to establish the upper bound for any other realistic strategy. For a broader discussion of this concept, see Prochazka et al. (2019).

3.4. FFA operator

In this section, we introduce a strategy that – contrary to the oracle operator – can be implemented in real life. Instead of assuming that perfectly known freight rates enter the optimization problem (2)–(5), only estimates of the future freight rates are used and dynamically updated throughout the simulation of the trading activity. The estimates are based on observable FFA prices.

3.4.1. Expected future spot rates and FFA prices

The above optimization model assumes that the future regional freight rates are known for the whole period, which is obviously unrealistic. While freight rates have some short-term predictability (positive serial autocorrelation) as shown in Benth and Koekebakker (2016), the question of whether their long-term dynamics represent a mean-reverting process or a non-stationary process has evolved over time (see, Koekebakker et al., 2006, for a detailed discussion). With longer time series available, recent empirical evidence suggests that spot freight rates are stationary (Moutzouris and Nomikos, 2019).

While spot rates are naturally uncertain, the output of the optimization problem (2)–(5) which maximizes expected cumulative profit will remain unchanged if we use estimates of their mean future values (i.e. a deterministic forecast) provided that we do not impose any risk- or cash-flow related constraints. In order to value the redelivery option, we need a realistic scenario for the joint evolution of future spot freight rates on the main routes. In principle we can solve this either by estimating a statistical model for the joint evolution of regional freight rates or by utilizing the market's expectations about future (average) spot freight rates embedded in the prices of traded FFAs. The latter option is preferable for a couple of reasons. Firstly, FFA prices incorporate both public information and the private information of traders in the market. Secondly, FFA prices are generally found to be unbiased estimators of future average spot rates, at least on short horizons of 1–3 months (Kavussanos and Nomikos, 1999; Kavussanos et al., 2004; Kavussanos and Visvikis, 2010).

FFAs are traded in a voice-brokered OTC market and cleared through clearing houses such as SGX and EEX. The contracts are settled against the average spot freight rate of each month and traded as either single months, quarters or calendar years, with liquidity typically focused on short-term maturities and the first calendar year (Alizadeh et al., 2015). However, drybulk FFAs are almost exclusively traded against the global average tripcharter indices for each vessel size category, as provided by the Baltic Exchange, with limited or no liquidity for individual routes. In order to derive realistic implied FFA prices for individual routes we therefore build on Adland et al. (2018), who show that the cointegrated system of regional spot freight rates can be decomposed into the global arithmetic tripcharter average, which is traded in the FFA market, and additive, mean-reverting regional rate differentials against that average. The mean reverting nature of regional route differentials reflects the fact that rational shipowners will tend to relocate their fleet towards high-rate geographical areas. At the same time, the asymmetry in cargo volumes between the Atlantic and Pacific oceans mean that the long-term average differentials for the fronthaul route is positive and negative for the backhaul route Adland et al. (2018).

In order to derive a scenario for the expected future regional spot rates that is consistent with traded FFA prices, the final step is then to model the path for the regional differentials. To avoid drawing conclusions on the basis of some backward-looking historical estimate, we choose instead to examine the impact of the two possible "extremes" in the speed of mean reversion: The "myopic" case (MO) where the future differentials remain identical to the current (spot) differential and the Rapid Mean Reversion (RMR) case where the differentials revert to their sample average within 30 days (i.e. the shortest horizon before the first decision has to be made). In our notation, *FFA-MO* denotes an operator that makes trading decisions on the basis of observed FFA prices and the assumption that spatial differentials remain, while *FFA-RMR* denotes an operator that assumes regional differentials will converge rapidly to their sample averages. Any intermediate speeds of mean reversion in the regional differentials will necessarily result in an option value between these two extremes.

3.4.2. Estimates of future rates

Formally, let us describe the forward curve on every day d[3] by prices $r^{\mathrm{FFA}}_{d\Delta}$, where Δ is the number of days counted from day d. We consider a rolling horizon with a forward curve composed of the nearest non-overlapping months and quarters. We assume that $r^{\mathrm{FFA}}_{d\Delta}$ equals the FFA price for the period that contains day $d + \Delta$.

The estimates of future rates for "rapid mean reversion" (FFA-RMR) and "myopic" (FFA-MO) operators are denoted by $\hat{r}^{d\Delta}_{ij}$. That is, $\hat{r}^{d\Delta}_{ij}$ represent the estimates of the future freight rates on the ij – route made on day d for the subsequent days $\Delta = 1, 2, 3, \ldots$

Let us denote the arithmetic average of the regional routes on every day d by $\bar{r}_d$, that is $\bar{r}_d = \frac{\sum_{ij} r_{ijd}}{|\mathcal{I}|^2}$. The regional differential δ_{ijd} is calculated as

$$\delta_{ijd} = r_{ijd} - \bar{r}_d \tag{6}$$

Let us calculate the long-term mean of differentials $\bar{\delta}_{ij}$ as the arithmetic average of δ_{ijd} over all days d that we consider.

The forecast for future freight rates for the FFA-RMR operator made on day d for the subsequent days $\Delta = 1, 2, 3, \ldots$ is given by

$$\hat{r}^{d\Delta}_{ij} = r^{\mathrm{FFA}}_{d\Delta} + \bar{\delta}_{ij} \tag{7}$$

That is, the regional differential jumps to its long-term mean "tomorrow". Technically, it does not matter for the optimization model (2)–(5), whether there is such a jump or a smooth transition to the long-term mean over several future days, since it takes at least 30 days (duration of the shortest trip) before a new decision is made.

As we use the sample averages of the regional differentials, δ_{ij} will technically contain future information. However, based on the clear stationarity and lack of trend documented in Adland et al. (2018) this approach can be justified.

The FFA-MO operator assumes that the current regional differential ζ_{ijd}, calculated as $\zeta_{ijd} = r_{ijd} - r^{\mathrm{FFA}}_{ijd}$, will persist in the future. That is, the estimates of future rates are

$$\hat{r}^{d\Delta}_{ij} = r^{\mathrm{FFA}}_{d\Delta} + \zeta_{ijd} \tag{8}$$

With knowledge of the prevailing FFA curve from the market prices and the regional differentials we obtain estimates of the implied regional forward freight rates by Eqs. (7) and (8) which are then used in the optimization model for the FFA operator described in the next section.

3.4.3. Modelling the ship trading pattern

We next illustrate how the optimal sequence of tripcharters for a single ship is determined. In the case of the oracle operator this is relatively straightforward. Armed with perfect knowledge of future regional rates, all the decisions, daily profits, etc. can be calculated in the beginning of the planning period by running the optimization model (2)–(5) once.

In contrast, the FFA operator updates and recalculates the model every day, since new information (new freight rates and, hence, new estimates of future freight rates) are obtained. With new estimates of the rates, the operator can also update the estimates of the expected future profit by running the optimization model (2)–(5) and if there is a decision to make (determine an action for a vessel), it is made according to the model.

To store estimates of the future profit (from the day $t + 1$ till the end of the planning period) we introduce a new variable P_t. Furthermore, the captured profit at day t is stored in M_t.

The procedure for simulating the trading is summarized in Algorithm 2. As the time t' progresses, the rates estimates are updated and the optimization programme (2)–(5) is solved with those current rates estimates obtained by (7) and (8). Naturally, for each (relative) day t in the future we need to assign the corresponding day expressed in absolute time $d + \Delta$.

From the optimal decisions x^*_{ijt} (i.e., a plan of what to do from the day t' till the end of the planning period), we get the profit $M_{t'}$ captured at time t' and estimates of the future expected cumulative profit $P_{t'}$. Then in the last 4 rows of the algorithm, we update the positions of the fractions of the vessel, that is, we "implement" the decision that takes effect at time t'.

[3] Notice that we use two different index notations for days: t and d; d refers to a specific calendar day, whereas index t is used for the day count relative to the start of each new contract.

Algorithm 2 Trade simulation

inputs: $\mathcal{I}, \mathcal{T}, r_{ijt}, \tau_{ij}^{\min}, \tau_{ij}^{\max}, \pi_{ij}$
outputs: M_t, P_t

set initially $P_{t'} = 0, M_{t'} = 0\ \forall t',\ R^C_{jt'} = 1$ for $i = i^D$ and $t' = 1$; 0 otherwise

for $t' = 1$ to T^L **do**
  update rates r_{ijt} for all the future days $t > t'$ by (7) or (8); recalculate e_{ijt} by (1)
  solve (2)–(5) to get optimal decisions x^*_{ijt}
  $M_{t'} = e_{ijt'} x^*_{ijt'}$
  $P_{t'} = \sum_{t>t'} \sum_{ij} e_{ijt} x^*_{ijt}$
  for $i \in \mathcal{I}$ **do**
    for $j \in \mathcal{I}$ **do**
      for $s = \tau_{ij}^{\min}$ to $\tau_{ij}^{\max}$ **do**
        $R^C_{i,t'+s} = R^C_{j,t'+s} + \pi_{ij} x^*_{ijt'}$
    $R^C_{it'} = 0$

4. Numerical analysis

In our numerical analysis, we work with a simplified model of the world with only two regions — the Atlantic and Pacific basins. In shipping industry parlance the Atlantic basin roughly corresponds to the ocean areas west of Suez/South Africa and east of the Americas, with the Pacific covering the remainder. This creates four possible routes for trade: trans-Atlantic (TA), trans-Pacific (TP), from the Atlantic to the Pacific basin, also called fronthaul (FH) in the shipping literature, and finally the backhaul (BH) trip from the Pacific to the Atlantic (see for instance Alizadeh and Nomikos, 2009). For each of the routes we use tripcharter spot rates for the period 2009–2015 provided by the Baltic exchange and obtained via the Clarksons Shipping Intelligence Network database for three segments of dry bulk shipping: Supramax (around 52,000 metric tonnes deadweight carrying capacity, DWT), Panamax (74,000 DWT) and Capesize (172,000 DWT). We use one-year timecharter (TC) rates, also provided by Clarksons Shipping Intelligence Network. FFA prices for the same period are obtained from the Baltic Exchange. In Fig. 1, the spot rates for the Supramax sector are displayed — we show the average rate over the four routes, and then the difference between rates at particular routes and the average (relative rates).

For all sectors we assume the same discrete uniform distribution of trip durations with the following ranges: TA: 30–45 days, TP: 30–40 days, FH: 60–70 days, BH: 60–70 days. The same setting is used in Adland and Jia (2017) and also matches standard

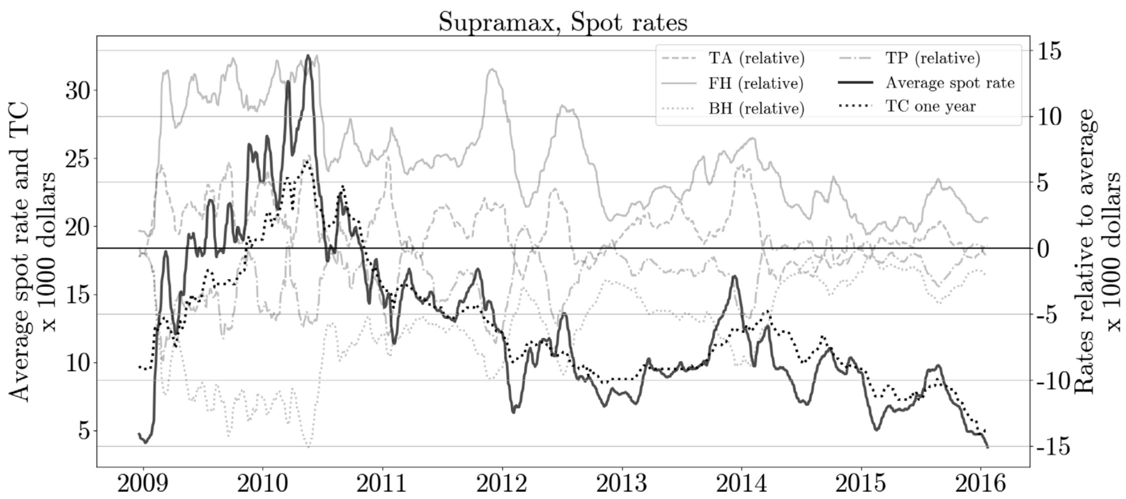

Fig. 1. Average spot rate and relative regional rates.
Source: Clarksons Shipping Intelligence Network.

Baltic Exchange assumptions. We assume that $T^F = 9$ months (270 days), with an extension of up to three months allowed, such that $T^L = 12$ months (360 days). This is one of the most common contractual setups for drybulk timecharters, based on fixture data from Clarkson Research Studies.[4] While there are other combinations of minimum and maximum timecharter durations observable in fixture data, the objective of our paper is to identify and isolate, as far as possible, the impact of the redelivery region. Accordingly, we restrict the duration dimension in our numerical example. Even so, we note that it is not possible to completely disentangle the spatial and temporal component of contractual optionality, as our algorithm determines the optimal time for redelivering the ship (within the three-month maximum extension period) conditional on the redelivery constraint. We assume the vessel is located in the Pacific basin (i^D) in the beginning of the planning period. This is where most ships will be open due to the aforementioned asymmetry in the global trading pattern, with China being by far the largest importer. We consider two cases for redelivery — the Atlantic (Atl) basin and the worldwide (WW) redelivery option, which obviously includes both the Atlantic and Pacific basin in the set of redelivery regions ($\mathcal{I}^L$).

The complete procedure for the simulation of one year of trading, described in Section 3.4.3, is calculated every seventh day. This is done for both the oracle (optimization model (2)–(5) run only once) and FFA operators (Algorithm 2), for both of the redelivery options (Atl and WW) and for all the three segments of vessels. However, while we have many combinations of settings, it turns out that it is mainly the magnitude of the option value estimates that differ and not the insights or commentary that can be drawn from them. Hence, for the remainder of the paper we comment only on one combination, displaying the plots for the other cases in Appendix B.

4.1. Trading profits

With the methodology described in Section 3 we calculate the overall profit accumulated over the entire planning period and compare the results of the oracle operator and two types of FFA operators. The profit is calculated on the basis of taking a vessel in on a timecharter (with maximum 12-month duration) and then re-letting it on consecutive tripcharters according to the optimal strategy identified by our model. This is done every seven days. Fig. 2 shows the comparison for the Supramax sector with WW redelivery option. The oracle operator obtains better results by definition, as it is not possible to outperform the profit obtained with perfect foresight. We also display the difference between FFA-MO and Oracle operators (grey line) that gives a hint of how (in)efficient the trading based purely on FFAs is.

We note that the myopic operator performs better than an operator assuming a rapid reversion of regional differentials to their respective means. This is simply a reflection of the relatively high persistence in regional differentials, that is, they will tend to revert only slowly (over several weeks) as the global fleet gradually relocates between the regions. For the purpose of fleet allocation, therefore, the assumption of 'no change' is a reasonable one. The well-known persistence of the Atlantic premium is discussed in detail in Adland et al. (2017b).

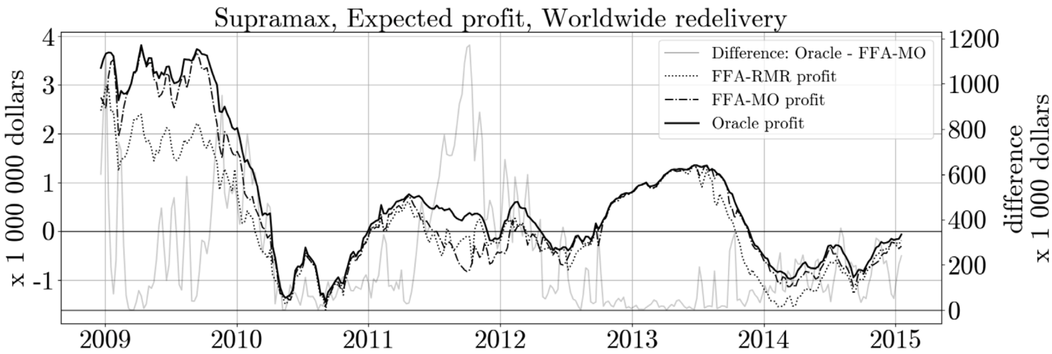

Fig. 2. Comparison of profits obtained by the oracle and FFA operators.
Source: Author's calculation.

In order to provide a deeper analysis of the inefficiencies, we would need to identify the points (in space and time) where decisions generated by the two operators differ and compare the real future rates with the estimates of rates derived from FFAs at that particular point. The difference between the estimated and realized future freight rate affects the choice of different decisions and hence, the overall profit. Such an analysis goes beyond the scope of this paper. However, it is very interesting to notice that the FFA-MO operator does not perform substantially worse than the oracle operator. This could either be an indication that FFA prices are good and unbiased estimates of the future direction of rates, or that the dynamics of regional rates are such that better foresight does not matter much over as short planning period of only 12 months, or a combination of the two.

[4] As the value of the redelivery option arise mainly at the end of a timecharter based on whether a final FH voyage is feasible, longer-duration timecharters will not generate a significantly different redelivery option value. Adland et al. (2017a) reports that the average duration of timecharters (measured to the mid-point of the extension period) is 10 months for Capesizes.

Importantly, we do not consider whether the naive strategy of always chartering in a vessel on a period timecharter and re-letting it in the spot market is the optimal choice. It is well-known that operators engaging in such naive "long-only" positioning will tend to profit in increasing spot markets and lose money in a declining market (Adland and Strandenes, 2006). We recognize this cyclical pattern also in Fig. 2, but what we care about is the difference between the various types of operators, not the absolute level of trading profits. If the objective of the exercise was to arrive at the optimal chartering strategy for a ship operator – as opposed to investigating the value of the redelivery option – we would need to consider more degrees of freedom, such as the ability to go short the physical freight market through Contracts of Affreightments or the ability to alter the duration of the timecharter depending on market conditions. As an example of the latter, Axarloglou et al. (2013) investigates the time-varying spread between spot and timecharter rates and shows how the allocation of vessels on charters of different durations affect activity and pricing.

4.2. Value of redelivery (VoR) option

Our primary focus is on the comparison of different regional redelivery options for a particular type of operator. The Value of Redelivery (VoR) option is defined as the difference between the overall accumulated expected profit when subject to worldwide and Atlantic redelivery, respectively.

Formally,

$$\mathrm{VoR}_d = \sum_{t=1}^{T^L} \left(M_t^{\mathrm{WW}} - M_t^{\mathrm{Atl}} \right), \tag{9}$$

where M_t^{WW} expresses the development of expected profit during the trading period when assuming worldwide redelivery; M_t^{Atl} for Atlantic redelivery. Naturally, the planning period starting at day d is considered. Again, we show results for the Supramax sector and both types of operators in Fig. 3.

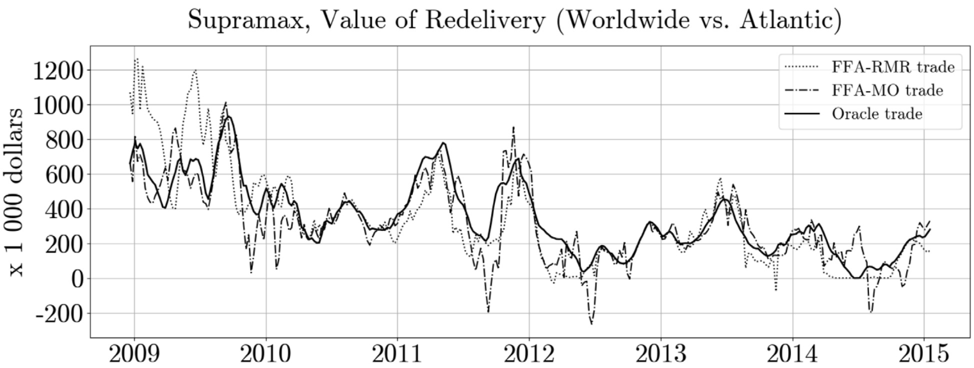

Fig. 3. Value of having Worldwide vs. Atlantic redelivery option.
Source: Author's calculation.

Since the Atlantic basin is included in the worldwide set, the oracle operator always reports a non-negative VoR. If it is optimal to redeliver in the Atlantic, the oracle operator will do so in the worldwide setting.

This is, however, not the case for FFA operators. Since the FFA estimates of future spot freight rates contain errors, they can lead to wrong decisions — for example to 'choose a backhaul trip assuming that the market in the Atlantic basin will be strong at the time of arrival'. If the market develops in an unexpected way and produce lower freight rates, such a decision can be very costly. However, a different redelivery option does not have to lead to the same incorrect decisions despite the fact that the estimates of future freight rates were equally inaccurate. Thus, almost arbitrarily bad decisions can be made for each redelivery option. It follows that the VoR is more volatile for FFA operators, but there is not a significant bias in the evaluation of the VoR for the oracle and both FFA operators.

We see that in the Supramax sector the VoR declines from around \$600k in the early part of the sample to around \$200k towards the end. This is related to the overall lower freight market (both tripcharter rates and TC rates) and corresponding lower volatility during the latter part of the sample. As a general point, we expect the value of optionality to increase with the volatility of spot freight rates and their regional differentials, as well as the level of freight rates themselves. While this is a general result in option pricing theory, Adland et al. (2017b) show that the oversupply of vessels implied by low freight rates tends to reduce regional freight rate differentials and their persistence, thereby reducing the value of spatial optimization. Similarly, an increase in the duration of the extension period will increase the value of optionality as it provides greater flexibility in terms of when the ship can be redelivered.

4.3. Predictability of VoR

The knowledge of the VoR would be especially useful in the beginning of the planning period when the contract is negotiated, where either the shipowner or the operator can take advantage of any mispricing. In this subsection, we show how the estimates of the VoR is developing throughout the planning period with the main focus on the beginning of the period. This is, obviously, meaningful only for the FFA operators. For the oracle operator, the VoR is known in the beginning of the planning period.

For any time t we calculate the estimation of the overall expected profit as the sum of all collected profits M_t obtained from the day 1 up to time t and the estimated future profit P_t. This is done for both redelivery options and their difference becomes the estimate of the VoR at time t. If we deduct the real VoR observed at the end of the planning period, we can assess the value of "how wrong the estimate of the VoR was at time t".

Using the upper script to distinguish between worldwide (WW) and Atlantic (Atl) redelivery, we can express the formula for VoR estimates made on tth day of trading activity starting at day d:

$$\widehat{\mathrm{VoR}}_{dt} = \sum_{s=1}^{t} \left(M_s^{\mathrm{WW}} - M_s^{\mathrm{Atl}} \right) + \sum_{s=t+1}^{T^L} \left(P_s^{\mathrm{WW}} - P_s^{\mathrm{Atl}} \right) \tag{10}$$

Looking retrospect (after the end of the trading when VoR is known), we can assess how accurate that estimate was on each day of trading. The error made at day t is:

$$\varepsilon_{dt} = \widehat{\mathrm{VoR}}_{dt} - \mathrm{VoR}_d \tag{11}$$

We aggregate these estimates of ε_{dt} for all days d where the new contract was assumed in order to see how accurate the estimates of the VoR were in general. Again, we show the results for the Supramax sector in Fig. 4, with the histogram of the estimates at day 0 and the mean and 10, 25, 75 and 90% percentiles highlighted in the plot. We show the results for the FFA-MO operator as this operator is slightly more realistic (technically it does not use any future information, see our discussion in Section 3.4.1), but more importantly shows better profits.

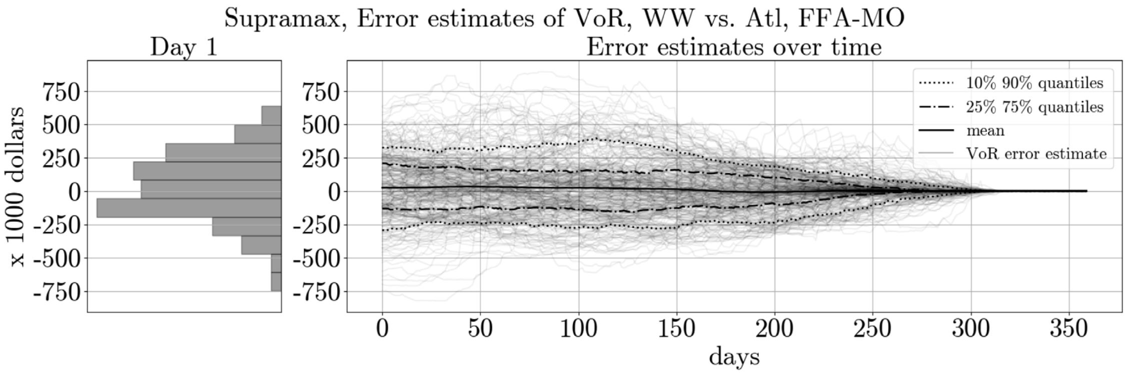

Fig. 4. Accuracy of estimates of the VoR over the planning period.
Source: Author's calculation.

We see that the forecast of the VoR basically does not improve for the first 150 days, the estimates continuously converge to the real values observed at the end. We offer the following explanation for this phenomenon: the decisions made in the first half of the period are most likely very similar for both options, because they are driven mainly by today's rates. That is, they are either equally bad or equally good from a long-term perspective. Thus, they imply similar captured profits. Moreover, the accuracy of the VoR is mainly driven by the accuracy of FFAs as forecasts of future regional rates. As the time approaches the end of the planning horizon, improved accuracy of FFAs and a more realistic plan for the remaining days (that takes into account different redelivery options) will both cause better predictability of the VoR.

5. Concluding remarks

In this paper we have developed a framework for the valuation of the redelivery option embedded in timecharters. Investigation of the value of such flexibility has not been considered previously in the literature. Our numerical analysis suggests that having worldwide redelivery instead of the more constraining Atlantic redelivery in the Supramax sector can add around $500,000 to the cumulative profit from a one-year timecharter. In terms of managerial implications, a very interesting result from our analysis is the observation that a ship operator that decides on the optimal chartering strategy based on observable FFA prices and the assumption that regional differentials are constant (FFA-MO) perform nearly as well as an oracle with perfect knowledge of future freight rates.

We acknowledge that there are some limitations in our research. Firstly, we estimate the VoR option value as a single number referring to incremental cumulative profit rather than a $/day value. This is because we cannot be certain of the optionality assumptions underlying the broker estimates of the prevailing one-year TC rate. Secondly, we are applying a rather simplified model of commercial ship operation as we assume that there is no waiting time between contracts (either voluntarily or imposed by poor market conditions), no ability to vary vessel speed, and no ability on the part of the ship operator to choose shorter or longer voyages according to expectations about market conditions.

Future research should consider relaxing one or more of these assumptions to make the trading of the ship more realistic. An improved model application should also focus more on decisions (behaviour), not just on VoR and its predictability. There is also scope for improvement in a more realistic treatment of stochasticity in rates which allows us to consider the riskiness of the proposed optimal trading pattern — certainly an aspect that is useful for a real ship operator.

CRediT authorship contribution statement

Roar Adland: Conceptualization, Writing - original draft, Funding acquisition, Writing - review & editing. **Vit Prochazka:** Conceptualization, Data curation, Methodology, Formal analysis, Visualization, Writing - original draft, Writing - review & editing.

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Appendix A. Dynamic programming reformulation

We show the reformulation of the optimization model for spatial and redelivery decisions (2)–(5) into a dynamic programming framework. In order to do that, we define values W_{iat} denoting expected earnings generated from time t till the end of the planning horizon by a unit vessel positioned in region i at time t and performing the action a (either choose a new destination or redeliver the vessel). In other words, we store the values of possible decisions that a unit vessel can make in region i at time t.

Then, we iterate backwards through the planning period and determine the optimal decisions by choosing the best action at each i, t point. That is, we choose the highest W_{iat} value out of all feasible actions. We store this highest value in variables[5] V_{it}. Notice that a decision made in any i, t point does not depend on any of the previous decisions. The entire procedure is summarized in Algorithm 3.

Algorithm 3 Dynamic programming for spatial positioning and redelivery optimization

inputs: $\mathcal{I}, \mathcal{T}, r_{ijt}, \tau_{ij}^{\min}, \tau_{ij}^{\max}, \pi_{ij}$
output: x_{ijt}

```
set W_iat = 0, V_it = −∞,  x_iat = 0  ∀i, a, t
for t := T^L  to  1 do
    for i ∈ I do
        a* = arg max_a {W_iat | f_iat = 1}
        V_it = W_ia*t
        x_ia*t = 1
    for j ∈ I do
        for i ∈ I do
            for τ := τ_ij^min  to  τ_ij^max do
                s = t − τ
                if s > 0 then
                    W_ias = W_ias + π_ij ((r_ijs − c) τ + V_jt)
```

[5] The values V_{it} correspond to dual variables of constraints (3) in the optimization model (2)–(5).

Appendix B. Figures for all sectors

See Figs. B.1–B.3.

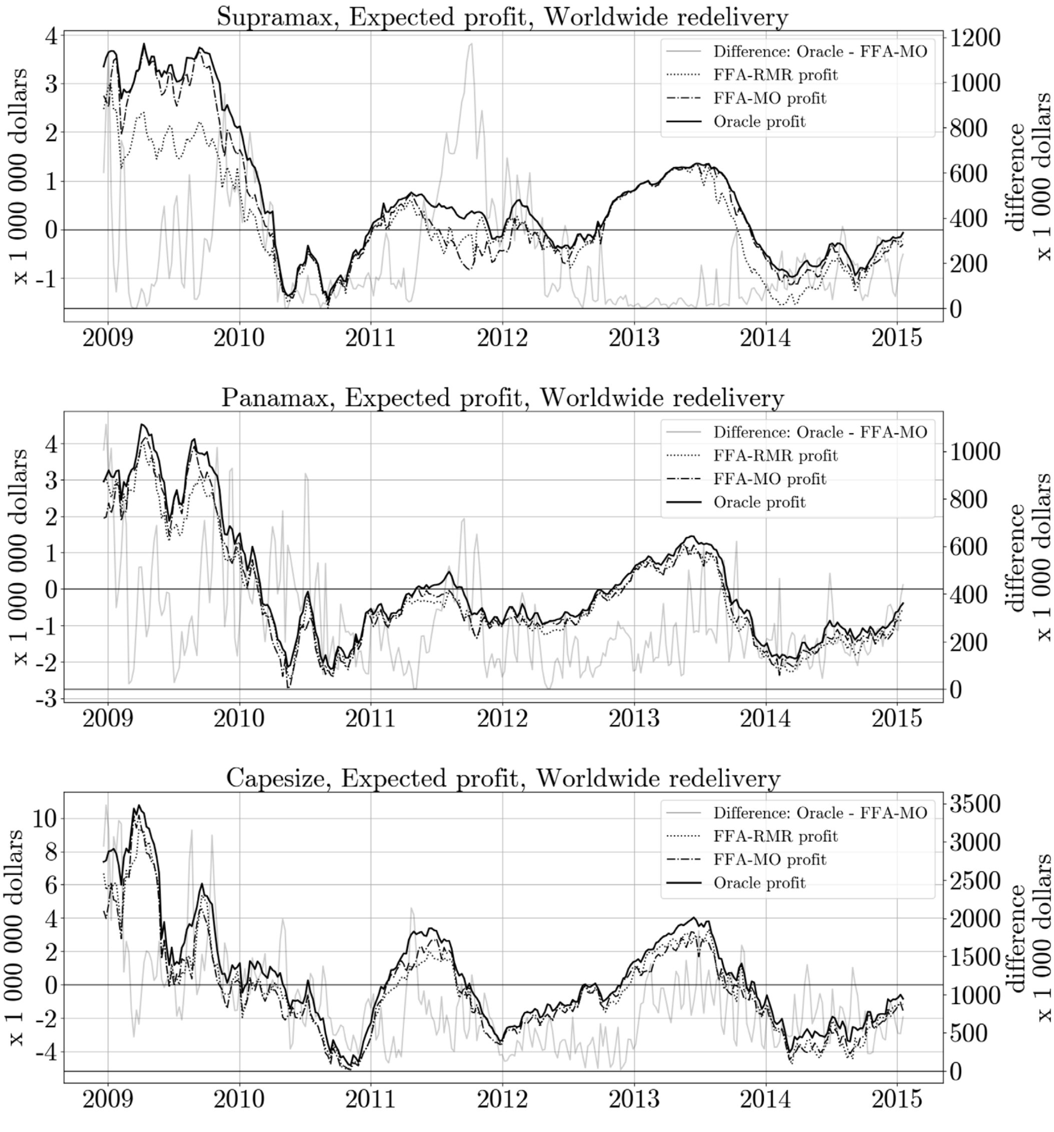

Fig. B.1. Comparison of profits obtained by the oracle and FFA operators.
Source: Author's calculation.

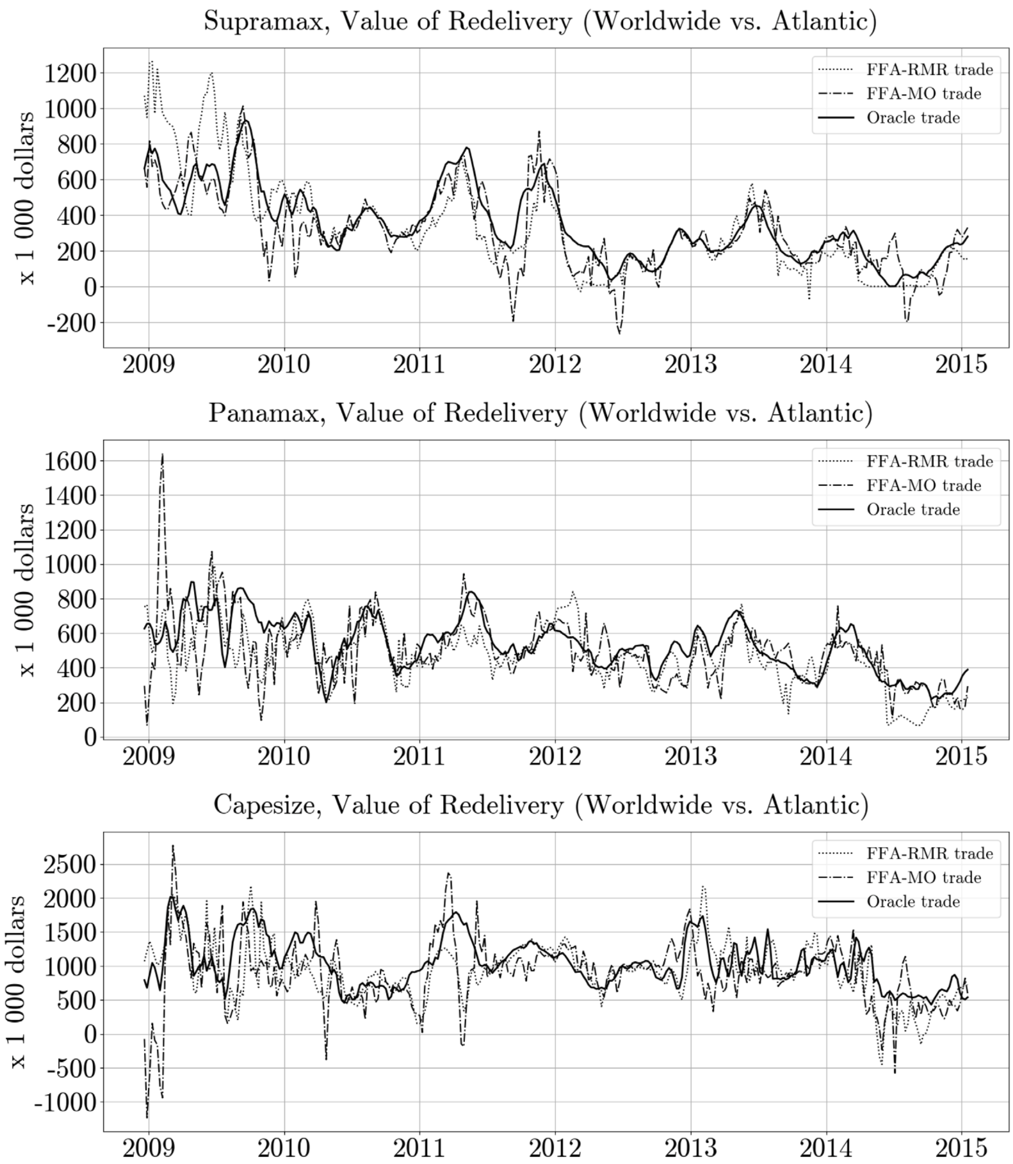

Fig. B.2. Value of having Worldwide vs. Atlantic redelivery option.
Source: Author's calculation.

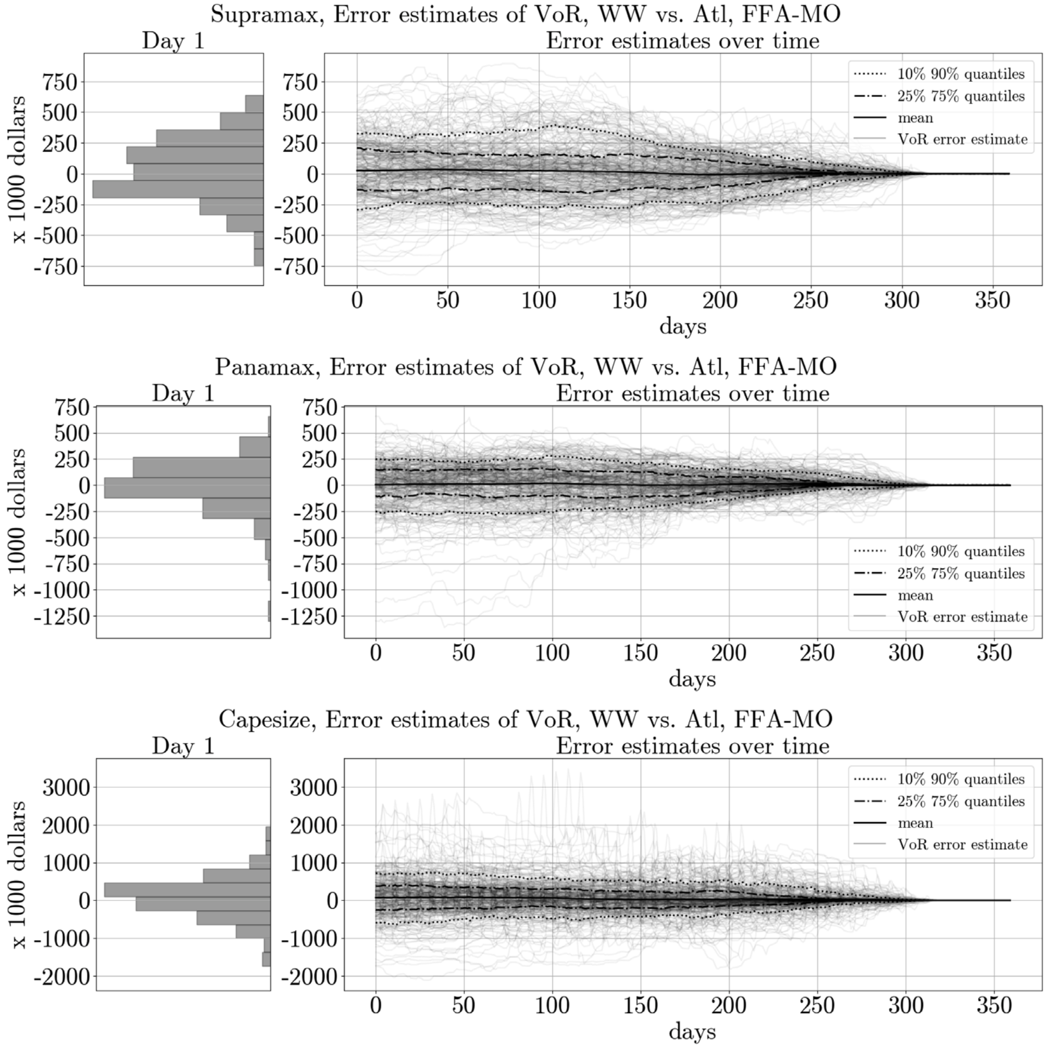

Fig. B.3. Progress of estimates of the VoR.
Source: Author's calculation.

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