

# Decisionmetrics: Dynamic Structural Estimation of Shipping Investment Decisions

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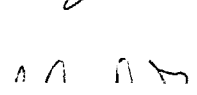
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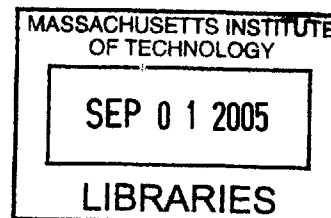


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# Decisionmetrics: Dynamic Structural Estimation of Shipping Investment Decisions

by George N. Dikos

Submitted to the department of Ocean Engineering on March 29, 2004, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Ocean Systems Management at the Massachusetts Institute of Technology.

## Abstract

This dissertation develops structural models for analyzing shipping investment decisions, namely ordering, scrapping and lay-up decisions in the tanker industry. We develop models, based on a microeconomic specification, that allow us to understand the dynamics of shipping investment decisions under uncertainty and test interrelated economic assertions with aggregate data.

The main framework is a three-party model with a structural specification of the time charter rate process, based on market clearing conditions. Structural estimation of shipping investment decisions is performed by using advanced econometric methods consistent with the Real Options and Market Microstructure literature. Several statistical tests are employed, in order to evaluate alternative specifications. Once the aggregate models have been identified and estimated, some of the early hypotheses in maritime economics are addressed and re-evaluated.

Finally we integrate the three different investment modules and reconstruct the structural transportation supply function that determines the equilibrium time charter rate. System identification techniques and advanced econometric methods are employed separately and then combined, resulting in an exceptional “within-sample”, as well as “out-of-sample” performance of the integrated model.

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## **Biography**

George Dikos attended the National Technical University of Athens, Greece, from 1995 to 1999, where he received his Diploma in Naval Architecture and Marine Engineering. From 2000-2001 he attended the City University Business School, London, where he received an M.S. in Shipping, Trade and Finance with distinction. In August 2001, Dikos was accepted as a graduate student in the Ocean Systems Management Program in the Department of Ocean Engineering at MIT. He graduated with an M.S. in February 2003 and a Ph.D. in the same field in June 2004.

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# 1 Objective and Project Statement

In this Chapter the basic problem and motivation for this research are discussed. Before describing the problem, existing research and methodology is reviewed and potential extensions are considered. This section is a broad description of the problem and the complications that arise when using aggregate data to infer individual actions, as well as the implications of heterogeneity of agents and some convenient shortcuts, that yield tractable solutions. Finally, it is a general introduction for the non-specialized reader.

## 1.1 Aggregate Shipping Investment Decisions

There are two main goals when evaluating investment decisions. On the one hand, a good understanding of the mechanics of the formation of decisions may provide a more efficient decision support system for managers and investors. On the other hand, it is crucial for policy makers and legislators to have a clear-cut understanding of the dynamics of the investment process. Furthermore, due to its competitive nature and fairly simple payoff structure, the shipping industry provides a very interesting framework for testing some of the main assumptions of Economic Theory.

In this thesis we shall consider three basic investment decisions, which are clearly interrelated. The first one is the investment in new vessels, or newbuildings. The second is the decision whether to charter or lay-up a vessel for a given time charter rate and the third one is the decision whether to scrap an existing vessel or not. The main difficulty with analyzing these decisions and the impact of different policies on the dynamics of the industry is that the researcher cannot match specific actions to specific persons and all the analysis has to be carried out on aggregate data. There is also a fourth decision that exists due to the dual nature of vessels as both consumption and capital assets: this is the decision to sell a second hand vessel in the second hand market, which is clearly an asset play decision that does not affect the other three decisions and markets. In her recent paper, Strandenes [57] makes a very interesting characterization of the first three markets and the market for second hand vessels. She considers the first three as **real markets**, that determine the transportation capacity supply through their structure, whereas the market for second hand vessels is considered as an **auxiliary or secondary market** with no profound impact on the transportation supply and the formation of the time charter rate. Although the transactions in

the second hand market do not affect the transportation capacity supply or demand, there could be some indirect effects on the prices of vessels and the time charter rate. To the knowledge of the author no research has been done on the effects of **trading volumes** in the second hand market on the dynamics of prices in the real markets.

In his pioneering work, Devanney [20] used Dynamic Programming to characterize optimal marine decisions under uncertainty and irreversibility and offered a complete specification for optimal individual actions. The derived policies depend on personal attributes towards risk and assessment of future uncertainty. The main drawback of this methodology is that it cannot be applied to aggregate data and only to individual specific data. Since data are available in aggregate form and individual actions are usually undisclosed, it is impossible to construct a model based on micro-foundations.

Adland [3] sets the Dynamic Programming problem in continuous time and considers the scrapping and lay-up or charter decisions simultaneously. He implicitly adopts the assumption that the value of these payoffs are spanned in financial markets and are tradable. However, he does not solve the full optimization problem. As stated “given the complexity and scope of the problem, only a special case is considered below and the solution to the general optimization problem is left for future research.” Adland [3] also adopts the assumption of rational expectations and separates the charter or lay-up decision from the scrapping decision. This will be the core of this model, but instead of using non-parametric methods to specify the dynamics of the time charter process, economic structure will indicate the specification of the functional form of the transportation supply function. This approach might shed some light on the empirical findings of Adland [3], namely that the time charter rate displays some non-Markovian dynamics.

Another implicit assumption introduced by Adland [3] is the assumption of **independence of actions**. Theoretically, every shipowner solves a complicated Dynamic Programming Problem that pins down his optimal investment, scrapping and charter versus lay-up policy. Following Adland [3] we shall consider these three actions independently. In this setting, the market for new vessels (newbuilding market hereafter) will be determined by the demand for new vessels, the scrapping of old vessels will be determined by the decision to exit and finally, the time charter rates will be determined by the decision to charter or lay-up a vessel. These three actions will comprise the core of the three modules of the model presented in this thesis.

Aggregate investment functions that specify the amount of deadweight

(*dwt* hereafter) ordered for a prevailing time charter rate, or the price of a new vessel, are similar to supply and demand functions for consumer goods. Considering investment decisions in assets, as supply and demand functions is a major step towards the understanding of investment in a market microstructure framework. Despite the significant similarities with consumer-production theory that arise in this setting, there is one main difference: In consumer theory, the main determinant of individual choice is consumer's positive definite utility, whereas in our case the sufficient statistic will be the **value function**. Whether this arises from each agent's Dynamic Programming problem or is uniquely determined in financial markets, depends on the level of market completeness. Aggregating all these different actions of heterogeneous individuals, forms the "demand" function for new vessels by the potential investors, the "supply" of transportation from existing owners and the "supply" of new vessels by the shipyards. Even when using the aggregate data specification, which mainly consists of specifying the appropriate functional form between the demand and supply functions and their explanatory variables, finding the correct specification is not an easy task. If we assume that markets are in equilibrium and supply equals demand, we only observe the equilibrium prices and we can only separate supply from demand functions (since we only observe their intersection) by using appropriate cost shifters. For an excellent discussion of identification and estimation of simultaneous equations see Hausman [37]. One of the main contributions of this thesis *is be the treatment of investment decisions in a market clearing supply and demand framework*. Using the advances in modern financial economics and economic intuition we try to identify the correct form of the aggregate demand function for new vessels, transportation supply function by existing carriers, supply function of new vessels by the yards and finally scrapping supply of old and obsolete carriers.

After the preliminary analysis of the performance of this three-party equilibrium (new investors, existing owners and yards) with an exogenously driven demand for transportation capacity, the main focus will be on the construction of a model that will be consistent with optimal individual actions. The methods employed to aggregate these actions will be the main topic of the next two sections.

## 1.2 Endogenous Time Charter Models

In the classical Devaney model [20] for optimal marine decisions under uncertainty, it is assumed that each agent has different preferences towards risk and the future state of demand. This implies that each agent has a different value function (the value of the Bellman equation [9]) and therefore different responses. However, if a set of risks is spanned in financial markets, then the value of each action spanned in these markets is a sufficient statistic for the characterization of optimal actions and exists in a closed form. If a subset of risks is spanned in financial markets and we can replicate the project by existing trading strategies, then we do not need to solve the dynamic programming policies or specify payoff functions in the micro levels. We can use directly the results of the Real Option literature as in Goncalves [30] and in the pioneering book of Dixit and Pindyck [28].

Given an exogenously specified process, we can calculate the value of each action explicitly. Investment dynamics may then be attributed to operating cost differences among operators and variations in the number of agents present in the industry, which depend on finance availability and participation fees. The assumption of complete markets, where namely all risks can be priced by combination of traded assets like futures, shares or bonds, allows us on the one hand to have a closed form for the value of each action, which is common for all agents and on the other hand it allows the usage of this unique value as an explanatory variable for the investment supply and demand functions. This assumption was first introduced in Maritime Economics by Goncalves [30].

If we assume that not all risks are spanned in financial markets, but all agents agree on the dynamics of the underlying process, the value function will only differ due to preferences towards risk. Using the existing literature on simulation methods [48], we may aggregate the different value functions into the aggregate investment supply and demand functions. Using economic theory and intuition allows us to gain some knowledge on the appropriate specification of the functional form and not assume an ad hoc specification of the functional form.

All the analysis of optimal marine decisions under uncertainty and the derivation of the associated value function is based on the prevailing spot rate. As noted already in 1971 in Devaney's pioneering work [20] "the charter rates are not the driving forces in this market. Rather they are determined by the underlying demand and supply of the type of shipping services." Agents

perceive the underlying process, form their optimal actions, they act and service the existing demand for transportation. The underlying process is determined in equilibrium when demand equals supply. This is due to the dual nature of the ship as capital and physical good. Assumptions on the existence of financial markets allow us to derive closed form optimal decision rules; however these actions affect the underlying process. As noted in Dixit and Pindyck [28] “each firm takes as exogenous the whole stochastic process of the price. So we start with a price process, let all agents respond to it, and then find the process that clears the market at each instant.” This is a function or a mapping that takes us from one stochastic process to another. We have an equilibrium if we get the same price process that we started with or a **fixed point**. It is very difficult to construct fixed point theorems or laws of large numbers for entire processes. The derivation of optimal actions, with an endogenously specified process, under uncertainty and irreversibility is one of the main contributions of this thesis, from a theoretical point of view. Specifying the rates endogenously will also lead to the correct specification of the transportation supply function.

In the basic three-party model, discussed in the previous section, the time charter process **may be perceived as exogenous for the characterization of investment decisions in new vessels**. This is due to two main reasons:

- 1) There is a construction lag between the investment order and the time when the ship is delivered and affects the investment process.
- 2) The amount of new tonnage is very small compared to the existing tonnage and therefore the time charter rate is determined exogenously for the investors.

This second **assumption of no feedback**, coupled with the **independence of actions assumption** allows us to study the entry, exit and waiting decisions in an independent framework, without considering any feedback effects.

Even though the above reasons allow us to forego endogeneity issues regarding the time charter rate (*tcrate*) for the investment demand function, the time charter rate has to be determined by market clearing conditions in the second hand chartering market, in a rational expectations general equilibrium framework. This framework, combined with the interaction of financial markets will provide the required structure for determining the transportation supply function of second hand vessels (already existing vessels). Having specified the functional form of the transportation supply function allows the

derivation of the general equilibrium time charter rate. Finally, uncertainty and irreversibility will clearly affect the functional form of the supply side and generate a different specification than the classical “step function” introduced by Devanney [20]. This observation has been made also by Adland [3], who demonstrated with Monte Carlo simulations that the short-term supply function in bulk shipping is determined not only by the lay-up option, but also by other unemployment risk factors.

If the time charter rate is specified by the dynamics in the second hand market, then potential investors will invest in new vessels only if technological progress provides a significant technical advantage that justifies investment in new vessels, given the discounted expected profit flow from the structural time charter rate process.

However, there is a third party that interferes with the dynamics of investing in new ships and this is the party of the shippers. The role of this party has not been taken into consideration in the existing literature, but has a significant impact on the demand for new vessels. In a frictionless market, shippers with a vertical demand function would operate the vessels themselves and would not purchase transportation services. Due to reasons of risk sharing, shippers are willing to offer a premium ( $rpr$  hereafter) for purchasing a long term contract for the services of a new vessel. Contingent on this contract, the shipowner will acquire finance for the new deal and go to the shipyards to launch the construction of a new vessel. At this point we can assume the  $rpr$  is an unobservable and we can either assume a stochastic process for  $rpr$ , which then will lead to an incomplete market specification for the objective value function and account for investor heterogeneity, or we can consider  $rpr$  as endogenous unobserved heterogeneity. This last observation provides the motivation for adding a stochastic term to each investor’s policy rule that makes econometric estimation non-degenerate. Finally, we can do semi-structural estimation by modelling  $rpr$  as the outcome of an auction between shipper and investor.

The above discussion allows us to separate the investment process in new vessels from the endogenous formation of the time charter rate and consider the time charter rate as exogenous, for both the “demand” function for new vessels, as well as the “supply” function of shipyards. This assumption will be crucial, since it simplifies the specification of a model with dynamic feedback from the new vessels to the existing ones.

From the above discussion and without using our economic reasoning to impose more structure on the functional forms of the investment demand for

new vessels, the supply and demand equations for the above model, are as follows, with  $new$  being the price of new vessels and  $dwt$  the tonnage ordered:

$$dwt = f_1(tcrate, rpr, new, other\ factors) \quad (1)$$

$$new = f_2(tcrate, dwt, productioncosts) \quad (2)$$

$$rpr = f_3(tcrate, dwt, financeavailability) \quad (3)$$

Finally, the demand for transportation and services of new vessels is exogenous, as well as the total demand for transportation that determines the time charter rate in the second hand market:

$$tcrate = g_1(demand) \quad (4)$$

This is a full structure model that specifies the time charter rate endogenously, with the supply function determined as a fixed point mapping. Once the process or the level of the time charter is specified, the prices of new vessels, the ordered deadweight and the paid premia to new investors are fully determined.

### 1.3 Modelling Investment in Incomplete Markets: Structural Estimation

Shipping markets are incomplete markets. This implies that it is not clear if all risks can be taken away by appropriate portfolios (e.g. a combination of second hand vessels, shipping shares, junk bonds). This question is a very interesting topic for further research and may have important implications for risk management in this industry. Furthermore, trading continuously is not straightforward in these markets, on the one hand due to transaction costs and on the other due to absence of liquidity. Finally, the objective value that determines optimal actions is not a positive definite utility that results in always positive values, but a value maximizing function that takes negative values for some sub-optimal actions. This is consistent with the observation that the aggregate “demand” investment function in new vessels is censored, with many periods where zero investment is observed and then large investment orders. The same crucial observation applies to scrapping decisions.

In an environment with heterogenous agents and shippers, each agent solves for his optimal investment rule. Instead of solving the full problem



we specify a **reduced form** for the policy rule. Using simulation estimators we may then aggregate all these different preferences and actions, in order to fit the actual data. In order to perform structural estimation we assume that the system is in equilibrium and that the observed *tcrate*, *new* and *dwt* are formed in a general competitive equilibrium. In this context, we do not need to care about the mechanics of the formation of the time charter rate. We perceive it as endogenous and use it as a variable in our estimation. The *rpr* is then the unobservable correlated effect that determines the probability of investment for each agent. We shall go one step further and address some other methods that will allow us to forego the rational expectations approach and the interrelated endogenous formation of the mechanics of the time charter rates. Using Laws of Large Numbers for discrete events (entry, exit) performed by agents with heterogeneous value functions and a competitive model from evolutionary biology, we may avoid the complicated derivation of rational equilibria. These alternative approaches will allow us to employ the estimated models for the *ex ante* estimation of the equilibrium time charter rate, which will be assumed exogenous (or an input) for the estimation of entry and exit decisions.

The simulation method was introduced by Berry, Levinsohn and Pakes [7] for analyzing discrete choice models of differentiated products demand. In their analysis, the objective function is consumer's utility, whereas in this analysis the objective function is the outcome of each agent's Dynamic Programming problem. Specifying a generalized form for the value function of each agent and accounting for individual heterogeneity, allows the usage of structural estimation, for the first time in investment theory. Simulation estimators allow the estimation of investment (entry - exit) decisions without any binding assumptions on market structure and the process of the time charter rate; however, they will not yield closed form solutions. Introducing **market completeness** is a binding assumption; however it reduces the complexity and dimensionality of estimation, since it yields a unique reduced form for all agents. The price we pay for the reduction of dimensionality is that we have to specify the mechanics of the underlying process, which either limits our analysis to partial equilibria, or makes the computation of a full equilibrium model very difficult. Finally, the econometric error appears only as a form of risk premium offered by the shipper and is necessary in order to make statistical estimation non-degenerate.

Furthermore, assuming complete markets reduces the dimensionality of complexity by implying a unique reduced form for the value function that

determines the actions of agents. In a setting with heterogenous agents any attempt to identify the structural function has to rely on Laws of Large Numbers or a strong restriction on the form of heterogeneity.

## 1.4 Existing Research and Methodologies

There has been a lot of theoretical and empirical research for optimal shipping investment decisions. In discrete time, Devanney [20] is the first to characterize optimal marine investment decisions on a “Bottom - Up” individual specification. In continuous time and in a complete market framework, several theoretical models for the valuation of ships, like any other real asset, have been developed over the years. Beenstock and Vergottis [6] take the approach that ships are demanded by investors who seek to earn a return on their wealth. Because the returns are risky, theory suggests that the proportion of wealth that investors wish to hold in tankers depends on the difference between the expected returns and the returns on competing investments. The return on tankers consists of profit from operation and capital gains. Capital theory then leads to a suggested equilibrium price. Tvedt [61], Martinussen [45] and Goncalves [30], regard the ship as a risky security that is a claim to the earnings process from ship operation. These authors use variations of parametric stochastic models to model the underlying freight rate. Furthermore, the value is calculated based on rational exercise of the option to scrap the vessel prior to expiration at a maximum age. Finally Dikos and Marcus [22] consider ship valuation in a two-risk factor framework, extending the seminal “Buy Low - Sell High” [44] in continuous time and in a stochastic environment.

Several weaknesses are inherent in the existing research: All the above are partial equilibrium models with an exogenously specified time charter process. To our knowledge, this is the first attempt to endogenize the time charter process as a fixed point of the system.

The pioneering “Top-Down” approach based on aggregate data is the classic work by Zannetos.[64], who not only specified the form of aggregate supply and demand functions, but also identified the role of expectations in the formation of investment decisions.

In this thesis we will use the advances of “Bottom - Up” individual type models to form the aggregate functions that we will bring to the data in a general equilibrium framework. Economic theory, intuition and advanced econometric methods will be the main artillery, to perform this full equilib-

rium exercise.

## 1.5 Review, Critique and Discussion of the Basic Underlying Assumptions

Before proceeding with a more detailed analysis of the assumptions and the methodology to be used we review some of the basic facts, that are industry specific and make the estimation of investment decisions very challenging.

It is clear that our main model consists of three equations, which are interrelated to each other. Beyond the issues of determining the functional form of the aggregate equations, important issues of endogeneity might arise in such systems, that may complicate estimation significantly. It is therefore important to discuss the assumptions made on the potential endogeneity of some variables, before proceeding with a more detailed description of our estimation techniques.

As discussed in the previous section, we assume **independence** of the reduced form of the optimal rule of each action as well as **exogeneity** of the time charter process for the determination of investment and (disinvestment) scrapping decisions. The main intuition for this assumption is the following:

1) There is a construction lag between the investment order and the time when the ship is delivered and enters active supply.

2) The amount of new tonnage is very small compared to the existing tonnage and therefore the time charter rate is determined exogenously for the investors.

3) The amount of vessels scrapped is very small compared to the existing tonnage.

The assumption of market **completeness** will determine the “tools” we will employ in order to “aggregate” individual decisions and determine the structural functional form of the equations of our system. Under complete markets and having specified a process for the time charter rate, the optimal action - inaction thresholds are sufficient to characterize the investing - scrapping decisions. Under this specification the functional forms of the three party model exist in closed form. However, some statistics of the time charter process have to be specified and this complicates estimation significantly. If one wants to avoid the above assumptions, the time charter is taken as exogenously specified in a rational expectations framework, with the risk premia  $r_{pr}$  a random error that allows the usage of econometric estimation. After

having discussed the key underlying assumptions, a more detailed road-map will follow, where the methodology employed will be presented in details, contingent on the prevailing assumptions.

Another crucial observation for our model and equations, is that the number of investment decisions does not affect the action - inaction rule. Therefore, the number of firms entering or exiting this market does not affect the entry - exit thresholds. The bulk shipping industry is perfectly competitive, which implies that agents cannot affect the underlying process and that the number of entering or exiting firms does not affect potential profitability as in the airline industry [8]. The underlying economic structure of this market, simplifies our analysis a lot since it does not require any assumptions on Nash equilibria. A similar analysis in the container industry would be totally different and would require the characterization of an oligopolistic equilibrium, in order to carry out this analysis (see Berry [8]).

Another potential source of endogeneity is the presence of the price of new vessels in both the “demand” function for new vessels, as well the supply function by shipyards. Since the price of new vessels appears as a dependent variable in the yards’ supply function and as an explanatory variable in the demand function, there is an issue of endogeneity, which has to be restored. This requires the selection of valid instruments whose validity shall be tested by employing the Hausman test.

Finally, the last potential source of endogeneity is the associated risk premium  $rpr$  that appears in both the demand for new vessels equation, as well as the shippers demand. Either a full functional form has to be specified, by assuming it is determined in a two party auction between shippers and investors, or it may be considered as a random error that will introduce individual heterogeneity and make the econometric estimation non-degenerate.

Having discussed the basic underlying assumptions we proceed with the following question: Even if the time charter rate is exogenous to the investment and scrapping process, how can we effectively determine the appropriate form of the time charter dynamics?

A structural process that is a result of all aggregate “lay-up or employ” decisions and simultaneously clears the market, can be determined in a Rational Expectations framework. In market equilibrium, supply of transportation is equal to demand. This equality provides a functional relation between freight rates and ship prices, and once correctly estimated it may be used to predict the impacts of policy, accidents and demand shocks on shipping cycles. The above observations are in line with the critique by Dixit and

Pindyck [28]. The sum of individual's agent responses to the time charter rate constitutes the industry's transport supply function. The equilibrium price is then determined by market clearing conditions that equate demand and supply. Following Lucas' critique, under uncertainty and irreversibility the transportation supply function depends on the underlying process and changes dynamically. A significant simplification arises from the perfectly competitive nature of the shipping industry: on the one hand the number of firms does not affect the transportation supply function and on the other hand demand for transportation services may be taken as vertical. The last observation takes away the implications of simultaneity, since the demand for transportation capacity does not depend on the prevailing freight rate, for the short term at least.

Specifying a structural time charter rate can result in highly non-linear processes with stochastic volatility, that make the associated Dynamic Programming Problem intractable in closed form. This implication, as well as the assumption of complete markets are foregone, once we adopt a Berry, Levinsohn and Pakes [7] full structural estimation approach for entry-exit decisions, which does not require a closed form derivation of the optimal action thresholds, by simply assuming an *ad hoc* specification of the individual value function. To avoid the burden of increased computation we shall introduce threshold and factor models in a semi-structural framework.

Having discussed the basic assumptions underlying this structural three-party model we now provide a road map to the different techniques to be used and the contributions on the modelling of investment decisions, generally.

## 2 Road Map

In this section we revisit the assumptions that appear essential for estimating the proposed three party model. The discussion in this section is for the specialized reader who wants to understand the economic intuition that allow us to adopt each assumption. The economic terms used are tied to the specifics of the tanker industry and a preliminary road map of model estimation is proposed.

### 2.1 Investment Models in Complete Markets

Under the assumption of complete markets the Real Option value [28] is a sufficient statistic for characterizing investment decisions under irreversibility. However, since data for the number of tanker ships ordered in each period are available in aggregate form, a model that will make the parameters estimable, needs to be specified. Even in the ‘Bottom - Up’ approach, where estimation is based on the actions of a particular agent or a set of agents, the estimation of the objective function or the sufficient statistic that characterizes the behavior of the agent, is part of the problem. If we take the approach that part of the underlying project and the associated risks are traded in the financial markets, then the objective value function is uniquely determined, up to the market price of risk, which is determined in equilibrium by the market.

Structural Estimation with complete markets allows the usage of the value function determined by “arbitrage” arguments, which simplifies the analysis a lot, **and does not require the solution to each agent’s Dynamic Programming problem.** However, the problems of aggregation are still open. In the first part we shall consider three different models, which will allow us to work with aggregate data. Our approach is similar to the pioneering work of Berry [8]. Berry, considers profits as a sufficient statistic for the characterization of entry and exit in airport hubs. He accounts for unobservables both in the profit function as well as in the error term, which represents characteristics of the market that are observed by the firms, but not by the econometrician. The basic motivation for including an error term in decision variables is to obtain statistically non-degenerate econometric models. Furthermore, if this error term was not present, direct investment could not be observed, since agents could replicate the payoff of the projects by existing traded securities. Structural Estimation with complete markets does not re-

quire the modelling of equilibrium choices over entire networks. Especially in the shipping industry, that is considered as a paradigm for a perfectly competitive market, the interactions of firm decisions may be disregarded. It requires however a market imperfection that will make the value function in a complete setting higher than the cost of the investment; under no arbitrage any value function should be always equal to the cost of the project since prices would adjust dynamically, in order to eliminate any arbitrage opportunities. To make the above argument more concrete, in a complete market setting, the value of the project spanned in financial markets (the value of the new vessel) should always equal the cost of the project (the price of a new vessel). The price quoted by the yards should reflect the discounted expected payoffs the owner will receive by operating this vessel. In order to use the “excess” or “arbitrage profits” as a sufficient statistic for characterizing investment decisions we need to introduce market imperfections or an econometric error for unobservables (the premia offered by the shippers in our case) that will make the estimation feasible. As noted in Strandenes [57] the market imperfection in this industry, is due to the overcapacity of production by the shipyards, that does not allow the adjustment of newbuilding prices to satisfy the “no arbitrage” condition, whereas the error term premium is either due to the term structure of time charter rates, or due to the premia offered by shippers. As Strandenes [57] notes “labor unions have been strong in shipbuilding, which traditionally has led to lower flexibility in the labor market.” This has led to systematic governmental intervention that has had significant effects on ship values and the functioning of the newbuilding market. Subsidization implies that new vessels are sold at lower than the market clearing or “no arbitrage” price that corresponds to a zero Real Option value. This imperfection, coupled with the presence of shippers, makes the usage of the Real Option value statistically non-degenerate.

In the first model we shall consider firm heterogeneity in the operating costs and an identification condition on the “most efficient operator” will be imposed. In the second model we shall consider equally efficient operators, as a result of the perfect competition in the industry and in our third model we shall consider the interaction and correction terms imposed by the supply side of shipyards. In *ModelIV* we shall consider the exit decision for equally efficient operators, whereas *ModelV* will be a description of aggregate exit decisions of heterogenous agents and finally *ModelVI* will be a search model of exit. We shall then proceed with the derivation of a structural time charter process. The term Semi Structural Estimation is used, because on the one

hand there are no requirements on Game Theoretical Equilibria and on the other hand, the objective value function is determined by the Real Option Theory. There is still space for unobservables in the above specifications that appear in the “risk premia” or the real option markup. If the econometrician gets the aggregate model right, then the “unobservables”, the “risk premia” or the option markup, are parameters of the estimation and the proposed models consist a new framework for identifying the effects of time varying unobservables in direct investment decisions and what Spyro Skouras [56] named “Decisionmetrics”.

Before proceeding with testing simultaneously both the significance of the Real Option value rule as well as the aggregation specification there are two final observations. First, the different assumptions imply that identification is not only a matter of functional form and second, we cannot develop a theory of investment independently of the market structure in which the firm operates, as well as the ability to span the under maximization value in financial markets.

## 2.2 Incomplete Markets

There has been one main assumption underlying the previous analysis: Markets were assumed complete and the potential investors could span the value of the project in financial markets. The presence of the econometric error was due to unobservables (and made the specification non-degenerate). However, the assumption of complete markets does not hold and in general, real assets are illiquid, and this makes it difficult to find replicating portfolios and there are huge transaction costs in this market.

Under the assumption that all agents have the same expectations regarding the underlying time charter process, heterogeneity arises due to differences in operating costs, as well as the market price of risk of each individual. Individual heterogeneity cannot be easily aggregated to elegant closed form solutions and estimation has to be conducted by using simulation techniques, unless we impose some restrictions on the heterogeneity. A prominent example is the one considered by Berry [8]; in our case however it has to be a dynamic analysis, rather than Berry’s static approach.

To give an example let us assume that the value of investing in a new vessel for agent  $j$  at time  $t$  is given by:



$$V_{opt}^{jt} = \frac{tcrate - opex}{\mu - \lambda_t^j \cdot \sigma - r} - mup(\lambda^j) \cdot I \quad (5)$$

Then the number of observed investments in each period is:

$$Ships_{ordered,t} = (n_t : V_{opt}^{jt} \geq 0, n_t \leq N_t) \quad (6)$$

$$N_t = \rho \circ N_{t-1} + \epsilon_t \quad (7)$$

with  $\epsilon_t \sim P(\lambda_t)$  and  $\rho$  the thinning operator as defined in Cameron and Trivedi [17].

Although the problem is solved in “static cases” (for  $N$  constant, [8]), it is a promising candidate for explaining dynamic investment decisions and a very interesting topic for further research.

### 2.3 Rational Equilibrium Time Charter Rates

Given the exogenously specified *demand* our three party model fully determines the equilibrium *rpr*, *tcrate*, *dwt*. For our analysis of investment decisions the time charter rate process is considered exogenous. In order to close our model we want to specify the dynamics of the charter rate from market clearing conditions. Furthermore, economic analysis will allow us to gain efficiency by improving the functional form specification of the estimated relations. Thus we are faced with a philosophical inconsistency: on the one hand the time charter process is used as exogenous for the estimation of investment decisions and on the other hand we aim to employ these models, in order to determine the time charter rate. We have achieved a rational expectations equilibrium, once the assumed and the actual process turn out to be equal.

In classical economics a Rational Expectations equilibrium is a convenient framework for estimating a structural time charter rate. Existing owners decide whether to charter their ship or lay it up and wait. If there was neither uncertainty nor irreversibility, then the operator would charter the vessel as long as the net operating profits would exceed fixed costs. Under uncertainty and irreversibility this rule has to be modified in order to account for the implicit option value of waiting. Once the value of each action has been calculated the aggregate supply of transportation for each prevailing rate may be derived.

It turns out the solving for a rational equilibrium with entry, exit and lay-up decisions simultaneously is almost impossible. We therefore consider each action independently (independence of actions assumption) and derive aggregate entry and exit models in a partial equilibrium framework. Assuming that the demand is exogenous we may then derive a structural time charter process in this Rational Expectations framework.

$$s(tcrate_t) = demand_t \quad (8)$$

$$tcrate_t = s^{-1}(demand_t) \quad (9)$$

Following Dixit and Pindyck [28] we shall consider competitive market equilibria under market uncertainty and firm specific uncertainty. Market uncertainty implies that the structural process has an upper reflecting barrier, whereas firm specific uncertainty has strong implications for the tonnage in Lay-Up and the dynamics of transportation capacity.

## 2.4 Sections and Model Estimation Review

Before proceeding with model estimation let us restate the basic assumptions and shortcuts as well as the plans for model estimation:

- Agent Heterogeneity and Dynamic Programming for Entry, Exit, Lay Up and Chartering actions.
- **Assumption 1:** Each action is separated from the other ones. (**Separability of actions**).
- **Assumption 2:** Entry and Exit actions perceive the time charter as exogenous. (**No feedback effects**).
- **Assumption 3:** The market is perfectly competitive: the number of entering and exiting firms does not affect profitability.
- **Assumption 4:** Agent heterogeneity arise from cost heterogeneity and shipper premia.
- **Model 1:** Rational Expectations and Complete Markets yield a unique entry-exit statistic.

- Model 2: Rational Expectations and Incompleteness yield heterogeneity in the discount factor. Each agent solves his own dynamic programming problem.
- Model 3: Heterogeneity in Expectations and Incompleteness yield a Market Microstructure Equilibrium with “wait and see” or “search” options.

The remainder of this thesis is organized as following:

In Chapter 3 we proceed with the analysis of the first module, namely the investment decisions in new vessels. We assume complete markets with rational investors. The time charter rate will be exogenous and the market for new vessels will be considered perfectly competitive. In the proposed models, the Real Option Value will be the unique sufficient statistic for characterizing investment decisions.

In Chapter 4 we analyze the scrapping data (exit decisions), which consists of the second module. We employ the same techniques and assumptions as in the first module; however due to the low quality of the data available in this market, we can only make qualitative observations on the scrapping dynamics. We finally include two more models: a model of heterogenous agents and a search model.

In Chapter 5 we consider structural time charter rates. As noted already in 1971 in Devaney’s [20] pioneering work “the charter rates are not the driving forces in this markets. Rather they are determined by the underlying demand and supply of the type of shipping services.” We start with market uncertainty and firm specific uncertainty and derive competitive equilibria in line with the models derived in Dixit and Pindyck [28]. We then proceed with a model of transportation capacity with switching costs, as in the classical 1983 Townsend model [60], in order to take the effects of speed adjustment on the formation of rates. This model has strong implications on the time charter rate dynamics; however it does not require the Lay-Up data. Furthermore, it provides an elegant structural framework for the Generalized Autoregressive Heteroscedastic (GARCH) [29] type models, as well as a structural interpretation for the coefficients of the GARCH specification, that have prevailed the last decade in the time charter literature by the pioneering work of Kavussanos [42]. Using robust control equilibria the Townsend [60] model may generate even more interesting dynamics. We

then relax the derivation of rational expectation price process and adopt the System Dynamics approach to price modelling. Finally, we work towards a synthesis of the mechanism that determines price formation in this market. By assuming myopic actions in the competitive equilibrium [28] we employ the estimated equations simultaneously, in order to determine the time charter process. We discuss several stabilizing mechanisms that are inconsistent to the market clearing approach, but sympathetic to the real data.

In Chapter 6 we derive a model for the valuation of second hand vessels in a partial equilibrium framework by employing the Real Options literature.

Finally in Chapter 7 we derive our conclusions and address topics for further research in this area.

## 2.5 Specification and Estimation: Empirical Limitations and the Decisionmetric Concept

*Before starting with the specification and estimation of our model we discuss the empirical limitations imposed by the data, as well as the choice of inputs. Finally we define the Decisionmetric Concept and discuss issues of model selection and order.*

### 2.5.1 Comments on the Empirical Data

Throughout this thesis, several different sets of data will be employed for the estimation of the different modules which constitute the transportation supply function. The economic reasoning for choosing a particular set of data in the model specification and estimation process is discussed explicitly for each module and differs significantly. However, even after economic reasoning and intuition have determined the required data, empirical limitations can impose significant restrictions on the magnitude of our results. In this section we address such issues.

All sets of data employed in our analysis are explicitly analyzed during the presentation of the models and consistently defined in the Glossary. In this section we will discuss *a priori* the limitations of our data, as well as some necessary transformations we had to apply, in order to carry out the program. Finally, we discuss the selection of categories for different tanker sizes. The main source of the data on maritime investment (orders for new vessels, scrapped tonnage, existing fleet and aggregate demand) has been *Marsoft*, (Boston) Inc., who has been very supportive and encouraging throughout this project. However, since data in Maritime Economics differ across different consulting firms, we have used various sources, in order to check the consistency and accuracy of our data, which in general has been of high quality.

Three key data series constitute the transportation supply function: The number of the vessels ordered in each period (*ship*), which determines the new entrants in each period, the tonnage scrapped (*scr*), which determines exit and finally the prevailing time charter rate (*tcrate*) that is determined in the market by the interactions between supply and demand (*dmd*). For the number of vessels ordered in each period we are in possession of quarterly data for five different categories, as defined by Marsoft, (Boston) Inc. in their data set. The five categories introduced in our analysis of orders for new

vessels in tonnes of deadweight (10000-60000, average 30000; 60000-80000; average 70000, 80000-120000; average 90000, 120000-200000; average 140000, and 200000+) have been directed by Marsoft and the particular nature of the data. In the relevant chapter (Chapter 3) we account for the individual effects of each category by estimating the model with Fixed Effects (FE) and Random Effects (RE), which correspond to fixed or random dummy variables across categories. In Chapter 5 we go one step further and estimate the time charter rate models separately for each category, as well as the Full Model. Performing this task we fully exploit throughout our analysis, the impact of size on decisions of entry and exit, as well as on the dynamics of the price process.

Our ability to account for size heterogeneity is limited, when performing the analysis of exit decisions (Chapter 4), since scrapping data are not available for each category. Although it turns out that the tonnage scrapped each period does not have a first order effect on time charter rates, the lack of scrapping data for each category, limits significantly our ability to address questions of Economic Theory related to exit decisions. We are therefore forced to forego size heterogeneity effects and estimate our scrapping models with aggregate data. In order to account for some source of heterogeneity without overparametrizing the model, we construct tonnage weighted indices of the time charter prices and operating expenses, denoted ( $tci$ ) and ( $opi$ ), respectively. Another significant complication is that data on scrap prices are not available in a consistent way for the entire period 1980-2002. As we will discuss in the relevant Chapter, the lack of scrap price data forces us to use instruments, whose validity we are not able to check.

Fortunately enough, price data for new vessels and for the key input (which is our ultimate target, too), namely the time charter rate process, are available for the entire 1980-2002 period and on a monthly basis. Therefore, for the price for new vessels ( $newprice$ ), which is a key input for the demand for new vessels and the time charter process ( $tcrate$ ) we have aggregated monthly data to quarterly data. In some sense we have not fully employed all available information and one could argue that we could try to use monthly data. One more crucial empirical limitation, which hinders any such attempt is the fact that the demand data ( $dmd$ ) are only available quarterly.

Interrelated to the time charter (price) process are operating expenses. Operating expenses ( $opex$ ) vary significantly across vessels, operators and age. However, since they are a crucial factor, especially for decisions of entry, we may focus on the operating expenses of new vessels, which anyhow

are a valid instrument for the operating expenses of any vessel. Our series on operating expenses have been constructed from different sources and this specific data set is complicated and is the outcome of averaging several different estimates.

All other variables that appear in the analysis are consistently defined in the Glossary and have been fully available from independent sources. Most of them are publicly quoted indexes (*air* is the Standard and Poor's transportation index, *oil* is the price of crude oil quoted by the Chicago Board of Trade, *lrate* the FED lending rate, etc.) and there is no ambiguity on their definition and quality.

Before concluding with this section there are some significant issues, which may account for the poor performance of different specifications and are therefore worth mentioning. Most of them are related to the limitations of our data that stem from the particular illiquid nature of shipping markets. Throughout this thesis, the time charter freight rate refers to an arithmetic average of time charter rates on the major routes for a particular vessel. In order to get consistent series the time charter rates are usually published for a representative vessel and since it is published in United States Dollars, the estimates quoted by different sources as the time charter rate include the effects of inflation and technological innovation. Furthermore, as the time series will represent averages (given the process has finite moments) the data will possess less volatility than the actual market price process. Finally, the market for long term contracts virtually disappears during poor freight markets [3]. The low number of fixtures makes it particularly difficult to determine accurate empirical measures of the time charter price in a depressed market. In our analysis we specifically choose the one year time charter rate, since it is the median of charter durations in this market ([3], p.28).

### 2.5.2 Decisionmetrics: Model Selection and Specification

Before proceeding with the estimation and specification of each module we provide a description of *what* our interim and **ultimate** targets are, as well as *how* we proceed pursuing them. Our final goal is to determine a model for the patterns of freight rate prices in the tanker industry, which is mainly a problem of **System Identification**. This system consists of agents who undertake dynamic decisions of exit, entry and temporary suspension and through these actions they fully determine the process, on which they base their actions; namely the dynamics of freight rates. Therefore, it is a very complicated system where the inputs of the system (the expectations on the price process) have to be consistent to the output.

The orthodox strategy according to Economic Theory is to solve the general Rational Expectations Problem and a simple version of this approach will be employed in 5.3 and 5.4. In his philosophical paper “Dealing with the Complexity of Economic Calculations” [53], John Rust, the pioneer of the large-scale computation “Bottom - Up” approach to economic modelling poses two questions:

*Does the computational complexity of economic calculations (i.e those required to implement various economic concepts such as **optimization, equilibrium**) place inherent limits on the ability of economists to model the behavior of economies and economic agents?*

*Does the computational complexity of economic calculations place inherent limits on the ability of economic agents to behave according to existing economic theories of optimization and equilibrium?*

For both questions Rust gives a negative answer and in some sense, most of the “empirical tests” of Economic Theory in this thesis will be totally supportive to his perception of complexity and economic behavior. In our analysis we use the term **Structural**, because we exploit the special structure of this particular industry, as a device that allows us to reduce the complexity of the system, without placing limits on the ability of economic agents to perform rationally and optimally. In Chapter 3 we use the “myopic equivalence” of the competitive equilibrium [28] and in Chapter 4 we demonstrate that under mild assumptions heterogenous agents converge to rationality and optimality by “cancelling out” sub-optimal policies. Our only deviation from the neoclassical theory doctrine is our Evolutionary approach



derived in 3.10; the main motivation is that the Evolutionary approach imposes minimal requirements on the price process.

However, our approach to the first question differs from the parallel computing schemes Rust suggests in his paper and subsequent work. By using the assumption of independence of actions we “break down” the Dynamic Programming Problem to the three submodules of entry, exit and temporary suspension. By the assumptions on the exogeneity of demand for new vessels with respect to vessel prices, the exogeneity of demand for transportation capacity with respect to the freight rate and finally, the absence of feedback effects from the new orders and scrapped vessels on the underlying process we proceed by isolating each sub-module. In a sense our strategy is a *Divide and Concur* strategy that is suitable only for this specific market and the specific assumptions. For each sub-module we simultaneously perform two interrelated tasks: We derive aggregate models based on modern Economic Theory and then test the validity of these models, as well as the validity of the underlying assumptions. The first term in the title, *Decisionmetrics* [56], refers to the performance of the estimation in a model selection framework, once *market assumptions*, *Economic Theory* and specific structure have helped us identify a family of inputs, outputs and models. Our “practical” needs to produce estimates that will help policy makers and agents make robust decisions, open the way to an engineering type approach, regarding the identification of the mechanics of the system. Economics will be used to derive models on structural assumptions and reduce the complexity of the system, whereas our ultimate goals remain to design a device that will produce robust measures of investment decisions in this market.

As discussed in the previous section, the choice of an input is performed on the basis of economic reasoning and the choice of order on the basis of advanced econometric methods. Besides choosing the data inputs and estimating the statistical significance of each parameter, we are faced with the essential problem of model specification and selection. Namely, we have to identify an “appropriate” functional form between our inputs and outputs. Although Economic Theory and special structure may reduce the complexity of the estimation process, whilst allowing us to address efficiently issues of aggregating individual actions into aggregate data, testing the specification of each model is a necessity. The Decisionmetric concept, as defined by the pioneering work of Spyro Skouras [56] is aimed at developing a possibly misspecified econometric model that will be used for making decisions under uncertainty. In order to limit the impacts of misidentification on the

robustness of our model, we thoroughly employ combinations of specification tests and choose those models that survive most of the tests. Following this approach, even if the structural assumptions of the model are non-testable or questionable, we still accept those classes of models that are very supportive to the data and reproduce an “equivalent class” of reality. Most empirical studies in economics are undertaken in order to *test* a hypothesis or *identify* parameters of economic significance on the basis of *a priori* knowledge. In the first case a structural model is formulated and estimation methods are employed to test the hypotheses and assertions of the model. Any test is then a joint test on both the hypotheses and the aggregate model; however, statistical evidence is used only to justify and characterize the validity of the economic hypotheses under question. In the second case, *a priori* knowledge on the actions of economic agents (Rust [53], economic agents behave *rationally* and *optimally*, whilst solving their Dynamic Programming problem) is imposed and advanced econometric methods are employed for the estimation of implied parameters (such as risk-aversion). Our approach is in some sense the opposite and this stems from our main objective, which is not the direct test of economic theory or underlying assumptions of economic behavior, but the identification of functional relationships. Although some of our interim goals are interrelated to testing some of the economic hypotheses that have dominated maritime economics, our ultimate goal is to construct estimates of the price process. Therefore, we derive our models on a “Bottom - Up” approach and accept those classes of models that are not rejected within a parametric class of families, we accept these models that “squeeze out” the utmost information from the data.

Instead of testing economic theory and assumptions, we employ economic theory in order to reduce the dimensionality of the problem and identify appropriate functional forms within parametric families, that survive certain tests. As it will turn out, economic intuition will contribute with utmost precision to the reduction of the dimensionality of the problem and provide valuable insights. Having completed the presentation of our assumptions and main identification strategy, let us now carry out the programme.

### 3 Module 1: Investing in New Vessels

*“...why should he order a replacement if the prospects for employment of the new vessel when it appears in the market are not promising? Would he not naturally **wait** until he is somehow assured about the immediate future?”*, (Zannetos [64], p.120).

The objective of our first Module is to propose models for aggregate newbuilding investment decisions, under the Real Option markup hypothesis. Due to uncertainty, irreversibility and significant construction times, there is a significant value in the option to wait, before constructing a new vessel. This is the motivation for using the Real Option Markup hypothesis, instead of traditional Net Present Value (NPV) criteria.

In the last years option theory has been important for economics and investment decisions. After the introduction of the “real option” value, implicit in investment decisions ([46]), uncertainty has played a key role in investment [28]. However, very few applications to specific investment models have been derived in this framework and therefore, it has been very difficult to test the Real Option theory. Pindyck and Solimano [50] tested the impact of uncertainty (volatility) on movements in investment, and they found supportive evidence for the theory. Serious problems of aggregation still have not made it easy to test the Real Option markup hypothesis on specific markets based on aggregate data.

Following Rust [51], there are two approaches one can follow in order to model investment behavior: The first is the ‘top down’ approach, where investment is computed by using a measure of a hypothetical continuous aggregate capital stock  $K$  and optimal investment policies arise as a result of value maximization, subject to convex costs of adjustment for capital. A significant benefit from this approach is that it allows us to use aggregate data to test the results of the models and the validity of ‘q-type’ investment decisions. Important testing of ‘top down’ models has been done by Jorgenson and his collaborators without significant success ([40], [13], p.301). At this point we should stress that optimal investment policies are derived with respect to value maximization. As discussed in [13] (p.291-293) “we cannot develop a theory of investment independently of the market structure in which the firm operates”. The ability to span the under maximization value in financial markets is also crucial for the connection between ‘q-type’ sufficient statistics and market value. If this is the case and the market

completeness assumption is adopted, then the value maximization objective function will be unique. This observation will turn out to be crucial even in the “bottom up” approach that will be described right now. Since the payoff of operating a ship is fairly straightforward (it is determined by the time charter rate minus the operating costs (fuel costs)) and an organized futures market exists (Baltic exchange) the assumption of complete markets in this case, is a realistic assumption. Under this assumption we do not need to solve a discrete time dynamic programming problem in order to determine the value function of the optimal investment policies. This value function is determined by the assets traded in financial markets. This takes the burden of estimating the parameters of the value function as in [52].

The contributions of our analysis in this section will be twofold: On the one hand we will test how well the real option ‘benchmark value’ suffices for entry decisions in a perfectly competitive industry. On the other hand, partial equilibrium assumptions and count data methods, as introduced in the seminal paper by Hausman [36] will allow us to test the theory by using aggregate data.

There is finally one more benefit from this approach. By observing investment decisions and using discrete choice econometric methods we can derive the values of unobservable parameters such as the real option markup in the tanker market industry.

### 3.1 Model Specification: Semi-Structural Estimation

We have discussed how the Real Option value is a sufficient statistic to characterize investment decisions under irreversibility. However, since we will use aggregate data for the number of tanker ships ordered in each period, we have to specify a model that will make the estimation feasible. Even in the “Bottom - Up” approach, where estimation is based on the actions of a particular agent or a set of agents, the estimation of the objective function or the sufficient statistic that characterizes the behavior of the agent, is part of the problem. If we take the approach that part of the underlying project and the associated risks are traded in the financial markets, then the objective value function is uniquely determined, up to the market price of risk, which is determined in equilibrium by the market. As we will discuss later, this approach seems reasonable in this market: An organized freight rate market (Baltic Exchange) exists, as well as many tanker companies are traded publicly.

This assumption allows the usage of the value function determined by “arbitrage” arguments, which simplifies the analysis. However, the problems of aggregation are still open. In our first Module we shall consider three different models, which will allow us to work with aggregate data. Our approach is similar to the earlier work of Berry [8]. Berry, considers profits as a sufficient statistic for the characterization of entry and exit in airport hubs. He accounts for unobservables both in the profit function, as well as in the error term, which represents characteristics of the market that are observed by the firms, but not by the econometrician. The basic motivation for including an error term in our decision variables is to obtain statistically non-degenerate econometric models and account for the structural errors arising from some level of market incompleteness. Furthermore, if this error term was not present, we would not observe direct investment, since the agents could replicate the payoff of the projects by existing traded securities. Complete markets and perfect competition do not require the modelling of equilibrium choices over entire networks. Especially in the shipping industry, that is considered as a paradigm for a perfectly competitive industry, we may disregard the interactions of firm decisions.

In the first model we shall consider firm heterogeneity in the operating costs and we shall impose an identification condition on the “most efficient operator”. In the second model we shall consider equally efficient operators, as a result of the perfect competition in the industry and in our third model

we shall consider the interaction and correction terms imposed by the supply side of shipyards. There is still space for unobservables in the above specifications that appear in the “risk premia” or the real option markup. If the econometrician gets the aggregate model right, then the “unobservables”, the “risk premia” or the option markup, are parameters of the estimation and the proposed models consist a new framework for identifying the effects of time varying unobservables in direct investment decisions.

Before proceeding with testing simultaneously, both the significance of the Real Option value rule, as well as the aggregation specification, there are two final observations. First, the different assumptions imply that identification is not only a matter of functional form and second, we cannot develop a theory of investment independently of the market structure in which the firm operates, as well as the ability to span the under maximization value in financial markets.

### 3.2 The Efficient Operator Specification

The shipping industry has some unique characteristics that allow us to conduct empirical tests. On the one hand it is well known that it is one of the very few examples of a perfect competitive industry, and on the other hand, freight rates are a sufficient statistic for the risky payoffs of operating a ship. Furthermore, the shipping industry is always suspect to unexpected regulation and pollution bills that affect directly the operating costs of vessels. Payoff uncertainty, as well as regulation and policy uncertainty imply that agents commit themselves to large-scale irreversible investments, when ordering a ship. From this point of view this industry has some unique characteristics that allow us to test the importance of irreversibility and uncertainty on the birth of investment decisions.

Perfect competition and the simple structure of the payoffs still do not resolve the issue of aggregation for firm heterogeneity. Firm heterogeneity may arise from the different running costs of different operators, preferential finance terms to credible investors and finally from the ability of the manager to achieve a long term time charter rate for the ship, before placing the order to the shipyard<sup>1</sup>. In this paper we shall tackle aggregation following the count data econometric specification, introduced by Hausman [36]. In all

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<sup>1</sup>This method was introduced by Aristotle Onassis: He first agreed on a long term fixed rate from the shipper and then ordered the ship. In some sense this was one of the earliest collateralized debt obligation structures.

three models we shall specify that the total number of investment decisions follows a generalized poisson process  $P(\lambda_t)$  with intensity depending on a set of factors  $X_t$ . This parametric model will be estimated using the conditional Poisson model introduced in the seminal paper by Hausman, Hall, and Griliches [36]. The same model was used by Becker and Henderson [5] with a very intuitive discussion on the micro-econometric foundation of such aggregate type models.

Following the “bottom-up” or “decisionmetric” approach to investment decisions, Becker and Henderson [5] argue that at each point in time, there is a supply of agents willing to place orders for new vessels. They argue that this supply relation is upward sloping in positive NPV values. Since it is well established that NPV is NOT the appropriate maximizing value under uncertainty and irreversibility, we shall assume that the supply of agents willing to commit themselves to shipping investment decisions is a positive function of the optimal value under uncertainty, as derived by Dixit and Pindyck [28] and Hausman [38]. As one moves up the supply curve, the higher this critical value, the more agents will place orders for new ships. Furthermore, the curve may shift outwards in periods where sources of finance are more accessible than in other periods. In the case where the underlying risk factors depend on unobservables (stochastic volatility), then the value function will depend on unobservables, too and this will shift the supply curve. The demand curve, or the number of shipyards willing to commit capacity in order to construct a ship within a pre-specified period, depends on the magnitude of government subsidies and uncertainty.

Total births of investment orders are then determined by the intersection of supply and demand, in birth- $V_{critical}$  space. This gives a reduced form equation:

$$B_{jt} = B(X_{jt}, f_j + e_{jt}) \quad (10)$$

where  $B_{jt}$  are the orders placed for ship type  $j$  at time  $t$  and  $X_{jt}$  is a vector including the critical Real Option investment rule, the accessibility of finance sources and other macroeconomic variables and  $f_j$  are ship type fixed effects of unmeasured time invariant features. At this point we should note that since the underlying asset, namely the spot rate is non-tradable, the critical value function shall depend on the market price of risk, that will be estimated as a parameter of the model. Regarding the above specification of the model, there are two issues of concern as discussed in Becker and Henderson [5]. The first issue regarding the type of equilibrium this model does not apply in this

market, due to perfect competition prevailing in this industry. The second issue regarding the nature of our data, namely discrete, with many zeros in periods of stagnancy and positive numbers makes the choice of the Poisson model a natural choice.

In order to make aggregation feasible and to impose more structure in the form of the intensity of the birth model, the following observation is made. At each point in time *the most efficient operator* has a known value, denoted by  $V_n$ , if proceeding with placing an order for a new vessel that will cost him  $I_n$ . This value  $V_n$  will be fully determined by the optimal investment rule that takes into account irreversibility and the option to wait. This rule is derived by Dixit and Pindyck [28] and is used in his discussion of telecommunications industry regulations by Hausman [38]. The value of this project  $V_n$  will be a function of the offer  $I_n$  by the shipyard, the depreciation rate of the asset, the current price of the underlying risk-factor, which is the time charter rate, and the first two moments of this process, as well as the market price of risk. Later on we will introduce uncertainty regarding the life time of the ship and the associated depreciation. Given this unobserved value the probability that the most efficient operator will not undertake investment will be given (assuming an extreme type-I error distribution) by the following formula:

$$P_{eff} = \frac{1}{1 + \exp(V_n)} \quad (11)$$

This probability is then equal to the probability of the event “no birth of investment decisions is observed in this period”. Since this probability corresponds to the most efficient operator, if he doesn’t undertake investment, no other operator will be expected to do so.<sup>2</sup> If we now impose the additional restriction that the probability specified above should be equal to the probability of zero investment births, implied by the Poisson specification, then we have imposed a structure to the intensity of the count model, consistent with the Real Option literature.

From our count data specification, the probability that no births will be observed at time  $t$  is given by:

$$P_{births} = \exp(-\lambda_t) \quad (12)$$

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<sup>2</sup>The same argument is used by Berry [8] in his study of entry decisions in airport hubs, where he defines the structural error that generates this specification as “ordered heterogeneity”.



Equating these two equations we now obtain the following parametric form for the intensity of the birth model:

$$\lambda_t = -\ln\left(\frac{1}{1 + \exp(V_n)}\right) \Rightarrow \lambda_t = -\ln(P_{eff}) \quad (13)$$

Since  $P_{eff}$  is the probability of the binary logit model, it is always restricted between zero and one, and as a consequence its negative logarithm is always positive, which is a necessary restriction for the intensity of the Poisson model. Furthermore, as discussed in Becker and Henderson [5], in order to have a stable equilibrium of supply and demand for new ships, the sign of  $\frac{\partial B_{jt}}{\partial X_t}$ , with  $X_t$  all the parameters that determine the value function, should be positive, which is the case indeed for the above specification. Thus, the larger the value implicit in investing in a new vessel, the higher the probability investors will proceed, and the larger the number of observed orders (births in our model).

The above model is simple, tractable, makes estimation identifiable and corresponds to a partial Nash equilibrium. It is similar to the “observed heterogeneity” model introduced by Berry ([8], p.899), where the probability that  $N$  agents invest is equal to the probability that  $N$  agents have a positive investment rule. However, there are two significant defects of this model. As noted by Berry, on the one hand it places strong restrictions on possible combinations of entering firms and on the other hand it assumes an infinite supply of the vessels at the given price, without interaction and adjustment from the shipyards to supply and demand shocks. In our calculations this model will be denoted as *Model I*.

### 3.3 A Perfect Competition Model

The tanker sector is a paradigm for perfect competition. We may therefore make the assumption that all operators are equally competitive and the probability that each of them will invest is the same, and is fully determined by the value of the investment minus the value of the option to wait. This probability, under the assumption of type I structural errors, is given by:

$$\pi_{invest} = \frac{\exp(V_{opt})}{1 + \exp(V_{opt})} \quad (14)$$

The total number of ships ordered in each period is then given by the count variable:

$$Y = \sum_{i=1,n} B_i \quad (15)$$

,where  $B_i$  is the outcome of each agent, and the total number of agents is  $n$ . If the total number of agents is given by a Poisson process  $P(\lambda_n)$ , since the outcome of each agent is an identically distributed Bernoulli trial, the total number of ordered ships will follow a Poisson process, with intensity  $\lambda_n \cdot \pi_{invest}$ . This specification allows a more flexible parametrization of the aggregate poisson count model, since the number of operators, may depend on other variables, too.

If we model the intensity of the number of operators as

$$\lambda_n = \exp(\alpha + \beta \cdot x) \cdot (1 + \exp(V_{opt})) \Rightarrow \lambda_n \cdot \pi_{invest} = \exp(\alpha + \beta \cdot x + c \cdot V_{opt}) \quad (16)$$

where  $x$  are some exogenous variables. This model provides us a very straightforward parametrization of the Poisson model, and it is the familiar exponential specification of the mean, which is the main common practice in most empirical studies that deal with count data. This model of perfect competition will be named *Model III*. As far as all operators being equally competitive and the value of the project is uniquely spanned in financial markets, the probability of action is unique and the same for each agent. Once the spanning assets are not enough, then each agent has a different probability and the Poisson aggregation argument breaks down.

### 3.4 A Simple Auction Equilibrium and the Supply Side

A more complete specification would result from considering the supply dynamics of the shipyard. Once a yard offers a ship at a given price  $I_t$  it commits itself to an irreversible process and occupies capacity for this specific ship. Thus, there is an option to wait for each shipyard, before committing production capacity to a specific project for a price  $I_t$ . Following the same threshold rule but from the yard's point of view, the probability that the most efficient operator will not offer the ship for  $I_t$  is given by:

$$P_{eff,y} = \frac{1}{1 + \exp(I - PC - W_{opt})} \quad (17)$$

In the above equation  $PC$  stands for the associated production costs and  $W_{opt}$  for the option to wait, before committing capacity to the production

of a ship. If uncertainty and irreversibility have to be taken into account for the shipyard, too, then the probability that no investment birth will be encountered takes the following form:

$$P_{0births} = P_{eff}(V_n) + (1 - P_{eff})(V_n) \cdot P_{eff,y}(I, PC, W_{opt}) \quad (18)$$

This implies that there is an additional correction term for the intensity that is the cross-product of the event *the efficient operator is willing to pay I for a ship, but no yard produces at this price*. The interaction between the investors and the shipyards may result into endogeneity of the ship prices, and as a consequence, endogeneity of the real option calculated formula. This result is familiar from the literature on simultaneous equations. In the special case where the shipyard supply is inelastic this correction probability becomes zero. In our third model we will take into consideration the effects of any potential endogeneity of the price of new vessels.

Having discussed our model we may now proceed with the description of the data, the estimation of our model and the hypotheses to be tested.

### 3.5 Data and Results

The tanker sector has always been considered as a paradigm of perfect competition. Investing in a new tanker requires a significant amount of capital, whose main source is bank finance. Shipping cycles exhibit significant variability and no individual has ever gained enough market power in order to control freight rates.

Regarding the data, the main source is Marsoft, (Boston) Inc.<sup>3</sup> and it is the same source used by Dixit and Pindyck [28] in Chapter 7, p.238. Marsoft provided the *orderbook* (the orders placed for the construction of new vessels) for tanker ships (crude oil carriers). This data set is accurate and precise. The data set is in quarters from 1980 until 2002. This implies that we are given 91 observations for each type of tanker carrier. Given the five different types of ships we have 455 observations. For this time period the data on Time Charter Rates are fully available and precise, as well as the prices of new vessels. The operating costs are fairly straightforward. A drawback is that the data on operating costs contain errors from 1980-1991. After that period they are known exactly.

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<sup>3</sup>I thank Dr. Arie Sterling, President of Marsoft, and Kevin Hazel for providing the data.

The second source is Clarksons, (London) Inc. The available data are from 1993 until 2002 and are monthly. They are consistent *quarterly* with the Marsoft data. However, there is strong evidence that on a monthly basis there are errors.

If there are enough spanning assets, then the value of investing in a new tanker is uniquely determined and the correct investment rule is: “invest only when the value of this asset exceeds the option to wait”. I will name this excess value, the Real Option Value ( $V_{opt}$  hereafter) and it will be derived in line with Dixit and Pindyck [28].  $V_{opt}$  depends not only on the underlying process for the time charter freight rates (which will be the lognormal, in line with Dixit and Pindyck), but also on the presence of bubbles. If all risks are traded, then this value is unique.

Regarding the calculation of the Real Option Value we follow closely Dixit and Pindyck [28], Chapter 7, p.238 and their discussion on tankers. The “dividend” rate  $\delta$  is taken equal to 0.02 (since the growth of time charter rates  $\alpha$  is closer to 0.02 than 0 in their analysis and the risk adjusted return to shipping  $\mu$  is closer to 0.04) and the depreciation rate  $\lambda$  is taken equal to 0.03, since ships have a life time of 30 years. There is however significant evidence that depreciation rates depend on market conditions in this industry. They use a real option markup of  $m = 2.5$  in their discussion, but this markup is correct only if depreciation is omitted. As pointed out in their table in page 204, the existence of depreciation lowers the markup. Therefore, for  $\sigma = 0.2$  and the above parameters, the correct choice for the markup  $mup$  seems to be  $mup = 1.30$ . Finally regarding the ‘dividend’ payout rate  $\delta$ , a value of 0.02 is mainly consistent with the dividend ratios of most listed shipping companies. Later on, we shall not impose any specific values on these parameters and instead we shall estimate the implied parameters. If the Real Option markup hypothesis holds, the implied parameters have to generate a  $mup$  at least higher than 1.

Then the excess real option value which appears as a regressor is:

$$V_{opt} = \frac{P}{\delta + \lambda} - mup \cdot I \quad (19)$$

In the above formula  $I$  is the price of the new vessels and  $P$  is the revenue per year obtained from the One Year Time Charter rate minus operating expenses. The calculation of the above formula for ships is accurate, since the value  $I$  is known and the revenue from employing the ship from one year is known from the one year employment rate. The above formula imposes a

linear restriction on the revenue (that equals the time charter rate minus the operating expenses) and the price of a new vessel. What we really have to test is the robustness of this linear restriction, implied by the Real Option Theory. This will be our last task, after we have specified our structural model.

Before testing the first model we should note that the number of ships ordered from 1980 until 2002 is split in five different categories. Handymax, Panamax, Aframax, Suezmax and VLCC's are the five different categories, classified on the transportation capacity of each category. Now let us test the first Model.

### 3.6 Model I

Given the efficient operator identification condition

$$\lambda_t = -\ln\left(\frac{1}{1 + \exp(V_n)}\right) \Rightarrow \lambda_t = -\ln(P_{eff}) \Rightarrow \lambda_t = \ln(1 + \exp(V_{opt})) \quad (20)$$

the number of ships ordered in each period are

$$Y \sim P(\lambda) \quad (21)$$

or

$$P(Y = k | \lambda(x)) = \exp(-\lambda(x)) \frac{(\lambda(x))^k}{k!} \quad (22)$$

with

$$\lambda = \lambda_t \cdot \alpha \Rightarrow \lambda = \ln(1 + V_{opt}) \cdot \alpha \Rightarrow \lambda = \exp(\ln(\ln(1 + V_{opt})) + a) \quad (23)$$

since we observe quarterly data and we do not know the decisionmaking frequency of the most efficient operator, we have to add a constant term in the exponential specification. This model is very restrictive since it imposes a coefficient of unity for the logarithm of the probability of zero investment, which is not the case in the specification of *Model II*. We shall now estimate this model by doing pooled maximum likelihood estimation, in line with HHG [36]. The data on new ships ordered contain 455 observations with 65 zero counts and a maximum value of ships ordered 66 (small size

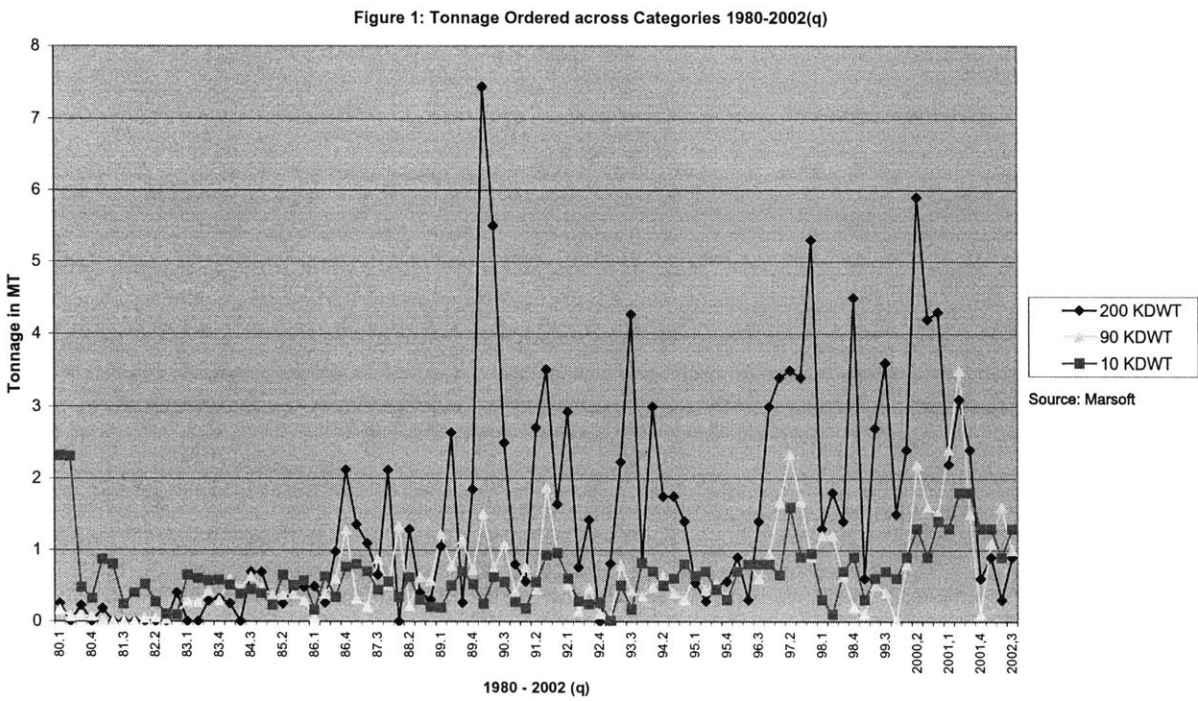


Figure 1: Tonnage Ordered across Categories 1980-2002(q)

**Table I Dependent Variable  $Y_t$  Descriptive Statistics**

Variable	Obs	Mean	Std. Dev.	Min	Max
ships	455	7.559471	9.296905	0	66
dwt	455	.7106032	.9347692	0	7.44

**Table II Model I (Conditional Mean: Eq.23)**

Model	NLLS (25)	PQMLE (24)	NB [36]	OLS
lnp	.3239 (.012)	.2901 (.028)	.3461 (.040)	2.691 (.352)
const	1.553 (.027)	1.622 (.067)	1.520 (.071)	4.468 (.380)
Log likelihood	-2413	-1623	-1358	n.a.
PseudoR2	0.1267	n.a.	0.0258	0.1451

60-DWT). Although our data set contains a significant number of zero orders, the average of ordered ships is 7.55 and the associated DWT is 0.71 million tons. There are two crucial observations at this point: On the one hand, the larger the tonnage category of the ship, the less the order counts observed in each period, and on the other hand once in the two periods of high freight rates investment “counts” appear to be high. This is the main reason why, despite the big number of zero counts (15 percent) the average number of ships ordered is 7.55 . Another crucial fact is that for all our observations, time charter rates are always significantly higher than operating costs. However, only in periods when they are significantly higher, investment counts are positive. These observations are indicative, that on the one hand investment in large vessels and uncertainty affect investment decisions and intuitively they provide supportive evidence for choosing the real option value as an investment statistic.

We now proceed with the estimation of the model and display the results in *TableII*. We do pooled Poisson maximum likelihood using the negative logarithm of the “no-investment most efficient operator” probability <sup>4</sup>, which we

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<sup>4</sup>

$$Y_t \sim P(\lambda_t \cdot \lambda_n), \lambda_t \cdot \lambda_n = \exp(X_t' \cdot \beta) \quad (24)$$

then compare with the Non Linear Least Squares (NLLS)<sup>5</sup> estimates under the exponential specification and with robust standard errors. Although it is well known from the Quasi Maximum Likelihood Estimation (QMLE) literature that maximum likelihood is still consistent, provided the conditional mean is correctly specified, a significant difference would indicate severe misspecification.

A significant improvement of the fit of the likelihood has been gained and a Hausman type test [35] yields 1.65. We then get the Negative Binomial (NB) estimates<sup>6</sup>, which improve the likelihood even more. Thus we find evidence for significant heterogeneity among operators. Finally, the predicted counts are compared with the actual data and there is clear evidence that the Poisson specification fails to capture not only the zero counts, but as well the excess counts observed for high real option values. To verify this observation the following diagnostic tests are conducted. The Pearson statistic normalized for the 454 degrees of freedom yields a value of 74.92313, which is supportive for the excess overdispersion of the data set. Furthermore, the “Goodness-of-fit” chi2 statistic is 3447.149, and rejects the Poisson specification with  $Prob > chi2(452) = 0.0000$ . Finally, the likelihood ratio for the parameter of overdispersion of the negative binomial, rejects the  $H_0 : \alpha = 0$  with probability one and  $\alpha = 1.080348$ .

Before proceeding with testing the second model, we consider fixed and random effects models.<sup>7</sup> The fixed effects model introduces a constant term for each of the five categories of ships. Intuitively, this implies that the frequency of investing orders differs among tonnage. The random effects model assumes heterogeneity among tonnage. Following [36], a Beta random effect specification is adopted, that leads to a closed form formula for the maximum likelihood. The introduction of multiplicative effects across different categories is equal to an intercept shift, which holds only for the exponential mean specification and corresponds to different frequencies of decisionmaking. The results are displayed in *Table III* and standard errors are reported. For a more formal derivation of the Fixed and Random Effects Specification see Cameron and Trivedi, [17] 1998, p.275.

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<sup>5</sup>

$$Y_t = \exp(X_t' \cdot \beta) + \epsilon_t, \epsilon_t \sim N(0, \sigma^2) \quad (25)$$

<sup>6</sup>The Negative Binomial specification allows for overdispersion, since it does not impose equality of the conditional mean and the conditional variance [36].

<sup>7</sup>For a detailed discussion of fixed and random effects see HHG, [36], 1984.



**Table III Model I with Fixed and Random Effects**

Model	NB Fixed	NB Random	Poisson FE	Poisson RE
lnp	.3802 (.0273)	.3799 (.0273)	.3859 (.0137)	.3857 (.0137)
const	.2142 (.1075)	.2124 (.1074)	n.a.	1.473 (.3070)
Log likelihood	-1201	-1237	-1491	-1528

The coefficient of  $lnp$  is now slightly higher than in the previous specification and the Log-likelihood is significantly higher. All estimated coefficients are still statistically significant. The Hausman test between Poisson Random and Fixed effects does not reject the random effects specification since it yields a  $\chi^2(1) = 0.23$  and the same result is verified for the Negative Binomial Random versus Fixed effects Hausman test with  $\chi^2(1) = 0.03$ . The Likelihood Ratio test of the Negative Binomial Random Effects specification versus the pooled estimates follows a  $\chi^2(1)$  with value 223.30, which indicates that the NB specification is far more suitable. Finally, by inspecting the predictions of the model it is clear that it captures successfully the low and zero counts, but it fails severely to predict the excess counts observed at the peak of the shipping cycle. Let us therefore proceed with Model II.

### 3.7 Model II

We now assume that the probability of a positive count is the same for all operators, which is a fairly good assumption for a competitive market like the market of crude oil carriers. As a consequence, the specification of the Poisson model has the following form:

$$P(Y = k | \lambda(x)) = \exp(-\lambda(x)) \frac{(\lambda(x))^k}{k!} \quad (26)$$

with

$$\lambda(x) = \exp(a + \beta \cdot x + \gamma V_{opt}) \quad (27)$$

Given our previous analysis the model should yield a  $\gamma = 1$  if the “structural errors” have an Extreme Type I distribution. However, if there are bubbles in the market, then the real option value is a power function of the

**Table IV Model II (Cond. Mean: Eq.27)**

Model	PQMLE (24)	NLLS (25)	NB(RE) [36]	OLS
ship1	.0362(.0051)	.0240(.0057)	.0611(.0067)	.6212(.0806)
$V_{opt}$	.0135(.0021)	.0149(.0050)	.0130(.0029)	.0724(.0210)
$V_{opt}^2$	-2.57(0.645)e-05	-2.66(0.100)e-05	-2.64(0.653)e-05	-1.189(0.433)e-04
newprice	-.0158(.0037)	-.0291(.0131)	-.01114(.0027)	-.0551(.0172)
accident	-.1517(.1483)	.0854(.1617)	-.3551(.1757)	1.405(1.720)
lrate	-.02349(.018)	.00602(.019)	-.0325(.0207)	.0619(.132)
$V_{opt,lag}$	-.002072(.00118)	-.002129(.00150)	-.0008354(.00206)	-.0290(.0129)
const	2.444(0.203)	2.787(.401)	2.097(.2351)	4.734(1.541)
$PseudoR^2$	0.3623	n.a.	0.0980	0.5278
Log L	-1758	-1497	-1255	n.a.

real option value  $V_{opt}$ .<sup>8</sup> Since it is difficult to identify the correct distribution of the errors, as well as a closed form solution of the option to wait, values less than one will be interpreted as evidence for the presence of bubbles.

Regarding the exogenous variables  $x$  that determine the expected number of investors, we use the following in the estimation of Eq.(27):

- *ship1* a lag of the number of ships ordered one quarter before
- $V_{opt}^2$  the squared value of  $V_{opt}$
- *accident* a dummy variable for the accident of *Erika* in December 1999
- *newprice* the price of new vessels
- *lrate* since the predominant source of ship finance is the bank we also include the lending rate in the regressors
- $V_{opt,lag}$  a lag of  $V_{opt}$

We now run Poisson likelihood estimation Eq.(24) (with robust standard errors), NLLS Eq.(25), Negative Binomial ([36]) with Random Effects and Ordinary Least Squares with robust errors. Results are reported in *Table IV*.

<sup>8</sup>For a derivation of the real option under the presence of bubbles, see the discussion in Dixit and Pindyck. [28]

It is clear that the real option value appears statistically significant for all the above specification. Conducting some diagnostic tests the Poisson  $\chi^2(n - k)$  has a value of 2140 and rejects the Poisson specification with probability one. The Pearson statistic normalized for the degrees of freedom has a value 44.3 that indicates severe overdispersion and the likelihood ratio test on the overdispersion parameter of the negative binomial rejects the  $H_0 : \alpha = 0$  with probability one. By inspecting the predictions of the negative binomial, the model fails to predict the zero counts as well some excess counts, especially for the lighter categories, where the most “excess events” are observed. Before proceeding with random and fixed effects specifications, we shall relax the real option calculations. The real option value is calculated as the profits from the one year time charter rates minus the operating costs discounted by the “dividend payout ratio” and the depreciation rate minus the newbuilding price, times the “real option” markup. We will re-estimate the parameters of the above model, including the one year time charter rate, the operating costs and the newbuilding prices in the regressors. It will then be checked if the implied estimated parameters are consistent with the real option specification Eq.(19), before proceeding with more complicated models.

The results of the four different specifications are presented in *Table V* and it is clear that for all these specifications the one year time charter rate, the operating expenses and the price of the new vessel are statistically significant. The *tcrate* is always positive and the other two variables are negative as expected. What is even more impressive is that the magnitude of the coefficient of the operating expenses is of the same significance and slightly higher than the corresponding coefficient of the time charter rates, which is as expected, since costs incur, even when the ships does not earn revenue (in the port, dry-dock, etc.). Furthermore, the *tcrate* and *opex* are on a *per – day* basis. Thus if we calculate the difference of these two coefficients and multiply it by 365 days, the number we get is of the same significance as the coefficient of the newbuilding price, but almost three times less, **exactly as predicted by the real option literature**. In order to make this point clear the estimation is repeated and instead of using *tcrate* and *opex* as regressors we use the value of the project *Val*, which is given by the formula  $Val = \frac{tcrate \cdot 355 - opex \cdot 365}{\delta + \lambda}$  and then the coefficient of this variable is compared with the coefficient of the *newprice*. (*Table VI*) If the real option literature is correct, the coefficient of *newprice* has to be higher than the coefficient of *Val*, which is exactly the case. As observed by the results, the real option

**Table V Model II with  $V_{opt}$  in reduced form**

Model	NLLS (25)	PQMLE (24)	NB(RE) [36]	OLS
ship1	.0277(.0047)	.0393(.0054)	.0491(.0034)	0.6196(0.0800)
tcrate	3.47(0.897)e-05	4.37(0.880)e-05	3.58(0.543)e-05	2.65(0.83)e-04
opex	-3.83(1.87)e-05	-2.68(1.83)e-05	-2.65(1.50)e-05	-1.755(1.091)e-04
newprice	-.0293(.0082)	-.0230(.0046)	-.0166(.0032)	-.1127(.0300)
lrate	-.0013(.019)	-.0361(.017)	-.0589(.017)	.0252(.1281)
accident	.2157(.2142)	-.1898(.1682)	-.3952(.1917)	.4585(1.700)
const	2.642(.288)	2.390(.208)	1.122(.261)	4.702(1.783)
$PseudoR^2$	n.a.	0.3398	n.a.	0.5195
Log L	-1515	-1820	-1257	n.a.

**Table VI Model II with a semi-parametric form for  $V_{opt}$**

Model	NLLS (25)	PQMLE (24)	NB(RE) [36]	OLS
ship1	.0276(.0049)	.0396(.0054)	.0491(.0034)	.6226(.0800)
$V_{at}$	.0049(.0012)	.0060(.0012)	.0049(.0007)	.0354(.0112)
newprice	-.0294(.0084)	-.0223(.0046)	-.0161(.0032)	-.1078(.0293)
lrate	-.00149(.01910)	-.03602(.01771)	-.0602(.0175)	.0081(.1230)
accident	.2127(.2078)	-.1630(.1638)	-.3741(.1881)	.6510(1.672)
const	2.632(.270)	2.478(.192)	1.175(.249)	5.351(1.529)
$PseudoR^2$	n.a.	0.3387	n.a.	0.5189
Log L	-1515	-1823	-1258	n.a.

markup implied by the data indicates a value close to 4, which corresponds to an implied volatility for the underlying profit flow process of 0.40! For the exponential mean specification the Akaike criterium indicates that the model performs better when the real option value is used as a regressor (with a markup of 1.3 for the excess option value) than using *tcrate*, *opex* and *newprice* as regressors. It is now clear that on the one hand the optimal combination between the variables that determine the value of the project and the option to wait, is the one predicted by the real option literature and on the other hand, not much can be gained by assuming a time varying markup specification.

However, the  $\chi^2$  still rejects the Poisson specification in favor of the Negative Binomial, since the Likelihood ratio test yields a statistic of 20.33. The Pearson statistic is lower than before (47.78), indicating that to some extent the problem of overdispersion has been corrected. Before going on with fixed effects and random effects models, we will add some non-linear variables and check the robustness of the previous findings.

It is argued that if the underlying process does not follow a lognormal distribution, or if bubbles are present, then the excess option value is a non-linear function of the variables of the project. To account for non-linearity we include in the exogenous variables  $x$  in Eq.(27):

- $VV$  the square of  $V_{opt}$
- $shipk$  the  $k - th$  lag of ordered ships
- $tcs$  the square of  $tcrate$
- $tcrate$  and  $opex$
- $newprice$  the price of new vessels
- $accident$  and  $lrate$

Finally, in order to account for category-specific effects we repeat our estimation and include a dummy variable for the “weight category” ( $dwg$ ). The dummy takes a value of one if the data of the related category are used for estimation and zero otherwise. The results of the estimation of Eq.(27), with different constants across categories, are displayed in *Table VII* and reconfirm the robustness of our previous findings. The intuition for including the lags of ordered ships is the following: Previous lags (one quarter and four quarters ago, respectively) of orders are an indicator of the transportation capacity demanded by shippers. Although the demand for transportation capacity is a derived demand from the demand for oil (and therefore it is inelastic with respect to the time charter rate) we consider lags of orders as a proxy for demand growth in this market.

Diagnostic tests still reject the Poisson specification, due to overdispersion. The Pearson statistic is significantly lower (33.96) and the Likelihood Ratio of the Negative Binomial Random Effects versus the pooled is still in favor of the

**Table VII Full Model “Free Parametrization”**

Model	NLLS (25)	PQMLE (24)	NB(RE) [36]	OLS
ship1	.0090(.0064)	.0200(.0057)	.0269(.0034)	.4727(.1006)
ship4	.0042(.0036)	.0134(.0035)	.0229(.0039)	.1669(.0551)
tcrate	11.2(9.72)e-05	7.19(3.16)e-05	4.58(1.39)e-05	55.93(30.33)e-05
opex	-10.82(3.28)e-05	-7.43(2.14)e-05	-4.20(1.45)e-05	-42.37(16.6)e-05
newprice	-.0286(.0240)	-.0118(.0056)	-.0102(.0049)	-.0437(.0316)
VV	-3.85(5.88)e-05	-4.93(1.80)e-05	-2.11(1.68)e-05	6.59(1.338)e-04
tcs	4.32e-10(2.34e-09)	8.89e-10(7.61e-10)	-1.89(6.45)e-10	-6.00(6.50)e-09
accident	.0296(.2041)	-.1753(.1538)	-1.185(.1913)	.4540(1.693)
lrate	.0285(.0139)	-.0017(.0164)	-.0755(.0171)	.1105(.1515)
dwg	-.0147(.0025)	-.0101(.0020)	-.0068(.0014)	-.0345(.0131)
cons	2.872(.3673)	2.304(.3072)	1.553(.3242)	3.320(2.761)
Pseudo R <sup>2</sup>	n.a.	0.4270	n.a.	0.5626
Log L	-1426	-1568	-1232	n.a.
Markup	1.90	1.26	1.57	n.a.

NBRE model. However, all Likelihood Ratio tests are supportive to the presence of these additional variables and the relationship between time charter rates, operating expenses and newbuilding prices is exactly the one predicted by the real option theory and with the implied markup being close to 1.35.<sup>9</sup> Finally the fourth lag of ships ordered (one year ago) and the dummy for deadweight category appear very significant, as well as the square of the real option value. The significance of the weight dummy is counterintuitive, since it implies that carrier capacity has a negative impact on the demand for new ships and it is against the “economies of scale” principle. Having derived these encouraging results for the different re-parametrizations of the underlying theory, we go on with the negative binomial specification and random versus fixed effects tests. We assume a time varying multiplicative effect for the expected mean, which is the same for all categories. However, to account for the impact of deadweight on the number of ordered ships, a deadweight dummy is included, although as discussed previously, such a variable should have no statistical significance, theoretically at least.

<sup>9</sup>The implied markup for the full parametrization is time varying and is calculated as following:  $mup = \frac{newprice \cdot V_{at}}{tcrate \cdot timecharter + opex \cdot op.costs}$

**Table VIII Full Model II Negative Binomial**

Model	NB Random Effects	NB Fixed Effects
ship1	.0269(.0034)	.0324(.0047)
ship4	.0229(.0039)	.0291(.0050)
tcrate	4.58(1.39)e-05	8.33(3.22)e-05
opex	-4.20(1.45)e-05	-4.89(1.61)e-05
newprice	-.0102(.0049)	-.0043(.0070) <sup>10</sup>
VV	-2.11(1.68)e-05	-4.36(1.96)e-04
tcs	-1.89(6.45)e-10	3.62(7.87)e-10
accident	-1.185(.1913)	-1.267(.4115)
lrate	-.0755(.0171)	-.0281(.0503)
dwg	-.0068(.0014)	-.0081(.0020)
cons	1.553(.3242)	.9513(.6672)
Log L	-1232	-821
Average Markup	1.57	0.611

Before commenting on the results we do a Hausman test between the NB Fixed and NB Random effects specification, displayed in *Table VIII*. If the RE model is correctly specified, then both FE and RE models are consistent, while if the RE are correlated with the regressors, the RE loses its consistency. The difference between these two estimators can be used as a basis for a Hausman test.<sup>11</sup> The statistic is  $\chi^2(6)$  distributed and has a value 34.84 and we reject the RE specification. The FE NB specification implies that there is a time varying effect, which accounts for the overdispersion of the data. The previous lags of ordered ships are statistically significant, as well as the time charter and operating expenses coefficients. The dummy for the *Erika* accident appears statistically significant and negative. This implies that the new regulation bill for the construction of new tankers, negatively affected investments in new tankers. Regulators and analysts expected that the new regulations would have a positive effect on the construction of new double-hull vessels, since all older vessels, past a certain age were not allowed to operate in U.S. ports any longer. What appears statistically insignificant and makes the real option specification questionable, is the coefficient of the price of new vessels (*newprice*). There are two explanations for this fact.

<sup>11</sup>This test was introduced in Hausman ([35] and [36] 1984, pp.921 and 928)

On the one hand it is possible that *newprice* has errors in variables. The price reported by the agencies is the average price of the ships ordered and it is reported by the shipyards. Since shipbuilding is heavily subsidized, it is possible that the reported prices do not include rebates or other “under the table” agreements. Another potential explanation is the endogeneity of *newprice* and autocorrelation in the errors. Both would lead to inconsistent estimates for the RE Negative Binomial specification. In order to test for endogeneity we use a set of instruments for the log of the price of new vessels and we then include the prediction error from this regression in the NB FE specification. Finally we shall test for both endogeneity as well as autocorrelation. More formally:

$$l_{nn} = \Pi \cdot Z + v_{res} \quad (28)$$

and for the NB RE specification:

$$ships_{it} = E[ships_{it}|x_{it}] + \alpha \cdot v_{res_{it}} + \epsilon_{it} \quad (29)$$

with  $E(\epsilon_{it} \cdot v_{res_{it}}) = 0$ .

$Z$  is the set of instruments, which in this case are the following: the Standard and Poor’s Oil Price index *spoil*, the crude oil price *oil*, the Standard and Poor’s Air Transportation Index *air* and all other exogenous regressors. To ensure that we do not have a unit root in the regressors (especially for the time charter rate) we do unit root tests, which are all rejected. The reason we include the transportation air index is the following: on the one hand it is correlated with economic, trade growth and their associated transportation networks, but uncorrelated with the demand for new vessels and on the other hand it is a proxy for alternative modes of transportation.

We then repeat the estimation of the model under the NB FE specification and we include the error *vres* of the projection of the price of new vessels on the instruments and the exogenous variables in the regressors. The results are displayed in *Table IX*.

In order to account for autocorrelation we also include the lag of the predicted error. Under the hypothesis of non-autocorrelated errors, the lag of the estimated residuals is included in the regressors; a non-significant coefficient implies that the null should not be rejected. Results are displayed in *Table X*.

Since both the residual of the instruments, as well as the lag of the predicted residuals appear statistically insignificant, endogeneity is rejected. Al-



**Table IX NB FE - Exogeneity Test**

ships	Coef.	Std.Err.	z	p-0
ship1	.0329	.0047	6.92	0.000
ship4	.0290	.0049	5.85	0.000
tcrate	8.39e-05	3.21e-05	2.61	0.009
opex	-4.25e-05	1.92e-05	-2.22	0.027
newprice	-.0087	.0102	-0.86	0.391
vres	.0035	.0256	0.14	0.891
VV	-4.82e-05	2.09e-05	-2.30	0.021
tcs	5.44e-10	8.40e-10	0.65	0.517
accident	-1.319	.4197	-3.14	0.002
lrate	-.0180	.0543	-0.33	0.740
dwg	-.0073	.0023	-3.17	0.002
cons	.8888	.6825	1.30	0.193

**Table X Model II NB FE - Exogeneity Test [36]**

ships	Coef.	Std.Err.	z	p-0
ship1	.0328	.0088	3.73	0.000
ship4	.0302	.0049	5.99	0.000
tcrate	8.12e-05	3.21e-05	2.53	0.009
opex	-4.32e-05	1.92e-05	-2.22	0.027
newprice	-.0096	.0101	-0.96	0.344
vres	.0038	.06305	0.06	0.007
u1	-.0008	.0091	-0.10	0.924
VV	-5.08e-05	2.10e-05	-2.41	0.016
tcs	6.36e-10	8.40e-10	0.76	0.449
accident	-1.346	.4160	-3.24	0.001
lrate	-.0298	.0541	-0.55	0.582
dwg	-.0071	.0023	-3.01	0.003
cons	1.030	.6821	1.51	0.131

**Table XI Model II NB FE-RE [36] Real Option Model Eq.(19)**

Model	NB FE	NB RE
ship1	.0327(.0047)	.0267(.0041)
ship4	.029(.0050)	.0231(.0046)
Vopt	.0069(.0017)	.0088(.0018)
tcs	1.24e-09(2.85)e-10	1.41e-09(2.82)e-10
VV	-6.27(1.18)e-05	-7.11(1.12)e-05
accident	-1.281(.4034)	-1.195(.2168)
lrate	-.0468(.0460)	-.0744(.0205)
dwg	-.0068(.0012)	-.0065(.0013)
cons	1.476(.4818)	1.518(.2305)
Log Likelihood	-822	-1271

though the coefficient of *newprice* has increased significantly and the markup has been restored above one, the price of new vessels still appears statistically insignificant. We will now estimate NB models using  $V_{opt}$  as an exogenous variable, instead of the price of new ships, time charter rates and operating expenses. This will allow me to compare the performance of these two parametrizations.

Now that we have derived the NB RE and FE specification with  $V_{opt}$  as an exogenous variable we conduct a Hausman test, that clearly rejects the NB RE specification. We now conduct the final test, in order to compare the estimates of the full model with the above estimates. Since we have specified the NB FE both with the  $V_{opt}$ , as well as with the full parametrization of *tcrate*, *opex* and *newprice*, we will use a “norm” to compare the deviation of the estimates. It is known from econometric theory, that if  $V_{opt}$  is correctly specified (in other words we have the correct relationship between *tcrate*, *opex* and *newprice*) the estimates are efficient. The full parametrization is consistent under the alternative parametrization, where  $V_{opt}$  is not the optimal combination. We therefore conduct a Hausman test and the statistic is  $\chi^2(6)$  and 1.62. We therefore accept that the optimal combination is the one derived by the real option literature.

### 3.8 Explaining Capacity Orders

In the previous analysis the coefficient for transportation capacity (deadweight) turned out statistically significant, implying that lighter ships have a higher demand. Although “economies of scale” tell us nothing about the supply and demand for this category, investing in larger vessels implies a higher degree of uncertainty and irreversibility. The observation that the number of investment counts depends on the specific ship category is something that has to be further examined. In order to account for the interaction between shipyards and investors we will adopt a more flexible model, that may account for the zero counts in a different sense than the previous specification.

We will use a *Tobit I* model for the *deadweight* (the net tonnage capacity ordered in each period). If the more efficient operator or the most efficient shipyard do not agree on a specific contract price for a ship, zero deadweight is ordered in this period and  $dwt = 0$ . If there is investment, then we observe the total (aggregate) deadweight ordered and  $dwt = f(x; \theta)$ , where  $x$  are the exogenous variables. In this case the identification condition is that the probability of zero investment is equal to the probability that the auction between the most efficient operator and the most efficient shipyard is unsuccessful.

Formally the model has the following form:

$$dwt_{it} = \max(\beta \cdot x_{it} + \epsilon_{it}, 0) \quad (30)$$

and

$$\epsilon_{it} \sim N(0, \sigma^2) \quad (31)$$

It is a standard Tobit I model and it can be estimated by pooled maximum likelihood estimation. It is well known that maximum likelihood is efficient if the specification of normally distributed errors is correct, but inconsistent if this assumption fails. From the above model the probability of zero investment is well defined:

$$P(0, inv|x_{it}) = P(\epsilon_{it} \leq -\beta \cdot x_{it}) \quad (32)$$

The following results of the estimation of Eq.(30) are displayed in *Table XII*, where the set of exogenous variables  $x_{it}$  are the first and fourth lag of the dependent variable  $dwt$ , the first and fourth lag of the real option value (19), the price of new vessels *newprice*, the square of the real option value  $VV$ , the lending rate *lrate*, the accident dummy and the price of oil *oil*. Finally,

**Table XII Pooled Tobit I Eq.(30)**

dwt	Coef.	Std. Err.	t	p-0
dwt1	.3878	.0459	8.45	0.000
dwt4	.2180	.0472	4.62	0.000
Vopt1	-.00397	.00151	-2.62	0.009
Vopt4	-.00194	.0010	-1.83	0.067
Val	.01216	.00171	7.07	0.000
newprice	-.0100	.0038	-2.63	0.009
VV	-10.3e-06	5.33e-06	-1.93	0.054
accident	-.2174	.1530	-1.42	0.156
lrate	-.0217	.0159	-1.37	0.172
oil	.0088	.0069	1.27	0.204
dwg	-.00047	.00091	-0.52	0.604
cons	.0682	.1638	0.42	0.677
Log Likelihood	-451			
Pseudo R <sup>2</sup>	0.2729			

we include a deadweight category dummy to capture the impact of different categories on orders.

The results are similar to the results obtained in the previous section. The value of the project  $V_{al}$  is statistically significant, as well as the price of the new vessel. The previous first and fourth lag of the ships ordered is significant as well as the lag of the real option value. The price of oil, the lending rate and the accident dummy are insignificant. The deadweight coefficient is statistically insignificant and restores the previous findings. The high number of counts observed for smaller ships, that accounts for the severe overdispersion with the count data specification, is not present when investment is measured in terms of transportation capacity.

A negative finding is that the coefficient of *newprice* is less than the coefficient of  $V_{al}$ , which contradicts the real option markup assumption. By performing diagnostic tests on the residuals it becomes clear that the “structural errors”  $\epsilon_{it}$  are not normally distributed, which implies that the reported statistics are too high. Median regression is far more robust to departures from the assumptions of normality and only requires that  $med(\epsilon|x) = 0$ . We perform censored median regression and the derived estimates are displayed

**Table XIII Median Regression**

dwt	Coef.	Std.Err.	t	p-0
dwt1	.3782	.0307	12.32	0.000
dwt4	.2379	.0313	7.59	0.000
Vopt1	-.00197	.00102	-1.93	0.054
Vopt4	-.00336	.00071	-4.73	0.000
Val	.00772	.00113	6.80	0.000
newprice	-.009200	.00252	-3.65	0.000
VV	-1.60e-06	3.56e-06	-0.45	0.653
accident	.1007	.1019	0.99	0.323
lrate	-.0151	.0103	-1.46	0.144
oil	.0081	.0046	1.76	0.080
dwg	-.00035	.00060	-0.59	0.559
cons	.1068	.1057	1.01	0.313
Min. Sum. Dev.	167.9			
Pseudo R <sup>2</sup>	0.3269			

in *Table XIII*. The coefficient of *newprice* divided by  $V_{at}$  has a value close to the one predicted by the real option literature and the previous shortcoming of the *TobitI* is now restored.

Median Regression is not efficient if the errors are normal, but it is still consistent. This fact allows the performance of a Hausman test, that clearly rejects the *TobitI* specification in favor of the median regression. Median regression is far more robust to “extreme type structural errors” and diagnostic quantile regression reveals that the real option markup is high for low quantiles, whereas for quantiles close to one the only significant variable, appears to be the passed lag of the order counts.

### 3.9 Conclusions

In this Module we have demonstrated that the value of a project as spanned in complete financial markets is a sufficient statistic for characterizing investment decisions. In the case of irreversibility and uncertainty the correct specification for this value is the one expected by the real options literature.

The value of the project not only has to exceed the investment cost, but also the option to wait. In the case of the perfect competitive market for new tankers, the statistical results for the last 22 years have verified both these hypotheses.

What is more interesting is that there is not much to be gained by assuming a time varying real option markup (or equivalently a time varying “option to invest” value). This implies that new observations on the underlying risk process do not change the market’s sentiment on the basic underlying parameters. Another important observation is the stickiness observed in the responses of all players in this market. Although economic theory suggests that shipyards should respond with significant price increases to the demand for new ships, this is not the case. The volatility of the prices quoted by the yards is far less than the volatility of the time charter rates and the value of the project. This imperfection is crucial for our analysis and will be thoroughly investigated in Paragraph 5.8.

The excess counts and subsequently the significant number of zero counts are explained by large deviations in the evolution of the  $V_{opt}$  variable. In a perfect competitive market and with frictionless markets, investment opportunities with  $V_{opt}$  positive, indicate an arbitrage opportunity that theoretically should not exist. Arbitrage opportunities should lead to an excess demand for new vessels and the shipyards should respond immediately with high prices for the demanded vessels. However, this is not the case revealed by our data and the price of new ships is the less volatile variable.

From this point of view the observed “count orders” could correspond to a dynamic game, where agents in a market react to an “arbitrage opportunity”, subject to the constraints imposed by lenders (bankers) and producers, or where different type of agents (noise traders, rational investors and intermediates) react to different information. The response to these different actions could result in the observed investment process and a dynamic Markov chain, or even a Markov chain with regime switching, that could account for the more “excess” characteristics of our data. Integer valued ARMA models and pure time series models like the Poisson INAR(1) model (that still correspond to a Markov chain) could be used in future research. <sup>12</sup>

Under the assumption of perfect competition and complete markets the slow adjustment of the shipyards to the investment process is still a puzzle. The key explanation to this action is irreversibility and uncertainty, exactly

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<sup>12</sup>For a more detailed discussion see Cameron and Trivedi, p.236

as predicted by the real options literature. In periods of low time charter rates and less demand for new vessels, shipyards do not offer investors much lower prices, because they do not want to exercise the option to wait before committing capacity. In periods of higher rates they try to keep the production rate constant and commit capacity to long term contracts. With this action they “hedge” their cash flows against periods of very low production rates. Furthermore, the shipbuilding industry has been heavily subsidized, due to political implications. Especially in Asia, shipyards have been used as “instruments” to attract U.S. dollars. This has led to accumulated excess capacity, which has resulted in the exogeneity of the price of new vessels and an inelastic supply function. The argument of the exogeneity of prices of new vessels is not new in Maritime Economics and has been addressed in the seminal monograph by Zannetos [64]. Due to its central role in the specification of our newbuilding module, as well as its effects on the stability of the system, this issue will be explicitly addressed in Paragraph 5.8.

Under the assumption of frictionless markets agents should respond immediately to positive  $V_{opt}$ . After periods of low rates and negative project values the response to positive opportunities is not as strong as theory expects. Since the main source of ship finance is bank finance and long term charter rates offered by shippers, after periods of long depression, finance is not always available for indirect investment and occurs only when lenders have a high real option markup on their collateral.

Irreversibility, uncertainty and intermediaries account for the time lags between action and response and the slow adjustment to equilibrium, observed in direct investment. Using the value of projects spanned in financial markets, investment actions are the responses of agents, noise traders, bankers and suppliers to expected arbitrage profits (or expected positive  $V_{opt}$ ). The value of the project as predicted by the real option specification is a sufficient benchmark of investment actions for heterogeneous agents, with the structural error accounting for heterogeneity. Integer Valued Count Models and Simulation Estimators with heterogeneity in the “market price of risk” in incomplete markets, might shed some more light on the evolution of the investment process. We shall now proceed with addressing an alternative framework for the derivation of structural models of entry that will not rely on the specification of the underlying process. This is necessary, since it will allow us to employ the estimated models, in order to determine the time charter rate.

### 3.10 An Evolutionary Approach to Entry Decisions

*In this section we discuss aggregate newbuilding “birth” models that do not rely on the specification of the underlying time charter process.*

The models of entry proposed in this section are implicitly derived in a partial equilibrium framework. Agents form their decisions based on an **exogenous** time charter rate, that is determined from optimal Lay-Up and chartering actions. This assumption implies that newbuilding decisions have no impact on the time charter process, since the newbuilding tonnage is relatively small compared to the existing tonnage. Furthermore, they prohibit us from employing the derived equations for the determination of the capacity supply function and the endogenous determination of the equilibrium time charter rate. In order to estimate the newbuilding equations in a structural framework, we have implicitly assumed that the time charter rate is, loosely speaking, an “input” to the demand for newbuildings. If we then employ the estimated demand for newbuildings, in order to determine the transportation supply function and the equilibrium time charter rate, this is a “philosophical” inconsistency, *unless we get the same time charter rate process, or unless “system input equals output”*. This is the concept of a rational expectations equilibrium. In order to avoid the complications of a rational expectations equilibrium we have to propose alternative schemes of aggregation. Although the estimation and specification of the model of orders remains intact, we cannot use the model to determine the equilibrium time charter rate, unless we introduce an alternative structural framework. In this section we shall propose some potential “exit strategies” that will allow us to use the estimated model, without relying on partial or general equilibrium assumptions.

One way to avoid the cornerstone of the necessary consistency between the expectations on the underlying process and the actual “outcome”, once all agents have exercised their optimal action plans, is to derive the structural equations as a function, **not of the whole stochastic process**, but of today’s value. In order to achieve this goal, we have to avoid the conventional path of agents who form optimal decisions under uncertainty. The simple way to get around this problem is to assume **rational myopic actions** and aggregate with Laws of Large Numbers.

More specifically let us assume each agent has a value function  $V_j(x_t)$  that depends on some exogenous parameters  $x_t$ . Let us assume  $N$  agents. Agents



enter once their value function is positive and the process of new orders in each period is given by:

$$B_t = \sum_{j=1}^N l(V_j(x_t) \geq 0) \quad (33)$$

And if we decompose the value function  $V_j(x_t) = V(x_t) + \epsilon_j$  then the process of births becomes equal to:

$$B_t = \sum_{j=1}^N l(-\epsilon_j \leq V(x_t)) \quad (34)$$

If the reduced form  $V(x_t)$  is a function of the number of agents  $N$  it can be shown that under some regularity assumptions on the distribution of the structural errors  $\epsilon_j$ , the process  $B_t$  converges to a Poisson process, whose intensity is determined by  $x_t$  and the distribution of the structural errors. In a partial equilibrium framework, this approach generates count data models for the entry decision, consistent with the models we estimated in the previous sections. One significant drawback of this model is that it does not allow for convergence to equilibrium and assumes an *ad hoc* specification of the value function.

A more revolutionary approach is to observe that newbuilding orders correspond to “births” of new vessels and determine the *population dynamics*. Thus, concepts from **Evolutionary Biology** seem particularly promising for providing us with an alternative framework for the derivation of structural equations, **that will not depend on the specification of the entire process, but only on the value of the relevant statistic prevailing today**. Newbuilding orders correspond to “births” of new vessels by the existing population of agents. The “birth rate” or fertility rate depends on the available resources for reproduction, which in our case are *profits*.

Another significant observation, supportive to the evolutionary approach, is that the number of new orders depends crucially on lags of orders, which is indicative for the existence of some form of strategic behavior. This observation violates our frictionless perfect competition assumption. Strategic behavior in the ordering process may be imposed by shipyards not due to price competition, but delivery dates of the under construction vessel.

Let us introduce a continuous evolutionary game theory framework for the analysis of newbuilding decisions. The number of vessels ordered in each period may be understood as the number of **births** and the **type** of each

new ship, as the **body size**. Continuous games are those where each player can choose from an infinite set of strategies over some range; the choice in our case are the characteristics of the vessel. On the assumption that the profits earned by the contract that corresponds to each category (*the food consumed is proportionate to body size*, coevolution of **competition** is often modelled by assuming investors vary **ship size** as a strategy to escape competition. Loosely speaking, they choose the size they believe will result in less competition and consequently higher returns. Ship size is a continuous strategy since it can take on any value over some reasonable range. The game of ship choice is played over many generations of investors.

There are three type of factors that influence vessel type choice *or the biology analogy of fitness*:

1. Frequency dependent: My frequency depends on what other individuals are doing. In competition for example if everybody has a draft of 20m and I come along with a draft of 10m I will be able to access ports (*food*) that no else can.
2. Density dependent: My fitness depends on population size.
3. Intrinsic: Fitness (ship size and characteristics) varies purely as a function of regulation, development and the environment.

Using Hammerstein's streetcar theory of evolution [16] the change of strategy (for example the strategy is ship tonnage category) is given by the equation:

$$\Delta U = \kappa \frac{\partial}{\partial u} W(u, U, N_t) \quad (35)$$

In the above equation  $u$  is the strategy of one individual,  $U$  is the strategy of the rest of the population and  $N$  is the evolution of the population. Once the system reaches an equilibrium the concept of an individual that invests in ship type  $u$  versus the rest of the population who choose  $U$  is eliminated. In equilibrium  $U^*$  is the dominant strategy and there is no more evolution of fitness (or different types). Although this approach does not provide any particular insight into the modelling of the birth and evolution of fitness (ship choices) it suggests that category effects and previous category choices should have a significant impact on the evolution process, which is in line with our findings in the the empirical analysis.

In a similar framework, models of **interacting Metapopulations** [16] seem convenient for modelling the evolution of the population of new vessels and provide us with some insight into the specification of the process. Consider a large number of  $K$  contracts (potentially habitable sites in population biology), each of which is occupied or unoccupied by an individual investor. Then we may assume that agents compete to “occupy” the contracts and the effects of competition result to periods of low orders (lower colonization rates or higher extinction rates). Huffaker [16] performed some experiments in order to test the Theory of Metapopulations. His data are very similar to the data of new orders (births), where periods of very low or even zero population presence is followed by periods of very high peaks.

The same argument is made by Tong [59] in his classical treatment of non-linear time series. In his analysis of ecological data, he introduces an exponential specification for the birth rate, namely  $b(x) = b \cdot x \exp(-\frac{x}{\kappa})$ , where  $x$  is a physiological condition such as nutrition state (or potential profits in our case). The exponential specification verified by experiments in ecology is similar to the specification we derived in our estimation of the model. The crucial feature of this type of curve is that when **population and resources** reach a critical point  $N_c$ , the competition for food (profits and time charter contracts in our case) reduces the average adult fecundity and the birth rate begins to fall of. Loosely speaking, periods of high rates (availability of food) result in an increase of the birth of new vessels (fertility). Newborns consume resources and the availability of food goes down causing a drop in the fertility rates. Human populations seem to contradict this simple cycle, since low income populations have higher reproduction rates. But this is because there are other social issues interrelated with human reproduction, which are irrelevant in our simple birth model for ships.

This critical threshold type characteristic for the birth curve is preserved with our exponential Poisson specification that assigns a positive probability of zero reproduction, especially in periods of low availability of resources (time charter rates in our case). The evolutionary approach to the modelling of birth rates in a competitive environment is a promising alternative, that does not require convergence of expectations to the underlying stochastic process. Future research in this area could provide some valuable insight into the derivation of birth rates in competitive environments, without the stringent assumptions of rational equilibria and myopic actions [28] in the competitive equilibrium. The case of new orders in tanker vessels and the associated choice of ship type (fitness in the biology framework) reveals some

striking similarities to the evolution of births observed in biological systems, especially once we replace physiological variables (available nutrition) with variables that determine profitability.

## 4 Module 2: Exiting the Market and Scrapping Dynamics

*Are scrapping decisions **exit** or **capital replacement decisions**? In this section we provide additional motivation to count data models for aggregate exit decisions with heterogenous agents. In a partial equilibrium framework, we address the impact of relevant investment variables on the exit process.*

### 4.1 Introduction and Data Analysis

In his influential work “The Theory of Oil Tankship Rates” [64] Zannetos discusses the factors that result in contraction of transportation supply and characterizes them as permanent or temporary. In this section we will analyze permanent actions, namely **scrapping** actions, whereas in the next section we will analyze temporary contraction of supply, which occurs due to slowdowns, extended repairs and lay-ups.

Zannetos contradicts Koopman’s earlier assertion “that the conditions which simulate new investment also favor replacement” ([64],p.119). According to his argument “there is no theoretical reason requiring sale or retirement of a vessel only after an order for its replacement has been placed or the replacement itself has been received...there is no reason why the placing of an order or the receipt of a presumed replacement should cause the economic value of an existing vessel to vanish”. Zannetos’ argument is in line with the postulates of neoclassical economics; an agent will exit the market only when the value of remaining active is below a threshold, which implies that **exit decisions are not necessarily capital replacement decisions**. One of the main aims of this section is to test this assertion.

Zannetos goes one step further and concludes: “We are confident that data would have refuted such a hypothesis...At low rates, when most of the retirements will take place because of the expiration of the economic value of vessels, retirements may only reduce existing surpluses.” Once we have derived models for aggregate scrapping data we will formally test the above: we will namely test the statistical significance of pending orders, which is expected to be zero and of time charter rates, which should be negative. Finally, one implication of the above discussion is that **age** of the fleet has only an indirect effect on scrapping dynamics. In periods of low rates older vessels are more likely to be scrapped, since they have a lower economic value,

due to higher operating costs. In periods of high rates, age is not expected to have a significant effect on scrapped tonnage. Since the age of the fleet is not directly observable, we will not be able to test formally this hypothesis, but only indirectly through the impact of pending orders.

Our main goal is to derive aggregate structural models of scrapping activity and test whether scrapping decisions are capital replacement or exit decisions. Finally we estimate models for aggregate scrapping data with agent heterogeneity under uncertainty and irreversibility and identify the relevant variables for decisions of exit. Before proceeding with the aggregation exercise and model estimation, let us discuss the data in this market.

Regarding the *data*, the main source is Marsoft, (Boston) Inc.<sup>13</sup> and it is the same source used by Dixit and Pindyck [28] in Chapter 7, p.238. Marsoft provided the *scrapping* data (the tonnage scrapped) for tanker ships. This data set is accurate and precise. The data set is in quarters from 1980 until the third quarter of 2002. This implies that we are given 91 observations for all types of tanker carrier. For this time period the data on Time Charter Rates are fully available and precise, but NOT the scrapping prices. The operating costs are fairly straightforward, once the age of each vessel is known. Since the average age of the fleet is not known, we will use as a proxy for the operating expenses the same variables we used in the previous section.

One main characteristic that clearly differentiates the scrapping observations from the newbuilding observations is that the data set appears to have **threshold-type** characteristics, due to the interactions and adverse effects of the three different forces that drive scrapping decisions. After the **26th** observation the dynamics of the process appear to change and the intuition behind this pattern is very clear. For the first 26 observations time charter rates are at historically low levels and economic returns are significantly low (the market is in a recession; later on we shall make this selection argument more formal and give a quantitative justification in Appendix D). Low returns indicate that it is more profitable to exit than to remain in the market and therefore the “exit” effect dominates the scrapping data. Once returns become significant the pattern of scrapped tonnage dynamics changes significantly; the “exit effect” becomes less predominant compared to the capital replacement effect, as well as natural depreciation. However, both series

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<sup>13</sup>I thank Dr. Arie Sterling, President of Marsoft, and Kevin Hazel for providing the data.

Figure2: Tonnage Scrapped 1980-2002(q)

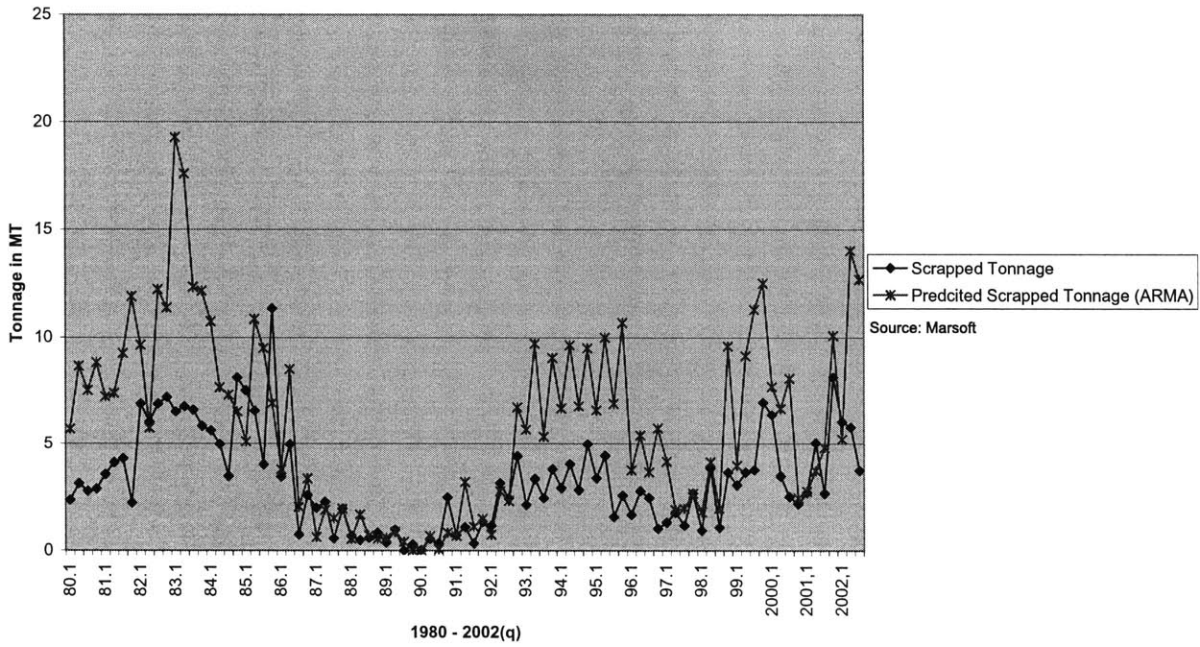


Figure 2: Tonnage Scrapped 1980-2002(q)

have a **natural scrapping trend** clearly interrelated to the obsolescence of the fleet. In the **bear-market regime** the trend is higher and decisions due to the exit effect exhibit higher volatility, whereas in the **bull-market regime** the trend is lower and exit decisions are less volatile, or outbalanced by capital replacement decisions. Our main task will be to develop structural models that will be sympathetic to the empirical facts demonstrated by the data.

## 4.2 Model IV: A Model of Heterogenous Agents

We now proceed with the presentation of aggregate models for **exit decisions** or **scrapping decisions** in the tanker industry. Staying in line with our previous analysis we assume perfect competition, which implies that the number of exits has no impact on profitability and the exogenous time charter rate is explicitly determined by the charter and lay-up decisions agents undertake. Our analysis is similar to Module 1; however, one important complication is that scrapping data and prices do not exist for each category and therefore we are forced to work with aggregate data across categories. The limitations imposed by the data will not allow us to perform an empirical test on the Real Option markup hypothesis; however based on the proposed aggregate models we shall address issues of economic behavior with homogenous and heterogenous agents. Besides proposing alternative structural models of exit, based on the “Bottom-Up” approach, we will test the relevance of “q-type” explanatory variables on decisions of exit and the Zannetos’ assertion.

In order to remain consistent to our previous analysis we shall work within the same framework. The number of scrapped vessels in each category is assumed to follow a Poisson process and consequently the sum across all categories is the sum of Poisson processes and follows a Poisson process, too (Appendix B). We shall now derive the dynamics of the aggregate scrapped tonnage and then we shall discuss the structural specification of the intensity of the Poisson process, which depends on the level of market completeness we adopt, the expectations of agents and the law of motion for the population of agents. For the five different categories we use the following Poisson specification, namely:

$$D_{scr}(t, t + T) = \sum_{j=1}^5 D_{j,(t,t+T)} \sim P(\lambda_t)$$



In the above specification  $D_{scr}(t, t + T)$  denotes the number of vessels scrapped for all categories between  $t$  and  $t + T$  and  $\lambda_t$  denotes the intensity of the Poisson process (22).

We now proceed with the structural framework that determines the intensity of the process. In both models we shall assume complete markets that span the Real Option threshold value of exit. The main drawback in this specification is that we do not have quoted prices for scrapped vessels. This implies that we cannot derive the Real Option value, neither use the scrapping price in the explanatory variables. Instead, we are forced to use instruments for the scrapping price, whose validity we cannot test, since scrapping prices are unavailable. This complication reduces the structure of the specification; however, we shall provide additional motivation for the count data models we introduced in the first module.

Staying in line with the partial equilibrium model we developed for the characterization of entry decisions, we assume  $n$  agents, whose probability of exiting or staying in the market is fully determined by the structural error, the value of staying in the market under a charter rate ( $V_{stay}$ ) and the value of scrapping the vessel ( $V_{exit}$ ) and foregoing the revenues from the spot market and the option to wait. This probability of remaining in the market, under the assumption of type I structural errors, is given by:

$$\pi_{stay} = \frac{\exp(V_{stay})}{\exp(V_{exit}) + \exp(V_{stay})} \quad (36)$$

We now proceed with the following aggregation scheme that will provide us with additional motivation for the count data models with *homogenous* intensity. Let us now consider a somehow different approach with heterogeneous agents, that under the assumption of complete markets, will result to the same multiplicative specification of the intensity in the number of agents. We assume  $n$  heterogeneous agents with **exponential utility** and we suppress the index  $j$  hereafter. We assume that each agent has a value  $V^{eq}$  for which he is willing to sell his vessel in the second hand market. The utility from this value is then equal to the expected utility from remaining in the market and operating the vessel:

$$-\exp(-V_{eq}) = EU(V) = \pi_{exit}U(V_{exit}) + \pi_{stay}U(V_{stay}) \Rightarrow \quad (37)$$

Furthermore, we assume that the number of vessels each agent scraps follows a Poisson process with intensity  $\lambda$  and the **probability of no exit**,

which equals the probability of staying in the market for each agent, is given by:

$$\pi_{stay} = \exp(-\lambda) \quad (38)$$

$$\exp(-V_{eq}) = \frac{\exp(V_{exit})}{\exp(V_{exit}) + \exp(V_{stay})} \cdot \exp(-V_{exit}) + \frac{\exp(V_{stay})}{\exp(V_{exit}) + \exp(V_{stay})} \cdot \exp(-V_{stay}) \Rightarrow \quad (39)$$

$$\exp(-V_{eq}) = 2 \cdot \exp(-\lambda) \cdot \exp(-V_{stay}) \Rightarrow$$

$$\lambda = \ln 2 + V_{eq} - V_{stay} \quad (42)$$

The intensity of the scrapping process is equal to the difference between the price of the vessel and the value of operating the vessel under a long term contract, whilst foregoing the option to scrap<sup>14</sup>. Since there exist organized markets for the second hand price of vessels, we assume that  $V_{eq}$  is the price of the vessel in the market and it is the same for all agents. Furthermore, the value from staying in the market under a long term contract and foregoing the option to scrap is fully determined by the long term contracts. Under the exponential specification and these mild assumptions on market completeness, we obtain the same specification for the aggregate intensity; namely the conditional mean is **multiplicative** in the number of agents without imposing the homogenous probability Bernoulli assumption.

The key conclusion of this simple model of heterogenous agents is that under the existence of organized markets and convergence of beliefs, **investor heterogeneity** does not have a significant impact and the intensity remains multiplicative in the number of agents. In this section we stay in line with our previous module of entry and assume that agents considering scrapping decisions, arrive with a Poisson process  $P(\lambda_n)$ . In the next section we shall demonstrate that unlike investor heterogeneity, the evolution of the population of the number of agents  $n$  is crucial to the specification of this model.

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<sup>14</sup>The intensity determined by an agent with an exponential utility coincides with the intensity we derive in Appendix D by using a first order approximation. The exponential utility assumption is replaced by convergence of expectations.

Before proceeding with the estimation of our count data models, let us discuss the motivation behind the choice of the exogenous variables in the specification of the intensity. The tanker sector has always been considered as a paradigm for perfect competition with three main incentives to exit the tanker market: The first and most important is the pure exit decision, where the value of exiting the market exceeds the value of staying and operating, as well as the option to wait. The second reason is capital replacement, whereas the third reason, which is clearly interrelated to the “demographics” of the fleet, is physical depreciation and technical obsolescence. The impact of these three different forces on the dynamics of scrapped tonnage will not be uniquely determined.

We now proceed with the estimation of the model, with  $Y_t$  the aggregate number of vessels scrapped at period  $t$  and  $X_t$  the set of the exogenous variables. We estimate the Poisson specification by Maximum Likelihood, namely:

$$Y_t \sim P(\lambda_t \cdot \lambda_n), \lambda_t \cdot \lambda_n = \exp(X_t' \cdot \beta) \quad (43)$$

The Poisson specification implies that the conditional mean (which is  $E[Y_t|X_t] = \exp(X_t' \cdot \beta)$ ) is equal to the conditional variance, which is a restrictive assumption. We therefore estimate the model with Non-Linear Least Squares, namely:

$$Y_t = \exp(X_t' \cdot \beta) + \epsilon_t, \epsilon_t \sim N(0, \sigma^2) \quad (44)$$

We now perform the estimation of the the model, which is a Poisson model with the standard exponential specification for the intensity and we include the following exogenous variables for  $X_t$ :

- *tci* and *opi* (deadweight weighted indices of the time charter rate and operating expenses for each category) from the reduced form of  $V_{stay}$
- the existing tonnage *fleet*, as a proxy for the rate of physical depreciation
- *new* the pending tonnage on order, as proxy for capital replacement decisions
- *scrk* lags of the dependent variable *scr*

**Table XIVa: Model IV**

Model	PQMLE Eq.(43)	NLLS Eq.(44)
scr1	.0204 (.030)	.0090 (.0407)
scr2	.1069 (.025)	.0770 (.0239)
tci	-.0000214 (.0000126)	-.0000268 (.0000149)
opi	.0002094 (.0001052)	.0001714 (.0001123)
crt	.00815 (.00457)	.00674 (.00397)
new	-.0488 (.0320)	-.0552 (.0396)
fleet	.000942 (.0063)	-.000899 (.0080)
oil	.00837 (.0152)	.01248 (.0193)
spoil	-.00596 (.0043)	-.00649 (.0046)
air	.00168 (.0014)	.00162 (.0018)
time	-.00396 (.0114)	-.00237 (.0137)
cons	-.4063 (1.527)	.5927 (1.992)

- *oil*, *spoil* as instruments for the unobserved **market price** of scrap and an index for air transportation *air*, for the same reasons we explained in Paragraph 3.8. Finally we include a *time* trend.

We shall now include one more “q-type” variable which will turn out to be a proxy for the prices of second hand vessels, especially in Chapter 6. According to the *Marshallian* rule of investment[28], under certainty the ratio  $\frac{tcrate-opex}{new}$  is the yield of the investment and investment should only be undertaken, if this yield exceeds the risk free rate. The inverse of this yield is a proxy for the time needed to recover capital and it is similar to the *P/E* ratio used in finance. This ratio will be named capital replacement ratio (*crt* hereafter) and will be included in the set of regressors. We now proceed with estimating (43, 44) and display the results in *Table XIVa-b*.

The Likelihood of the Quasi Maximum Likelihood Estimate has a value of  $L_{PQMLE} = -145.9$  and a Pseudo -  $R^2 = 0.2495$ , which is particularly low, whereas the Wald statistic for the joint statistical significance of the coefficients is 221.04 and accepts the specification with probability one. For the Non - Linear Least Squares model the Log Pseudo - Likelihood is  $L_{NLLS} = -157.1$  and the Pearson statistic is 2.31, which is relatively close to one. Before analyzing and discussing the results we perform additional specification tests. We perform a Hausman [35] test between the two models and the test has a  $\chi^2(9) = 0.44$ , which implies we should not reject the model.

**Table XIVb: Model IV**

Model	PQMLE Eq.(43)	NLLS Eq.(44)
scr1	-.0277 (.2151)	.0747 (.2669)
scr2	.3939 (.1534)	.344 (.2771)
ures1	.0272 (.2348)	-.0952 (.2910)
ures2	-.3215 (.1611)	-.3018 (.3042)
tci	-.0000218 (.0000116)	-.0000184 (.0000152)
opi	.0002208 (.0001132)	.0002096 (.0001132)
crt	.00564 (.00454)	.00530 (.00403)
new	-.0536 (.0359)	-.0675 (.0530)
fleet	.00259 (.0055)	-.00051 (.0073)
oil	.00234 (.0140)	.0086 (.0172)
spoil	-.00841 (.0050)	-.00998 (.0058)
air	.00142 (.0014)	.00162 (.0017)
time	-.00384 (.0110)	-.00578 (.0129)
cons	-.6741 (1.329)	.4333 (1.684)

However, by inspecting the residuals, the model clearly fails to fit the data and it systematically underpredicts the scrapped tonnage, especially for the first 26 observations, where tonnage activity is really high. What is even more puzzling is that the model predicts the correct sign of the innovations  $scr_t - scr_{t-1}$  for 24 out of the 26 first observations, whereas it clearly fails to predict the scrapped tonnage. For the subsequent observations, the model does much better in predicting the scrapped tonnage, but clearly fails to assign the correct sign to the predicted innovations.

In our previous results we included two lagged endogenous variables in the regressors, which under autocorrelated errors will lead to inconsistency. To account for this source of endogeneity we include the two lags of the estimated residuals in the regressors and repeat the estimation of Eq.(43) and Eq.(44). Results are displayed in *Table XIVb*.

Only in the Poisson Quasi Maximum Likelihood estimation the second lag of the residual appears statistically significant; however we perform a Hausman [35] test and the test has a  $\chi^2(9) = 0.44$ , which still implies we should not reject the model. Although the model is incapable of fitting the data, all coefficients have the right sign; it fails to account for the volatility displayed by the data, especially for the first 26 observations. In order

**Table XV: Model IV**

Model	NBQMLE	OLS
scr1	.0204 (.0301)	-.0111 (.1116)
scr2	.1070 (.0252)	.3556 (.0925)
tci	-.0000214 (.0000126)	-.0000731 (.0000386)
opi	.000210 (.000105)	.0003771 (.000358)
crt	.0082 (.0046)	.0546 (.0215)
new	-.0488 (.0320)	-.1039 (.0665)
fleet	.00094 (.00623)	.0002 (.0239)
oil	.0084 (.0152)	.0296 (.0467)
spoil	-.0060 (.0043)	-.0156 (.0109)
air	.0018 (.0014)	.0048 (.0050)
time	-.0040 (.0114)	.0116 (.0437)
cons	-.4063 (1.527)	-.4864 (5.629)
R <sup>2</sup>	.2145	.6660

to allow for overdispersion of the data we estimate the Negative Binomial Model that does not impose equality between the conditional mean and the conditional variance<sup>15</sup>, as well as Ordinary Least Squares.

Although the Negative Binomial model does not improve our results significantly, what seems encouraging for the exponential specification is the fact that all regressors have the right sign, in line with Investment Theory: The *tcrate* has a negative effect on exit decisions (low rates result in higher exit rates), *opex* has a strong positive effect, implying that operating costs are far more significant for the exit decision than income, *crt* has a positive effect, since higher capital replacement periods make the industry less attractive and finally pending orders *new* have a negative impact, which implies that exit decisions in this industry are not due to capital replacement. Finally, the constant appears statistically insignificant for all specifications.

Having completed specification and estimation let us now discuss our results. Although the count data models survive the various specification test, we are still facing two significant drawbacks: On the one hand the models seem unable to predict the large exit decisions, especially in the periods of low rates. On the other hand, one structural implication of the above speci-

<sup>15</sup>In the Negative Binomial specification, the conditional variance is equal to the conditional mean times a factor greater than one.

cation is that the coefficients of  $tci$  and  $opi$  have to be equal, which is clearly violated by the results presented in *Table XIV*. We shall now try to relax some of the assumptions of our model, in order to induce more volatility and avoid the restrictive assumptions on the process of agents.

### 4.3 Model V: Equilibrium Models of Exit

In this section we assume heterogenous agents with a different distribution for the evolution of the number of agents  $n$ .

We remain now in line with our previous analysis; namely heterogenous agents who scrap their vessels according to a Poisson process. We adopt one simplification and assume that the difference between the second hand value of the vessel and the value of staying in the market and fixing it under a long term contract (this difference is equal to the option to wait) is constant and does not vary with time. This implies that the aggregate Poisson (22) intensity is constant and will be denoted  $\hat{\lambda}$  hereafter. We go one step further and assume the following reduced form specification for the **endogenous evolution** of agents in this industry:

$$dN_t = N_t \cdot \mu_N(N_t)dt + N_t \cdot \sigma_N(N_t)dW^t \quad (45)$$

And in a simpler form, the above population equation admits the factor representation:

$$N_t = \frac{1}{\lambda} \exp(C \cdot X_t) \quad (46)$$

where  $X_t$  is the state vector of all exogenous variables and summarizes all the uncertainty regarding the dynamics of the population. We assume that  $X_t$  evolves according to the following Stochastic Differential Equation:

$$dX_t = \mu_X(X) \cdot dt + \sigma_X(X) \cdot dW^t \quad (47)$$

Then we can express the terms  $\mu_N(), \sigma_N()$  in terms of  $\mu_X$  and  $\sigma_X$  simply by applying Ito's Lemma [28]. Our heterogenous agents model can now be written in compact form:

$$E[Y_t|N_t] = \exp(C \cdot X_t) \quad (48)$$

with  $X_t$  the Markov process that summarizes all the factors that determine the evolution of agents:

$$dX_t = \mu_X(X) \cdot dt + \sigma_X(X) \cdot dW^t \quad (49)$$

We consider estimation of the model:

$$Y_t = \exp(C \cdot X_t) \quad (50)$$



where  $X_t$  is an Ito process that admits a discrete time Markov process approximation:

$$X_t = A \cdot X_{t-1} + B \cdot v_t, v_t \sim N(0, \sigma^2) \quad (51)$$

At this point we should note that Dixit and Pindyck ([28], p.268) derive this specification in a general equilibrium framework. They assume that the state variable  $X_t$  is firm specific uncertainty and any one firm's inverse demand curve becomes  $P = XD(Q)$ . They then construct a two-stage general equilibrium model with  $Q$  active firms,  $N$  new entrants and an exogenous exit rate  $\lambda$ . In equilibrium the exit flow of firms is multiplicative in  $N$  ([28], p.276):

$$\lambda \cdot Q = NF(x^*) \quad (52)$$

$x^*$  depends on the statistics of uncertainty and both  $x^*$  and  $Q$  are determined in equilibrium by the activation condition and the free entry condition. Then the number of new entrants  $N$  is determined in equilibrium by the last equation. If we assume that instead of  $\lambda$ ,  $N$  is exogenous, then the Dixit and Pindyck general equilibrium model is equivalent to the multi-factor Markov model introduced in this section, at least from an estimation point of view. In our equilibrium model of heterogenous agents and in the Dixit and Pindyck model of firm heterogeneity the exit rate is multiplicative in the number of agents  $N$ . If the number of agents  $N$  follows a Markovian process (as implied by the equilibrium) then taking the logarithm of  $Y_t$ , ( $Y_t = \lambda \cdot Q$ ) the above specification implies that there is a unique Autoregressive Moving Average Process of order  $p, q$ <sup>16</sup>(ARMA(p,q)) specification for the dependent variable  $y_t = \ln(Y_t)$ . A rigorous proof of this result is given by Tong [59]. Having specified the ARMA process we can then solve for the parameters of the state variable  $X_t$  and the parameters of the population dynamics, consequently. The dimension of the ARMA process depends on the number of factors that determine the evolution of  $N$ ; namely the exogenous factors in  $V_{stay}, V_{exit}$ . In our analysis, we shall assume four explanatory variables, namely the time charter rate, the operating costs, existing fleet and the capital recovery rate. Although the ARMA process could had been well specified beforehand (due to Wold's Theorem [59]) this structural derivation provides a hintful insight

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$$y_t = \sum_{j=1}^p arLj \cdot y_{t-j} + X'_t \cdot \beta + \sum_{k=0}^q maLk \cdot \epsilon_{t-k}, \epsilon_t \sim N(0, \sigma^2) \quad (53)$$

**Table XVI ARMA(2,4) Eq.(53) Regression**

lnscrap	Coef.	Std.Err.	z	p-0
tci	-.0000327	.0000104	-3.16	0.002
opi	.0002185	.0001097	1.99	0.046
crt	.0093303	.0096151	0.97	0.332
fleet	.0046969	.006889	0.68	0.495
cst	-1.556678	2.856471	-0.54	0.586
arL1	-.0818781	.0874084	-0.94	0.349
arL2	.8449426	.0844727	10.00	0.000
maL1	.3953347	.0959368	4.12	0.000
maL2	-.1644294	.1216234	-1.35	0.176
maL3	-.0225011	.1015424	-0.22	0.825
maL4	-.1701627	.1197236	-1.42	0.155
sigma	.6212577	.1393909	4.46	0.000

into the structural interpretation of the parameters as well as to where the volatility stems from and has an equilibrium interpretation in this setting.

After estimating several parametrizations we conclude to the specification of an  $ARMA(p = 2, q = 4)$  (53) with *tci*, *crt*, *opi* and *fleet* included in the regressors  $X'_t$ . Under the  $ARMA(4, 4)$  specification, due to the representation theorem, all the exogenous variables should appear statistically insignificant, which is the case indeed. However, we choose to include them in the regressors and include a smaller number of lags than population factors, since this allows us to control for their impact on the scrapping process and test their significance. Results of the estimation of (53) are displayed in *Table XVI*.

The Log pseudo-likelihood is  $L = -86.51$  and the cumulative periodogram white-noise test for the residuals has a Bartlett statistic  $B = 0.4732$  and does not reject for the 0.05 confidence level. The above specification is efficient, if the selection of the MA terms is correct, but inconsistent if the number of MA terms is different than  $q = 4$ , or if the errors are non-linear. To account for a misspecification of the distribution of errors we proceed by estimating the model with the Double Two Stage Least Absolute Deviations Estimator (D2SLAD) as proposed in the seminal paper of Amemiya [4]. We use as instruments for the estimation the fifth and sixth lag of the dependent variable *lnscrap* and the results are displayed in *Table XVII*. The coefficients

**Table XVII D2SLAD AR(2) Estimation [4]**

Inscrap	Coef.	Std.Err.	z	p-0
q1	-.731826	.293291	-2.50	0.015
q2	1.184666	.2439871	4.86	0.000
tci	-.0000364	.0000205	-1.77	0.080
opi	.00023	.0000809	2.84	0.006
crt	.0120658	.0132641	0.91	0.366
fleet	.0058475	.0060778	0.96	0.339
cst	-2.253896	1.452131	-1.55	0.125
Pseudo R2	0.4004			

of the exogenous variables appear to be in line with the ARMA estimation and the Hausman specification test [36] is  $\chi^2(4) = 0.03$  which strongly suggests we should not reject the null; namely the ARMA(2,4) specification. Finally, from a theoretical point of view it seems particularly interesting to examine the performance of the D2SLAD estimator for ARMA processes as well as the optimal IV moment conditions for this estimator. In this setting the Hausman specification test can provide us with a powerful tool for the selection of the model.

Before concluding we estimate the model by using the classical Two Stage Least Squares (2SLS)<sup>17</sup> estimator ([37]) with the fifth and sixth lag of the dependent variable as instruments for the first and second lag. Results are displayed in *Table XVIII* (where *Lag1* and *Lag2* refer to the first two lags of the dependent variable) and all coefficients are in line with the previous estimates.

In line with our previous argument, 2SLS is consistent, as long as the error term is uncorrelated with the instruments, namely the fifth and sixth lag, but inefficient if the model is indeed ARMA(2,4). This leaves space for a Hausman specification test that yields a value  $\chi^2(4) = 2.35$  and slightly rejects the null. Overall, different estimation methods are supportive to the ARMA(2,4) specification. The ARMA(2,4) results suggest that the particular combination of lags is not a cause of endogeneity. We therefore perform

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<sup>17</sup>

$$\beta_{2SLS} = (X'Z(Z'Z)^{-1}Z'X)^{-1}(X'Z(Z'Z)^{-1}Z'y)$$

**Table XVIII IV 2SLS AR(2) Estimation**

Inscrap	Coef.	Std.Err.	z	p-0
Lag1	-.152339	.329644	-0.46	0.645
Lag2	.8784917	.2319875	3.79	0.000
tci	-.000023	.0000106	-2.17	0.033
opi	.0001688	.0000859	1.97	0.053
crt	.0073308	.0114263	0.64	0.523
fleet	.0052652	.0041309	1.27	0.206
cst	-2.139099	1.154969	-1.85	0.068
R2=	.6244	Root MSE=	.72939	F(6,78)=15.21

Ordinary Least Squares estimation of the model and perform a Hausman test with the Instrumental Variable 2SLS ([37]) estimator and the test is  $\chi^2(2) = 2.36$  which slightly rejects the exogeneity hypothesis. Finally for the OLS estimation the  $R^2=0.6819$  and the Mean Squared Error is *Root MSE=0.656*.

Having completed the specification and estimation of our model of scrapped tonnage let us discuss the results. All coefficients of the exogenous variables  $X'_t$  are in line with economic theory. The level of time charter rates has a negative effect on scrapping decisions, since higher rates provide less motivation for scrapping a vessel, whereas operating expenses have an adverse positive effect on scrapping decisions. Finally the total fleet appears to have no impact on scrapping dynamics.

## 4.4 Conclusions

In this section we have proposed structural models for the exit (scrapping) data in the tanker market industry. Besides providing a good fit to the data we have proposed models that are supportive to the following:

1) Under the existence of an organized market for the asset and convergence of the expectations of heterogeneous agents, heterogeneity has found to have no direct impact on the specification of the model. On the other hand, the evolution of the number of agents, considering scrapping decisions, has turned out to be critical for the specification of the model.

2) Operating costs appear statistically more significant than operating revenues for the exit decision. Furthermore, existing tonnage and pending orders appear to have no significant effect on the scrapping process, which implies that exit decisions in this industry are mainly not due to capital replacement. This contradicts the earlier hypothesis of Koopmans and to the knowledge of the author this is the first study that provides supportive empirical evidence to the Zannetos assertion, discussed in the introduction.

3) Models with less structure than partial equilibrium models (like the one derived in Dixit and Pindyck, Chapter 8 [28]) appear to have more explanatory power. Simple Markov factor models seem more flexible and sympathetic to exit dynamics, in this industry at least. However, all the proposed models have a Markovian representation and correspond to the existence of an equilibrium. This will be particularly useful in the next section, where these models will be employed in order to determine the transportation supply function.

Concluding this section and having identified the underlying forces behind exit and entry dynamics we may now proceed with our ultimate goal, namely the identification and estimation of time charter rate models. In summary we may verify one more of the assertions of Zannetos [64] in his classical monograph: “Retirements of vessels are negatively correlated with rates and for this reason are equilibrating. To the extent that they are quantitatively insignificant however, *the retirements have not caused in the past, and are not expected in the future to cause sufficient contraction in the supply schedules to restore equilibrium in a depressed market.*” Although scrapping and newbuilding dynamics are both stabilizing factors (in the contrast with newbuilding prices, as it will be demonstrated later on) they do not suffice to restore equilibrium and the task we will undertake in the following section is the estimation and specification of a Lay-Up function that on the one hand

will be consistent with Economic Theory and on the other hand will provide us with a consistent “tool” for the modelling of time charter rates.

## 5 Module 3: Structural Time Charter Rates

*“Naturally, each owner hopes that all the others will tie up their vessels first; but as soon as some major owner loses hope and starts extensive tie-ups, all the rest take this as an indication of extended depression and, paradoxically, do likewise, even though they originally started with a ‘let someone else do it’ attitude.”*, (Zannetos [64], p.144).

Having completed the estimation and specification of the mass of entry and exit with heterogenous competitive investors, we can now proceed with the most ambitious task: namely the determination of the transportation supply framework and the market clearing equilibrium time charter rate. The first study that determines a structural equilibrium rate is the 1971 model of Jack Devanney [20]. Devanney characterizes optimal marine investment decisions under uncertainty and using a representative agent, he specifies a quantitative framework for calculating equilibrium rates. Both the approaches we undertake are inherent in Devanney’s work: the first one is the Rational Expectations General Equilibrium approach and the second one is the Engineering type approach or System Dynamics approach.

Taking the Rational Equilibrium approach with infinite living firms and no entry and exit, we assume that entry and exit decisions “cancel off” and have no impact on the formation of the time charter rates (prices). Although our previous findings clearly contradict this assumption, new orders and scrapped vessels constitute only a small fraction of the existing active fleet. Therefore, by assuming they cancel off, we forego their non-linear effects on the system, in order to achieve tractability and closed form solutions. Adland [3] estimates non-Markovian specifications for the time charter process and finds supportive evidence for such models. It is likely indeed, that the non-Markovian nature in Adland’s models is due to the non-linear feedback effects of construction lags between new orders and deliveries. Furthermore, from the early literature in Maritime Economics it is well acknowledged that retirements do not cause sufficient contraction in the supply function ([64], p.126), which is clearly not the case for new vessels. Solving for a Rational Equilibrium with Lay-Up, Entry and Exit simultaneously, is very complicated and we therefore assume that scrapping and newbuilding decisions “cancel off” and propose a simple rational expectations framework with heterogenous agents and no entry or exit decisions. The model is introduced in 5.2 and corresponds to a Markov model for the innovation of prices. Specification and

estimation follows in 5.3. The Rational Equilibrium approach is self-content, since it does not rely on the previous modules and provides us with a simple Markovian model for price dynamics, with a structural economic interpretation for the parameters. Although Adland [3] finds supportive empirical evidence for non-Markovian specifications, which result from the non-linear effects on construction lags and other contraction factors, such as repairs and slowdowns, there are two significant drawbacks in his approach: First, there is no structural economic framework for these models and second they do not allow us to control for exogenous events.

The Engineering or System Dynamics approach sacrifices some of the structural assumptions and the rationality of expectations, in order to allow for a better visualization of the supply function and provide us with more tools for controlling exogenous events. In this setting we use the entry and exit equations we estimated in the previous modules for the determination of the transportation supply function. After estimating the Lay-Up function in 5.1 and 5.4 we bring supply to demand and derive the time charter rate. The system dynamics approach allows us to control for several events and provides a very intuitive framework for business applications. The main drawback is that there is a “philosophical” inconsistency: Estimation of the previous two modules has been performed on the assumption of an exogenous time charter rate (price). We are now employing these equations in order to determine the price we previously considered exogenous.

Although the second approach violates the principles of Economic Theory, one would think it is bound to provide a much better explanation to price formation, due to its complicated structure. As it will turn out the simple Markovian models that correspond to a Rational Equilibrium after all, will provide a much simpler and better fit to price dynamics. This is one more indication of the power of the ideas of Neoclassical Economic Theory and suggests why these models have been so abundant the last 25 years, enjoying far more success compared to any engineering type approach to the modelling of complex systems. Although non-Markovian models [3] or complex system dynamics models correspond to a more realistic representation of non-linear phenomena, such as construction lags and scrapping, their over-parameterization, on the one hand reduces the power of the model and on the other hand increases the propagation of errors through the system. Simple Markovian models require estimation of very few parameters and have a unique economic interpretation.

Before proceeding with the description and estimation of the models, we



have to remind the reader of two crucial facts that are applicable in the tanker market and reduce the complexity of the problem significantly. On the one hand the tanker market is perfectly competitive, where “each ship is the firm” and on the other hand, demand is derived from the demand for oil and therefore it is completely exogenous. In this Module demand is completely exogenous and once more, Marsoft was kind enough to provide the necessary data for the period 1980-2002, quarterly.

## 5.1 Lay - Up: A Feedback Mechanism

The Lay-Up process is a significant capacity adjustment mechanism that operators can employ, when exercising their option of temporary suspending operation. In periods of low economic returns, when the value from operating the vessel is less than the cost of temporary suspension and the option to wait, operators may Lay-Up some of their capacity. This gives them the option to wait before deciding to commit their vessels at low rates for a long period. The value of this option has not been recognized in the early literature. In his classical monograph Zannetos ([64], p. 148) wonders “*why do they (owners) wait months before they decide to tie-up their vessels it is difficult to understand. Many of the voyages undertaken during depressed periods barely yield over out-of-pocket minus initial tie-up cost.*” In this section we will specify a model for aggregate scrapping data. However, due to lack of data we will not be able to test the Theory or the Model; instead we will estimate an aggregate scrapping function and then employ the system dynamics approach to calibrate the scrapping for each category.

The intuition behind the model we propose is the following: the value of having vessels in Lay-Up status, stems from “the option of waiting”; in periods of low returns, each agent decides to keep some capacity in Lay-Up status with the expectation to achieve higher economic returns in subsequent periods.

We proceed with our analysis within the basic assumptions of our model: we assume that each owner decides the capacity in Lay-Up status optimally and **independently** from his other actions, whereas the time charter process is assumed **independent** and **exogenous**. We assume each agent maximizes his value function at each period and following the discussion in our previous two modules the result is the exponential specification model, using the same reasoning as in 4.2 and 4.3 with the value of exiting  $V_{exit}$  replaced by the value of waiting in Lay-Up.

Unfortunately there are no category specific data available for the tonnage in Lay-Up in each period. Since we do not need to determine the Lay-Up function for the specification of time charter rates (prices) in the general equilibrium framework (both prices and capacity will be determined **endogenously**), we only need the specification for the system dynamics approach. Therefore, we will work backwards: instead of specifying the Lay-Up function *a priori* (which is impossible, due to the lack of data) we will solve the inverse problem: namely choose the function that optimizes the perfor-

**Table XIX-XX Module 3: Lay Up Sub-Module**

lay	Coef.	Std.Err.	z	p-0
Linear (55)	R <sup>2</sup> =	0.9605	MSE=	2.6416
lay1	.3120859	.1163104	2.68	0.010
itci	1131.664	268.6553	4.21	0.000
opi	-.6154064	.3903409	-1.58	0.121
fleet	.1375468	.0449575	3.06	0.004
cons	-32.51883	12.251	-2.65	0.011
Exponential (44)	Log L=	-136.21025	Pearson=	7.788
lay1	.0082943	.0024281	3.42	0.001
itci	28.96685	4.399429	6.58	0.000
tci	-.009425	.0061836	-1.52	0.127
opi	-.1183389	.0239284	-4.95	0.000
fleet	.0051974	.0014438	3.60	0.000
cons	1.666984	.5313913	3.14	0.002
Poisson QMLE (43)	Pseudo R <sup>2</sup> =	0.6008	Log L=-136.37883	
lay1	.014042	.0049969	2.81	0.005
itci	25.80664	8.833191	2.92	0.003
tci	-.009425	.0061836	-1.52	0.127
opi	-.1124957	.0227551	-4.94	0.000
fleet	.0061776	.0016009	3.86	0.000
cons	1.062377	.5420046	1.96	0.050

mance of the system for each category. This will be our task in 5.4. We now proceed with the econometric estimation and specification of aggregate tonnage in Lay-Up and compare the exponential model with the quantitative relationship proposed by Zannetos ([64], p.155), based on his 1945-1958 data set. The data set employed in this section is from *Clarksons* and from 1980 – 2003.

Following the same lines of argument with 4.2 we estimate the following exponential specification, where  $Y_t$  is the tonnage in Lay-Up and  $X_t$  are the exogenous variables:

$$E[Y_t] = \exp(X_t' \cdot \beta) \tag{54}$$

For the estimation of (54) we use NLLS (44) and PQMLE (43). Finally, we

stay in line with the analysis by Zannetos and estimate his linear parametric form; namely:

$$Y_t = X_t' \cdot \beta + \epsilon_t, \epsilon_t \sim N(0, \sigma^2) \quad (55)$$

Results of estimating (54) and (55) are displayed in *Table XIX – XX* where we use as exogenous, explanatory variables the following  $X_t'$ :

- *lay* is the dependent variable (tonnage in Lay-Up)
- *lay1* the first lag
- *tci* and *opi* are the category weighted time charter and operating expenses indices
- *itci* is the inverse square of *tci*
- *fleet* is the total fleet

The results are in line with the basic economic principles, since the tonnage in lay-up is decreasing in time charter rates and operating expenses and increases with the size of the fleet. To verify our findings, we finally conduct a Hausman specification test [36] between the Poisson QMLE and the Exponential Mean specification and the test is  $\chi^6 = 1.60$  and does not reject the exponential mean specification. This analysis concludes this section and having verified the exponential mean suggested in our previous two modules and in the seminal monograph of Zannetos ([64], p.155), we proceed with the estimation and derivation of structural time charter rates. At this point we should remind the reader that as with the scrapping data, the lay-up function has been derived based on aggregate data and it will be part of the System Dynamics “calibration” to identify the appropriate shares of tonnage in lay-up for each specific category.

## 5.2 Rational Expectations Equilibrium: A Structural Framework for Time Charter Dynamics

The aim of this section will be to provide a structural framework for the existing diffusion-type time charter models, in the framework of a competitive general equilibrium. We remain in line with our basic assumptions, namely

the exogeneity of the time charter process with respect to entry and exit decisions.

The main task will be the derivation of the dynamics of the time charter process in a Rational General Equilibrium framework that will allow us a structural interpretation to the vast majority of statistical models employed for the statistical modelling of the time charter rates.<sup>18</sup> Let us assume  $n$  agents, where each agent maximizes the discounted sum of his profits with a discount factor  $\beta$ :

$$\max \sum_{t=1}^{\infty} \beta^{t-1} \pi_{it-1} = \max \sum_{t=1}^{\infty} p_t y_{it} - c(y_{it} - y_{it-1})^2 \quad (56)$$

Hereafter,  $\pi$  denotes profits,  $p_t$  is the time charter rate for period  $t, t+1$ ,  $y$  denotes transportation capacity employed (which may be adjusted through lay-up actions or velocity adjustments) and  $c$  is the cost of adjusting capacity. Costs of adjusting capacity depend on the choice of speed, vessel utilization ratio and the days spent at sea. They are clearly interrelated to the notion of fleet productivity that we will explicitly define and estimate later on in our analysis. However, as it will become apparent, the calculation of  $c$  is not required in this framework and we will avoid plugging in any value, by deriving a reduced parametric form for the price process. (The inverse problem of backing up  $c$  from the parameters of the price process is what economists name “solving for the competitive equilibrium”, which is irrelevant to the pursuit of our goals and is left as a very interesting topic for further research.) Finally  $Y$  stands for the **aggregate** capacity in this market, which corresponds to the active fleet multiplied with the average velocity. By assuming perfect foresight each agent solves his Dynamic Programming Problem:

$$V(y_{it}, Y_t) = \max [p_{t+1} y_{it+1} - c(y_{it+1} - y_{it})^2 + \beta \cdot V(y_{it+1}, Y_{t+1})] \quad (57)$$

and we assume the following **law of motion** for the dynamics of aggregate fleet capacity in this market:

$$Y_{t+1} = H(Y_t) \quad (58)$$

Plugging into the Dynamic Programming Problem we get:

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<sup>18</sup>This model is the same as the one discussed in [54], Chapter 6.

$$V(y_{it}, Y_t) = \max[p_{t+1}y_{it+1} - c(y_{it+1} - y_{it})^2 + \beta \cdot V(y_{it+1}, H(Y_t))] \quad (59)$$

We then make the following assumption on pricing:

$$p_t = \alpha_0 - \alpha_1 \cdot Y_t \quad (60)$$

By plugging in once more we obtain the optimal policy for agent  $i$ :

$$y_{it+1} = h(y_{it}, Y_t) \quad (61)$$

And if we assume  $n$  homogenous operators with the same discount factors, then:

$$Y_{t+1} = \sum_{i=1}^n y_{it+1} = nh(y_t, Y_t) = H(Y_t) \quad (62)$$

This implies the following structural equation for prices:

$$p_{t+1} = \alpha_0 - \alpha_1 H(\alpha_0 - \alpha_1 p_t) \quad (63)$$

What becomes apparent from this analysis, is that even in this relatively simple Rational Expectations Equilibrium model, the resulting structural time charter (price) process turns out to be very complicated and non-linear. Before proceeding with specification and estimation of the time charter process, it becomes apparent that the competitive equilibrium framework generates Markov processes, since  $p_{t+1}$  depends only on  $p_t$ . This contradicts recent empirical findings in this field of research (see Adland [3] for non-Markovian models), that one may attribute to non-linear dynamics in this industry, due to construction lags and scrapping activity. Although non-Markovian models seem more realistic, it turns out that the equilibrium models proposed in this section and estimated in 5.3, are far more powerful than complicated models that allow for feedback, as the one estimated in 5.4 and finally, they lack the structural economic framework. The main drawback of these statistical models is that they do not allow for controlling external events in the demand side and suffer from Lucas' critique: Let us assume that we use a statistical model in order to evaluate a new policy. Under the new policy agents have a different dynamic programming problem and consequently a different optimal policy which results in a different process. Therefore, using

the statistical model to evaluate the outcomes of new policies may eventually result into biased outcomes.

At this point we should stress that the tanker market industry is a unique paradigm that satisfies most of the assumptions of general equilibrium models. The ship is the firm, owners can adjust capacity instantly by Lay-Up or speed adjustment and the demand is exogenous. These facts open the road for a rational expectations equilibrium model and the associated specification of price (time charter) dynamics.

The model we propose in this section is Townsend's [60] model, which on the one hand allows for investors to make "forecasts on the forecasts" of others and on the other hand allows us a structural interpretation to the standard linear time series models for time charter rates. For an excellent survey on these models in Maritime Economics see Kavussanos. [41]

We shall now enrich the structure of our model by accounting for heterogeneous agents similar to the Townsend [60] model. The main implication of this model will be that prices (the time charter process) follow an ARMA process, which will correspond to a discrete time approximation of a diffusion process and allows a structural interpretation of the ARMA parameters of the process. However backing up the parameters of the process (or solving for the general equilibrium) is beyond the scope of this thesis and is left for further research. Solving for the structural parameters is crucial, since it allow us to perform simulations and model policy shifts.

Following Townsend [60] we assume the set of  $i = 1, I$  for the different tanker types and a continuum of firms in each market  $i$ , where each firm has a transportation supply function of the form:

$$y_t^i = f_0 k_t^i \tag{64}$$

$k_t^i$  is the capacity of the firm at time  $t$  after choosing Lay-Up or other capacity adjustments and we assume a linear "production function" that determines transportation supply in terms of tonnes times miles. Each market is confronted with an exogenous linear demand schedule, which is buffeted by persistent shocks and transitory shocks with the transitory independent across markets and the persistent component is common.

The decision problem confronting each firm is the neoclassical firm's problem, where profits are maximized over time and firms choose their optimal levels of capacity in deadweight. Shipping firms choose a sequence of contingent plans for their capacity and maximize discounted profits:

$$E_0^i \sum_{t=0}^{\infty} \beta^t [P_t^i f_0 k_t^i - \frac{f_1}{2} (k_t^i)^2 - \frac{f_2}{2} (k_{t+1}^i - k_t^i)^2] \quad (65)$$

Here  $E_0$  denotes the expectations conditioned on the information  $\Omega_t^i$ , available to each firm at time  $t$ . Firms maximize their expected profits, namely transportation supply times charter rates  $P_t$ , minus a term for “long-run” decreasing returns to scale and an adjustment cost, due to Lay-Up, slow steaming or scrapping.

A typical firm solves the Dynamic Programming and determines its optimal policy, which is a mapping from the space of information to the space of actions:

$$k_{t+1}^i = k_{t+1}^i(\Omega_t^i) \quad (66)$$

The information set includes current and passed values of capacity and prices and the specification of the structure of information and information sharing has a crucial impact on the model. The “difficulty” of solving for the optimal policy is due to the fact that agents have to make assumptions on the statistics of the price process. After making their optimal decisions and undertaking optimal actions, the generated outcome of prices has to be consistent with their assumptions. This is the notion of a Rational Expectations Equilibrium; namely expectations converge to the true underlying process and prices are endogenously determined. By skipping entry and exit decisions we are confronted with solving for an equilibrium under capacity adjustment costs. Once we include a more detailed transportation function and account for entry and exit decisions (as it will be the case in 5.4) we lose this property of the **self-consistency** of the price process, with the ultimate hope to achieve a richer framework for our model.

Although it is beyond the scope of this Thesis to discuss the definition of rational expectations equilibria and solve for the structural parameters we give an informal definition of a dynamic linear equilibrium with rational, but possibly disparate expectations, in line with the 1983 Townsend model [60].

Agents assume a linear relationship between time charter rates ( $P_t$ ) and total capacity ( $K_t$ ) for each market  $i$ :

$$P_t^i = \theta_t + \epsilon_t - b_1 f_0 K_t^i, \epsilon_t \sim N(0, \sigma^2) \quad (67)$$

and an aggregate law of motion for capacity (total fleet capacity) in each market  $i$ :



$$K_{t+1}^i = h_1 K_t^i + h_2 M_t^i \quad (68)$$

where  $\theta$  is the unobservable that generates uncertainty in demand:

$$\theta_{t+1} = \rho\theta_t + u_{t+1}, u_t \sim N(0, \sigma^2) \quad (69)$$

and  $M_t^i = E(\theta_t | \Omega_t^i)$  is the aggregate estimator of the unobservable parameter  $\theta$ , conditional on the set of available information at time  $t$ , based on which agents form their forecasts.

Assuming linear forecasting formulas for  $\theta_{t+s}$  in each market  $i$  and the firm specific laws of motion for the capital stock in each market  $i$ :

$$k_{t+1}^i = g_1 k_t^i + g_2 K_t^i + g_3 M_t^i \quad (70)$$

Townsend [60] proves that (67), (68) and (70) are a solution of (65), which implies that based on (67), (68) and (70),  $k_t$  is an optimal policy that is consistent to the laws of motion for  $K_t$ ,  $M_t$  and  $P_t$ . It must be noted here that the above definition is very sensitive to the specification of the state space of the available information set  $\Omega_t$ , with respect to which agents form their expectations. Given statistically correct forecasts determining  $M_t^i$  it turns out that the law of motion for aggregate fleet capacity is:

$$K_{t+1}^i = \gamma_1 K_t^i + \frac{f_0 \gamma_1 \beta \rho M_t^i}{f_2 (1 - \gamma_1 \beta \rho)} \quad (71)$$

At this point we have reached our goal. Combining (67) and (71) it becomes apparent that from the Markovian representation Theorem ([59]) the price process admits an ARMA (53) representation, where the parameters of the ARMA process have a structural interpretation. Regardless of the formation of forecasts and the interaction of information structures, rational expectations models have a Markovian state space representation. Following the representation Theorem (see Tong for a proof [59]) it is well established that these models have a finite ARMA representation. To account for richer structures of learning and filtering we assume that volatility admits a Markovian representation, too. As a result the entire specification of the process belongs to the GARCH family.

In this section we have provided a structural framework for the identification and specification of Markovian models for time charter processes (prices). The Tanker Industry satisfies most of the necessary assumptions of

Rational Expectations Equilibrium Models, once we are prepared to forego “feedback” effects of construction times and scrapping decisions. By proposing a general equilibrium framework we provide a structural interpretation into the estimated parameters and challenge Economic Theory with a unique industry for the implementation of rational equilibria models. The full task is left for further research in the field. We now proceed with identifying and estimating GARCH models for the time charter process, in line with the work by Kavussanos [41]. We take this work one step further by including “control variates” in the volatility specification and compare the model with the outcome of the system dynamics approach in 5.4.

### 5.3 GARCH Models for Time Charter Rates Revisited

GARCH [29] models for time charter rate modelling are not new in Maritime Economics. Kavussanos [41] was the first to introduce these models and has an excellent review in the recently published Handbook of Maritime Economics and Business [41]. Adland [3] goes one step further and estimates one factor diffusion processes for the time charter rates, using non-parametric methods. Although he claims these models seem more appropriate for time charter modelling, he does not really depart from the (G)ARCH [29] specification, since it is well known that the limit of a (G)ARCH process is a diffusion process. Furthermore, the diffusion specification does not allow control for exogenous shifts and does not have a clear economic interpretation in this setting. Adland [3] goes one step further by estimating non-Markovian models. Although these models provide a better statistical fit, they have no economic interpretation. Furthermore, Adland [3] employs these models to derive option prices in this industry, which is inconsistent, since it is well known that non-Markovian processes violate the “No-Arbitrage” principle.

The contribution of this approach is twofold. On the one hand we have proposed a structural competitive equilibrium framework for an ARMA specification of the time charter rate and on the other hand we estimate an E-GARCH specification [29], in order to compare it with the system dynamics approach that follows in 5.4. In our model we include some exogenous variables in the mean, in order to allow for controls to exogenous shifts in the transportation demand and structure patterns. Finally we estimate a full model with common coefficients for all categories and a category effect and perform specification tests to determine model choice and selection.

**Table XXIa EGARCH Eq.(72) Category Specific**

D.tcrate	200K	140K	90K
D.dmd	141.2303 (5.41)	33.32992 (1.25)	-54.07486 (-1.21)
D.oil	-43.33327 (-1.50)	28.66992 (7.42)	17.54504 (1.03)
D.air	1.898793 (0.25)	-4.968332 (-3.79)	5.867934 (5.62)
cst	436.9023 (7.99)	329.041 (3.28)	213.2873 (2.79)
arL1	-.1369706 (-1.41)	.5913442 (2.64)	-.698012 (-3.34)
arL2	.7476088 (7.01)	-.191612 (-1.09)	-.0507881 (-0.31)
maL1	-.2789064 (-2.89)	-.3290286 (-1.33)	1.299079 (7.88)
maL2	-.6873644 (-8.85)	.3033841 (2.24)	.5481894 (4.64)
hetoil	.0801924 (2.15)	.2489624 (4.85)	n.a.
hetair	.0074299 (2.22)	-.01578 (-2.65)	n.a.
hetcst	14.9645 (85.22)	5.304335 (3.25)	1.836747 (1.44)
earchL1	.2326598 (1.28)	-.6749507 (-2.92)	-.0943001 (-0.46)
earchL2	.1197455 (0.85)	1.350995 (5.12)	.3393986 (1.61)
earchaL1	-.0904995 (-0.29)	.7973006 (1.86)	.5818458 (1.69)
earchaL2	1.851378 (6.78)	.4256043 (1.07)	.7703161 (1.60)
egarchL1	.2214109 (2.05)	.1117651 (1.36)	1.002537 (3.39)
egarchL2	-.1815302 (-1.83)	.4925325 (4.91)	-.1315213 (-0.42)
Portmanteu (Q) Statistic=	25.4331	27.2467	38.5793
LogL	-833.3258	-742.62	-761.1517

**Table XXIb EGARCH Eq.(72) Category Specific**

D.tcrate	70K	30K
D.dmd	175.1661 (6.19)	30.46509 (1.31)
D.oil	-40.81963 (-7.38)	-13.90432 (-4.33)
D.air	-5.432436 (-8.43)	3.237825 (3.56)
cst	105.8723 (6.34)	70.0575 (2.04)
arL1	.2650564 (2.47)	.2743948 (2.68)
arL2	.0348373 (0.38)	-.4471913 (-5.05)
maL1	-.1749011 (-1.61)	.3277954 (4.19)
maL2	-.2299142 (-2.18)	.6126087 (13.09)
hetoil	.0149307 (0.67)	-.008494 (-0.24)
hetair	-.0165257 (-4.24)	-.0034418 (-1.42)
hetcst	14.45358 (72.42)	5.305832 (2.06)
earchL1	.2758082 (1.95)	.2195905 (0.87)
earchL2	-.1695445 (-0.76)	-.642163 (-1.76)
earchaL1	.2771507 (1.31)	-.446263 (-1.31)
earchaL2	2.456648 (9.04)	2.966821 (5.30)
egarchL1	.2486424 (3.84)	.2992776 (2.15)
egarchL2	-.3398756 (-4.88)	.2637244 (1.48)
Portmanteu (Q) Statistic=	21.0528	46.0650
LogL	-733.4231	-701.5889

**Table XXII EGARCH Eq.(72) Full System**

D.tcrate	Coef.	Std.Err.	z	p-0
D.dmd	26.68532	9.859361	2.71	0.007
D.oil	-6.114392	5.200239	-1.18	0.240
D.air	2.102692	.7528104	2.79	0.005
cat	2.381073	1.00944	2.36	0.018
cst	80.41757	103.1651	0.78	0.436
arL1	-.1741156	.2083539	-0.84	0.403
arL2	.3122444	.1346323	2.32	0.020
maL1	.5392456	.2113437	2.55	0.011
maL2	.0092492	.1159338	0.08	0.936
hetoil	-.0005653	.0069262	-0.08	0.935
hetair	-.0030327	.0006501	-4.67	0.000
hetcat	.0006398	.0001605	3.99	0.000
hetcst	.6729367	.1318034	5.11	0.000
earchL1	.198154	.0414593	4.78	0.000
earchL2	-.1886759	.0482094	-3.91	0.000
earchaL1	.6155819	.0768264	8.01	0.000
earchaL2	-.3615577	.1097607	-3.29	0.001
egarchL1	1.75096	.0650815	26.90	0.000
egarchL2	-.8019969	.0604445	-13.27	0.000
LogL	-3856.066			

The models we estimate hereafter are EGARCH<sup>19</sup> models as defined in ([29], p.10-11) where the dependent variable is the first difference (denoted D. hereafter) of the time charter rate and the set of exogenous variables  $X'_t$

<sup>19</sup>

$$y_t = \sum_{j=1}^p arLj \cdot y_{t-j} + X'_t \cdot \beta + \sum_{k=0}^q maLk \cdot \epsilon_{t-k}, \epsilon_t \sim N(0, \sigma_t^2) \quad (72)$$

and

$$\ln \sigma_t^2 = \sum_{j=1}^p earchLj \cdot \ln \sigma_{t-j}^2 + Z'_t \cdot het_{factors} + \sum_{k=0}^q egarchLk \cdot z_{t-k}, z_t \sim N(0, \sigma^2) \quad (73)$$

are the first differences of:

- *dmd* the demand for tonnage
- *oil* the price of oil
- *air* the air transportation index

In *Tables XIa-b* we estimate the above specification for each specific category, whereas in *Table XII* we estimate the Full Model and account for differences across categories, by using a deadweight dummy *cat* in the regressors  $X'_i$ . At this point we should note that unlike Chapter 3 we do not report standard errors in the parentheses, but t-statistics.

The Full System EGARCH specification implies that there is no endogeneity between the error and the endogenous lagged variables, since the first lag of the endogenous variable and the second lag of the disturbance appear statistically insignificant. In order to further test this specification we perform linear regression on the factors (demand for oil, air and tonnage demand) and the two lags of the endogenous variable and compare the results with the instrumented variables estimator, which remains consistent under the loss of exogeneity. We then perform a Hausman [36] test between the two estimators that clearly does not reject the null. This provides us further supportive evidence for our choice of the order of the model. We finally perform a Hausman test between the efficient EGARCH specification (which is inconsistent under a misspecified order of the error component) and the Fixed Effects specification (*Table XXIII*), which is  $\chi^2(4) = 2.85$  and slightly rejects the EGARCH specification. The power of the test is questionable in this setting and although it rejects the null it is indicative that the discrepancy between the two models is not totally inadmissible, from an empirical point of view.

Although the Full System EGARCH specification provides a very good fit to the data and the estimated coefficients are in line with economic theory, there is still some doubt as to the specification of the model. We therefore employ quantile regression, in order to perform a final specification test. Our results are displayed in *Table XXIV* and are not supportive of the EGARCH specification (equality of coefficients across quantiles is not rejected), but to the ARMA specification, which is a subclass of EGARCH. This empirical founding seems a contradiction, but might be attributed to finite sample

**Table XXIII EGARCH Specification Tests**

D.tcrate	Fixed Effects.	IV Fixed Effects
D.dmd	105.3288 (49.6602)	466.451 (429.961)
D.oil	-12.95621 (42.07292)	-115.0315 (214.0735)
D.air	1.449658 (4.60636)	-15.20672 (26.67828)
cst	38.38965 (168.6543)	181.9107 (771.723)
arL1	-.1583706 (.0467406)	-3.599837 (3.598272)
arL2	.1678794 (.0466096)	-2.966071 (3.103768)
R2 Within	0.0727	.
R2 Between	0.7152	0.9611
R2 Overall	0.0723	0.0060
Hausman Statistic	$\chi^2(5)$	1.03

bias or the biased estimation of the bootstrapped standard errors. However, since the EGARCH specification encompasses the ARCH class and since the diagnostic tests reject the ARCH specification in favor of EGARCH, we conclude our empirical modelling in this section and proceed with the System Dynamics approach. Having estimated the statistical model for time charter rates we proceed with an economic discussion of the results and the differences between the category specific models and the full system model. We will revert to the statistical specification in 5.7 where we will combine all models, for the first time in System Modelling, in order to evaluate the forecasting performance of mixed strategies.

The Full System specification is supportive of the fact that the market for all tankers is not the same, as first proposed by Glen and Martin in their recent chapter in the Handbook of Maritime Economics. What is particularly interesting is that the category variable is positive and statistically significant, which implies that time charter innovations are higher for larger categories. This finding indicates that returns are higher for larger categories, perhaps due to the higher level of concentration of market power in larger categories. Glen and Martin attribute the distinctness to the nature of ships as financial assets and the presence of some degree of differentiation in the market. However it seems more appropriate to view the differences in volatility and returns in different tanker sectors, due to the different levels of **market concentration** in the different sectors. Intuition suggests that mar-

**Table XXIV Quantile Regression Specification Tests**

dtr	Coef.	Std.Err.	z	p-0
Quantile	0.30	Pseudo R <sup>2</sup>	0.0354	
dtc1	.0155286	.2177214	0.07	0.943
dtc2	.1967912	.1742905	1.13	0.259
ddmd	64.79136	52.58403	1.23	0.219
doil	-9.014069	14.00159	-0.64	0.520
dair	-.2557242	4.633931	-0.06	0.956
cst	-336.2624	68.11856	-4.94	0.000
Quantile	0.50	Pseudo R <sup>2</sup>	0.0369	
dtc1	.0554697	.163911	0.34	0.735
dtc2	.1535424	.1521358	1.01	0.313
ddmd	48.54745	37.02594	1.31	0.190
doil	-25.19109	11.90087	-2.12	0.035
dair	-.8643211	3.956634	-0.22	0.827
cst	85.5907	41.37934	2.07	0.039
Quantile	0.70	Pseudo R <sup>2</sup>	0.0352	
dtc1	.0405127	.1664556	0.24	0.808
dtc2	.1421057	.1702656	0.83	0.404
ddmd	32.45365	33.82148	0.96	0.338
doil	-22.65734	11.99547	-1.89	0.060
dair	-1.020277	3.29403	-0.31	0.757
cst	484.8732	80.93843	5.99	0.000



ket concentration is an increasing function of transportation capacity, due to abundant capital requirements and wide-scale uncertainty on the outcome of the investment. Our empirical findings, namely the positive category coefficient *cat* and the positive constant *cst* in *TableXXII*, support the assertion that returns to larger categories are higher. Finally, the parameters of the specification depend crucially on the structure of operating costs across different sizes. Another potential explanation is that higher returns for larger vessels are due to **economies of scale**. It is now clear that heterogeneity across categories is due to these two different forces and it still remains unclear where heterogeneity stems from. However, the final argument made by Glen and Martin, that namely the segments of the tanker sector cannot be viewed as independent, needs to be further investigated and is not supported by the Full model.

#### 5.4 Busdyn@: The System Dynamics Approach and Implications for Structural Processes

In the previous section we discussed the strong implications imposed by general equilibria on the dynamics of the price process. We discussed the problem of **self-consistency** and presented rational expectations equilibria models, that provide us with a consistent framework for the existing time charter rate models, such as the statistical models in [41]. We went one step further and re-estimated these models, allowing for some control factors. In this section we take a different approach, by sacrificing the assumption of a general equilibrium, where the derived price process is consistent with the one rational agents assume. We maintain the assumption of independence of actions; however, all the structural framework we employed for deriving exit and entry decisions is not valid any more and requires some modification, in order to allow us the usage of the structural equations derived in the previous sections. In our exit and entry analysis we assumed an **exogenous** time charter process and derived the mass of newcomers and leavers, based on the dynamics of this process.

In this section we shall use the mass of new firms and exiting firms, as well as the lay-up dynamics, in order to determine the transportation supply function, which determines the spot price and consequently the short term time charter price once set equal to demand. From this highly nonlinear approach it is obvious that the dynamics of the time charter process will be

inconsistent with the process assumed, in order to derive entry, exit and lay-up decisions in the partial equilibria. Namely, we pay the price of losing the structural framework of our analysis with the hope to achieve more complex feedback mechanisms, as well as a more realistic description of price dynamics. This is a **system theoretic** approach that allows us some control on the input of the system, which in this case is the exogenous demand for transportation capacity. The drawback of this approach is that it is subject to Lucas' critique: rational agents in equilibrium should respond to exogenous shifts and update their supply of capacity. By using the equations of new vessels, scrapped vessels and lay-up, in order to determine the transportation supply function, we do not take into account optimal reactions of agents to external shifts.

Although the framework of classic Economic Theory is very complicated for the derivation of a Rational Expectations Equilibrium with ordering, scrapping and lay-up decisions, we can still assume that the equations we derived in our previous analysis, once coupled all together, may yield reliable and more business oriented price estimates. Furthermore, not everything is lost by the loss of our equilibrium framework: The close connection of the birth and death of firms (ships) to the **dynamics of populations**, leaves still some space open for the derivation of structural equations by using **Laws of Large Numbers** and models used in Evolutionary Biology, similar to the evolutionary models introduced in 3.10 . Finally, the partial equilibrium models with heterogenous agents resulted in an exponential specification which was statistically verified in *Module I* and *Module II*, as well as the Lay-Up specification in 5.1 and may still hold without strong implications for the time charter process.

In this section we proceed as follows: We use the equations we derived in the previous sections in order to determine the transportation supply function (with an adjustment for velocity and fleet productivity) and then use as an input to the system the historical values of demand for 1980-2002. We force the system to reach equilibrium and we calculate the equilibrium time charter rate. We then compare in a probabilistic sense this result with our results, as well as with the observed outcomes. Our main goal is to “compare” the statistical models presented and estimated in the previous section with the System Dynamics models we discuss hereafter. As it will become apparent later on, the System Dynamics approach is a relatively deterministic approach, where uncertainty has no particular role. In section 5.7 we evaluate hybrid models that combine System Dynamics with statistical mod-

els. Finally we discuss filtering techniques that can make the system more robust and incorporate the notations of **learning and updating** into the system input-output approach.

Our main goal is to avoid the derivation of a competitive equilibrium, where the **whole stochastic process** is determined endogenously as a fixed point of the system, but preserve some structure that will justify the validity of our estimation in the previous two modules. In order to avoid the search for a **fixed point** in the functional space of processes, we aim to the derivation of structural equations that depend only on the current value of the variable, which is then determined endogenously by the outcome of the system. Furthermore, we want structural equations that take into account heterogeneity and competition, without the restrictions imposed by rational expectations competitive equilibria.

Before we proceed with the specification and estimation of the system let us discuss some alternative approaches that will allow us to use the equations that were derived based on an exogenous time charter rate, to determine the rate *expost*. In order to use the equations for the mass of entry and exiting firms we have to make some small changes in our analysis. Regarding the exit decisions, we recall the assumption that in a competitive equilibrium each firm can act **myopically** ([28], p.336). We further assume that each firm acts myopically and that the premia offered by the shippers make the statistical estimation non-degenerate, by introducing the structural error. We then stick with the most efficient operator, but instead of using the Real Option formula we simply assume a reduced form for the value function of the agent, which is the outcome to the myopic solution of his dynamic programming problem. Under the prisma of this approach, we may well then use as newbuilding equation, the model we estimated in Chapter 3. If we are not satisfied with the myopic action approach we may use the evolutionary approach proposed in 3.10, which does not require the notion of an equilibrium and relies only on Laws of Large Numbers. In line with our previous discussion we use as scrapping equation the model estimated in Chapter 4.

In order to make this section as self contained as possible let us present the newbuilding and scrapping equation we will use in our system for the category of 200.000DWT. In the working paper [26] Dikos *et. al.* present the equations for all categories, which are available in the *Busdyn@Excell<sup>TM</sup>* version of the model upon request. For the period 1980-2002 we use the model derived in Chapter 4 for the scrapped tonnage in each quarter:

$$5 \cdot y_t = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \beta_1 tcrate + \beta_2 opex + \beta_3 fleet + \beta_4 new + \eta_t \quad (74)$$

Where  $y_t$  is the ln of the scrapped deadweight in each periods,  $y_{t-1}, y_{t-2}$  are the two lags and  $tcrate$  is the time charter rate,  $opex$  the annualized operating expenses,  $fleet$  the total deadweight of the fleet and  $crt$  the expected capital replacement time. The structure of the stochastic innovation is:

$$\eta_t = \gamma_0 \epsilon_t + \gamma_1 \epsilon_{t-1} + \gamma_2 \epsilon_{t-2} + \gamma_3 \epsilon_{t-3} + v_t \quad (75)$$

The coefficients are estimated with the techniques we discussed in the estimation of the scrapping module, where a structural interpretation of the estimated parameters was provided. The coefficients are reported in the *Module 2: Scrapping Flow*. We now proceed with modelling the orders in new vessels. Instead of using the results of Chapter 3, we re-estimate the model only for the category of 200.000DWT, based on the specification we derived in Chapter 3. The results are displayed in *Module 1: Newbuilding Flow*. We now combine new orders and scrapped tonnage with the existing fleet and bring the total supply function to demand; by equating both, we determine the equilibrium time charter rate. We assume no specific functions for construction lag, lay-up or velocity adjustments for the transportation supply function. Later on we shall choose the parameters for these non-linear correction mechanisms, in order to optimize the performance of the system. Due to the absence of reliable data on construction lags, lay-up and velocity adjustments, we shall take these effects into account, in a way that will allow us to increase the performance of the system. We shall use the functional forms proposed in 5.1, but determine the parameters that optimize the performance of the system, endogenously. Let us now proceed with some discussion on the system dynamics approach to the implementation of equilibrium time charter modelling.

The most important task, before proceeding with the structural determination of the time charter rate, is the precise definition of the transportation supply and demand function. In this section we shall follow very closely the notation and discussion in the classical “Maritime Economics” [58] authoritative tome by Martin Stopford. Stopford discusses a similar model for the determination of the short term time charter rate, with perfect foresight

**Table XXV Category 200K Module 1: Ordering Flow Eq.(27)**

DWT200ships	Coef.	Std.Err.	z	p-0
ship1	.0523926	.0152012	3.45	0.001
ship4	.0268763	.0149868	1.79	0.073
Vopt	.0105514	.0037807	2.79	0.005
VV	-.0000118	.0000109	-1.08	0.281
tc2	-1.65e-10	3.90e-10	-0.42	0.672
accident	-.939874	.284901	-3.30	0.001
lrate	-.1256983	.06114	-2.06	0.040
oil	.0033014	.0155313	0.21	0.832
cnst	2.115132	.5120404	4.13	0.000
alpha	.3340101	.1061391		

**Table XXVI Category 200K Module 2: Scrapping Flow Eq.(74)**

lnscrap	Coef.	Std.Err.	z	p-0
tcrate	-.0000327	.0000104	-3.16	0.002
opex	.0002185	.0001097	1.99	0.046
crt	.0093303	.0096151	0.97	0.332
fleet	.0046969	.006889	0.68	0.495
alpha0	-1.556678	2.856471	-0.54	0.586
alpha1	-.0818781	.0874084	-0.94	0.349
alpha2	.8449426	.0844727	10.00	0.000
gamma0	.3953347	.0959368	4.12	0.000
gamma1	-.1644294	.1216234	-1.35	0.176
gamma2	-.0225011	.1015424	-0.22	0.825
gamma3	-.1701627	.1197236	-1.42	0.155
sigmav	.6212577	.1393909	4.46	0.000

and no structural interpretation into submodules. However, once we have derived the exit and entry equations from first principles under uncertainty and derived the aggregate functions, the determination of the equilibrium price is in the same spirit with the model discussed in Stopford. The most crucial aspect is that demand and supply do not solely depend on the available deadweight or tonnage, but also on the average haul that goods have to be transported. A ton of oil transported from the Middle East to Western Europe via the Cape generates two or three times as much demand for sea transport as the same tonnage of oil shipped from Libya to Marseilles. This distance effect corresponds to the **average haul** which explains why sea transport demand and supply is measured in **ton-miles**. Following the definition by Stopford [58] it is “the tonnage of cargo shipped, multiplied by the average distance over which it is transported.” The effect of changes in the average haul on ship demand is dramatic and significant movements in spot and time charter prices are often due to political events that have a direct effect on the average haul. A recent example with a severe impact on the haul is the Iraq war.

On the supply side, although the fleet is fixed in terms of deadweight or tonnage, the **productivity** with which the ships are used determines the transportation supply function. Tanker productivity adds an element of flexibility to the specification of the transportation supply function, but it is impossible to measure it directly since there are no available data on productivity. Most of our efforts in identifying the system will be devoted to the specification of an appropriate productivity function. All the equations and notation in this section are presented and discussed by Stopford [58] in his “Introduction to Ship Market Modelling”. ([58], p.515) Although the equilibrium modelling of ship markets is inherent in the pioneering Zannetos monograph, to the knowledge of the author, this Thesis is the first study that derives the aggregate equations based on micro foundations and solid economic assumptions. Although the specification of the specific submodels depends crucially on the advances in Economic Theory, the key idea between the supply and demand modelling of spot and short term charter rates, remains unchanged. In the previous sections we have employed the most advanced methods for the specification and estimation of the **entry** and **exit** submodules that determine the tonnage supply function; in this section we combine all “isolated” decisions that determine the supply function and try to identify the quantitative relation with demand. The philosophy of the model is visualized in Figure 3, whereas a table of the inputs and outputs of

each sub-module and the full system is attached.

In the previous sections and in 5.1 we have discussed specification and estimation of the three sub-modules that constitute the active tonnage in each period. In this section we shall discuss the main adjusting mechanism of transportation supply in **ton-miles**; namely the notion of the **average productivity of the fleet**. In the entire Thesis demand will be considered exogenous and in this section, demand in ton-miles, is the input of the system.

Let us now proceed with the precise definition of the average productivity of fleet, which will turn out to be a key factor for the modelling of the price process. We will then devote the next two sections to the calibration of the model and the estimation of the output. Staying consistent with Stopford's notation let  $P_t$  stand for productivity at time  $t$ ,  $S_t$  the average operating speed per hour,  $LD_t$  the loaded days at sea per annum,  $DWU_t$  the deadweight utilization and  $r_t$  the time charter rate. Then:

$$P_t(r_t) = 24 \cdot S_t(r_t) \cdot LD_t(r_t) \cdot DWU_t \quad (76)$$

Then the transportation supply function becomes:

$$SS_t(r_t) = AMF_t(r_t) \cdot P_t(r_t)$$

The transportation supply function in ton-miles is denoted  $SS_t$ , the active merchant fleet  $AMF_t$ , the average haul  $AH_t$  and the tons of cargo transported in time period  $CT_t$ . The active merchant fleet is equal to the existing fleet the previous period, plus any new deliveries, minus scrapped tonnage and vessels in lay-up. Practically, leaving economics aside, the previous two sections have been devoted to the estimation of the active merchant fleet. Therefore, in the full system we shall use the equations derived in the previous two Modules, in order to determine the active merchant fleet endogenously as a function of the time charter rate. What complicates our analysis significantly is that we do not have data both on productivity, as well as on category-specific tonnage in lay-up. Finally the equilibrium time charter rate is determined in equilibrium by equating supply  $SS_t(r_t)$  with demand  $DD_t$ , where demand is measured in ton-miles and is assumed completely exogenous. Then:

$$SS_t(r_t) = DD_t \quad (78)$$

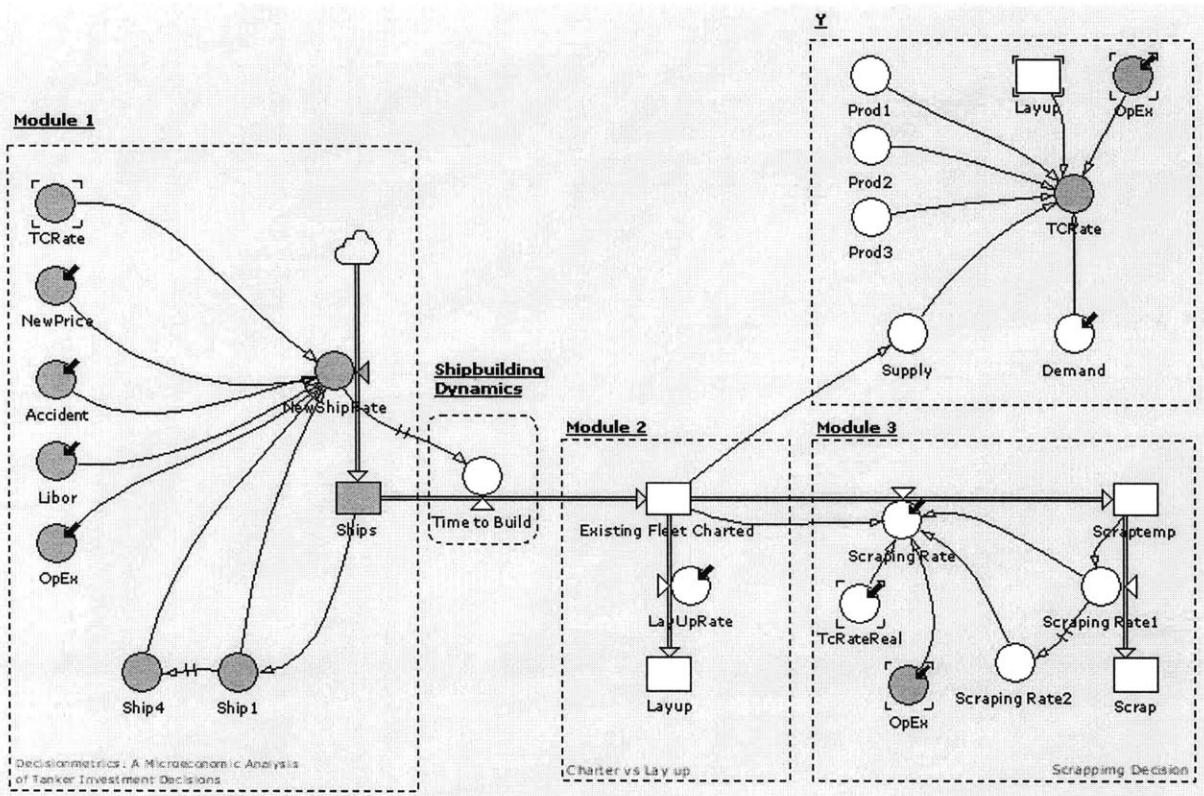


Figure 3: System Dynamics Modelling of Freight Rates



We have now two options: We can make assumptions on the **productivity and lay-up** functions and solve for the time charter rate process or we can use the time charter data and calculate the required productivity and lay-up that keeps the system in equilibrium. In the System Dynamics approach we are facing a problem of system identification. In the next section we solve the **inverse problem**. We assume that the system namely is in equilibrium and solve for the theoretical productivity and lay-up required.

Let us now proceed with estimation, specification and identification of the system. Before presenting the results we present a unified approach to the “problem” of freight rate modelling.

## 5.5 System Identification

In the previous section we introduced the System Dynamics approach to freight rate modelling and discussed the construction of the structural supply function, based on our earlier results. We then introduced the notion of average productivity of the fleet and defined precisely the associated variables.

The key problem we are dealing with, once integrating each module towards a complete system, is a problem of System Identification. Due to lack of reliable data we are unable to construct the productivity adjusting mechanism and category specific Lay-Up module *ex ante*. We are facing a typical problem of **System Identification and Specification**. Economic Theory and intuition has helped us reduce the dimensionality and complexity of the problem. Furthermore it has provided us with valuable insight into the parametric specification of the submodules. More specifically:

We suppress the time index and assume an exogenous demand

$$DD$$

in ton-miles, which has been kindly provided by Marsoft, (Boston) Inc. and the demand data in the book of Martin Stopford [58]. Then, the key equation that determines the time charter rate  $r$  is the one that relates supply

$$SS(r, x)$$

with demand ( $x$  stands for the vector of all exogenous variables hereafter, such as operating expenses *opex* and all other “system inputs” described in the previous sections and explicitly in Figure 3):

$$\Psi(SS(r, x), DD) = 0 \quad (79)$$

Furthermore, supply is determined by the active merchant fleet (tonnes) times the average productivity of the fleet, as defined in the previous section:

$$SS(r, x) = AMF(r, x) \cdot P(r, x) \quad (80)$$

And finally, the innovation of  $AMF$  each period is determined by the new deliveries  $N(r, x)$ , the scrapped levels  $Sc(r, x)$  and the tonnage in lay-up  $Lay(r, x)$  :

$$AMF_{t+1}(r, x) = AMF_t(r, x) + N(r, x) - Sc(r, x) - Lay(r, x) \quad (81)$$

We are facing a non linear problem with three unknowns and three equations. What complicates the problem is that our unknowns are **functions**, namely: the fraction of the lay-up function  $Lay(r, x)$  for each category<sup>20</sup>, the productivity  $P(r, x)$  and the functional relation  $\Psi$  between supply and demand. As it will turn out the complexity of the system will depend on the dimensionality of the  $\Psi$  function, whose order will determine the degrees of freedom of the system.

Following our usual strategy we will start our analysis by employing intuition and economic theory, in order to reduce the dimensionality of the system. We will start with the lowest possible dimension, which in our case corresponds to the simplest functional relationships.

Regarding the  $\Psi$  function that determines the relationship between supply and demand, we choose the simplest form, which stems from the neoclassical assumption that requires markets to clear and “demands” that supply is equal to demand. This specification contradicts the discussion in the seminal monograph by Zannetos ([64], Chapter 8), where Zannetos speculates that the price (spot and time charter) generating mechanism is far more complicated than equality, due to the “Cobweb” Theorem and the elasticity of expectations. At this point the reader may question the ability of the system to generate such volatile price outputs (hereafter price stands for the spot and time charter rate), since the input of the system (demand) is far less

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<sup>20</sup>Although in 5.1 we derived the Lay-Up function for aggregate data the task of deriving the fraction for each category lies still ahead

volatile and relatively stable. As it will turn out, market clearing modelling of prices will be sufficient for the specification of the system.

We now proceed with our second unknown, namely the lay-up function. Using the principle of similarity we will assume that the parametric form of the lay-up function is the same across categories. The optimal fraction of lay-up assigned to each category is chosen by employing simulation techniques. The algorithm we use in order to calibrate the system will be thoroughly discussed, once we have addressed the final and most crucial unknown, which is the average productivity of the fleet.

The final and most crucial unknown is the function of productivity. Stopford ([58], Appendix 1) derives average fleet productivity based on the previous assumption of market clearing (supply equals demand). There are two significant problems with the numbers presented by Stopford: on the one hand these numbers are annual, which does not leave them enough space to account for the volatility observed in each quarter, and on the other hand they are averaged across categories. However, Stopford's data are not entirely meaningless: we will use them to determine the parametric form between productivity and prices and then choose the parameters that optimize system performance for each specific category, by simulation.

Having discussed the assumptions and shortcuts we undertake let us now present the “calibration” algorithm. First of all, we consider hereafter three different categories, mainly due to data limitations: The first one is  $10 - 60K$  DWT, the second  $70 - 140K$  and the last one is  $200 + K$  DWT. Based on our previous discussion the average merchant fleet is determined by the recursive state equation:

$$AMF_{t+1,j}(r, x) = AMF_{t,j}(r, x) + N_j(r, x) - Sc_j(r, x) - Lay(r, x; \beta_j) \quad (82)$$

The newbuildings  $N_j(r, x)$  are given by the function determined in Chapter 3 (Module 1), the scrapped tonnage  $Sc_j(r, x)$  by the equation derived in Chapter 4 (Module 2) and the tonnage in lay-up status by the parametric specification derived in Paragraph 5.1, which is known up to the parameter  $\beta_j$ , where  $j$  stands for the three different categories. Furthermore, the productivity function is determined parametrically from the Stopford productivity data set, up to some unknown parameter  $\theta_j$ . Since the productivity function is the main “device” that adds the necessary volatility to the price generating mechanism, estimation and specification of will be discussed thoroughly in

the next section. Finally, the estimated  $\hat{r}$  rate is determined in equilibrium by solving the equation:

$$AMF_{t,j}(\hat{r}, x) \cdot P(\hat{r}, x, \theta_j) = DD_t \quad (83)$$

In order to choose the parameters  $\beta_j, \theta_j$  optimally for each category and calibrate the system (within the sample) we use as input the real prices observed in our data set and choose the parameters that minimize the mean squared error between supply and demand. Since it is very difficult to solve the non-linear optimization problem we employ simulation methods to estimate the unknown parameters. The simulation methods and the associated calibration of the model are part of the *Powersim<sup>TM</sup>* and *Excell<sup>TM</sup>* version of the System Dynamics time charter model, which is available upon request. The calibration process is essential but not particularly interesting. What remains a little bit subtle, though has the highest impact on the outcome of the model, is the specification of the parametric form of average productivity. The next section will be devoted to the derivation of the parametric form of the average productivity and the presentation of the outcome of the calibrated system.

## 5.6 Performance Evaluation across Categories

Having specified the three sub-modules that determine the active merchant fleet we may observe that this variable is far less volatile than the observed spot and time charter rates. Since we have based all our previous analysis on short term time charter rates, we will remain consistent hereafter and derive all our results on the basis of short term (six months to one year) time charter rates. These rates do not differ significantly from the time charter rate equivalent of spot rates. Preliminary research and the calibration process have been supportive to expressing our forecasts in terms of short term time charter rates, which have a very high co-movement and almost perfect correlation with the spot time charter rate equivalent.

Demand, which is exogenous and the main “driving force” of the system, is far less volatile, too and relatively stable. This observation implies that **in a market clearing model, average productivity of fleet is the only mechanism that can generate the volatility observed in prices.** On the other hand this observation leads us to the logical consequence that **productivity has to be a function of the price**, if there is any value in

attempting to model the price process as the outcome of the interaction of supply and demand. If productivity is exogenous, then any set of prices may well satisfy the “request” that markets are in equilibrium, since for every  $r$  there will be a  $P$  that satisfies Eq.(79) for any  $\Psi$ ; if it is to make the system non-degenerate, then productivity has to be a function of time charter rates and potentially of other variables, too.

In our market clearing specification the most important unknown is the average fleet productivity function. In order to identify the parametric form of the function and optimize accordingly we will use the following strategy, which is the one introduced by Stopford ([58], Appendix 1). Stopford uses the actual active merchant fleet and solves for the **implied average fleet productivity**, that equilibrates supply with demand. In order to stay consistent to our approach we may use the predicted active merchant fleet (which does not depart significantly from the true active merchant fleet) and solve for the implied average fleet productivity. The ability of the system to generate accurate time charter estimates **depends crucially on the level of correlation between the implied average productivity and the observed prices**. To make this point clear, let us assume that average productivity is totally random; then an infinite set of prices satisfies the three equations presented in the previous section. If productivity is fully determined by some (unknown) functional dependence with prices, then we may solve for the implied productivity ( $\frac{DD_t}{AMF(r_t)} = P(r_t)$ ) that brings the system in equilibrium and has a straightforward solution, and then solve for the unknown price. Stopford [58] follows this approach and derives average fleet productivity, by dividing the demand in ton-miles with the average merchant fleet in each period from 1980 – 1995 on an annual basis. Although his data are for the total fleet, do not differ across categories and are quoted on an annual basis, we use them as a benchmark, in order to generate a first estimate of the parametric form of the average productivity function.

Using simple regressions between annual prices and levels of implied productivity, we acquire a fit of 0.7869, which although remarkable, is not sufficient enough to generate the rich patterns of spot and time charter rates. However, the average fleet productivity function, derived on aggregate data, has the following parametric form, which guarantees the non-negativity of the time charter rate:

$$P(r_t) = \theta_{1,j} \cdot \ln(r_t) - \theta_{2,j} \tag{84}$$

We now proceed with the presentation of the calibration algorithm that will allow us to estimate the unknown parameters of the lay-up and productivity function,  $\beta$  and  $\theta$  in Eq.(81) respectively, as well as, any “hidden” functional relationships that will improve the system. This algorithm is in a sense a typical learning algorithm that reduces significantly the **dimensionality** of the identification problem. We start with the lowest possibly parametrization and increase the dimensionality only when a higher performance is accomplished.

## Calibration Algorithm

- Using the actual numbers for ships in lay-up, scrapped tonnage and new orders we derive the average merchant fleet. We then divide the exogenous demand with the  $AMF_t$  and within the market clearing approach, we derive the estimates of average fleet productivity  $P_t$ . We start with the actual numbers for  $AMF_t$  and  $DD$  and not with their structural models derived in the previous sections.
- We regress the implied productivity for each category with the actual prices (time charter rates  $r_t$ ) and derive the unknown parameters  $\theta_j$  for the productivity function, for each category. It is crucial to understand that the performance of the system is fully determined by the level of fit acquired in this step. We then obtain an estimate of the productivity function  $P(\widehat{r}_{t,j}, \theta_j)$ .
- We now repeat Step 1, but instead of solving for  $P_t$  we use  $P(\widehat{r}_t, \theta)$  (we suppress the category index  $j$ ) and solve for  $\widehat{r}_t$ . We then obtain the mean squared error between the actual prices  $r_t$  and the output of the system,  $\widehat{r}_t$ . If this error is acceptable we proceed to the following step; if not we try to improve the estimation and specification in the previous step.
- Having an acceptable estimate of the implied productivity we proceed now with full system estimation. Instead of using the actual active merchant fleet  $AMF_t$ , we now use the functions we derived in our previous modules and solve simultaneously the highly non-linear equation:

$$(AMF_{t-1,j} + N_{t,j}(r_{t,j}, x_t) - Sc_{t,j}(r_{t,j}, x_t) - Lay(r_{t,j}, x_t; \beta_j)) \cdot P(r_{t,j}, x_t, \theta_j) = DD_{t,j}$$

, where  $DD_{t,j}$  and  $x_t$  are the exogenous inputs to the system. Solving for the equilibrium rate  $\widehat{r}_{t,j}$  we achieve all the goals set: We derive the forecast for prices and fully determine the new orders and scrapped vessels. We then calculate the mean squared error between the new estimates and the actual prices and derive the new parameters  $\theta_j, \beta_j$  that minimize the error. Note that at this point the estimates of  $\theta_j$  may differ significantly from the estimates in the previous step.

- If the mean squared error is acceptable we stop. If not, we go back to Step 2 and add some of the exogenous variables to the specification of the productivity function. We then repeat all the steps (we suppress the category  $j$  index once more), whereas instead of using  $P(r_t, \theta)$  we employ  $P(r_t, x_t, \theta)$ . If this action is insufficient then we abandon the market clearing approach and search for a more sophisticated relation between supply and demand.

We are now able to proceed as discussed in the calibration algorithm in the previous section. We start with the most simple specification; namely we start directly from Step 3 by replacing the parameters  $\theta_{1,j}$  and  $\theta_{2,j}$  with the results implied by the annualized average productivity derived by Stopford ([58], Appendix 1). To get a “touch” regarding the performance of the system we start with a productivity function that does not differ across categories and is a linear function of the time charter rate. The generated outcome captures the main trend of the actual market prices, but is far below the performance of the statistical models and is much less volatile than the real market prices. Furthermore, especially in the region of low rates, the implied productivity values do not guarantee the non-negativity of the price process and the output of the system generates negative values for the estimated time charter process. The results are displayed in Figure 4 and are representative of the miss-performance especially for the larger categories. The failure of the outcome may be attributed to two other basic reasons: Either the market clearing assumption does not hold, or productivity differs significantly across categories. We therefore abandon the aggregate annual productivity, and proceed with the implementation of all steps of the calibration algorithm, where productivity is derived endogenously for each category, as the ratio of the demand in ton-miles with the active merchant fleet and the estimation method accounts for heterogeneity across categories.

We implement the full algorithm and derive different parameters for the productivity function across categories. The results are far more improved, but they still lack the necessary volatility observed in actual market prices. As discussed earlier, the dynamics of the actual merchant fleet and the exogenous demand, are far less volatile than the spot and time charter rates observed in the markets. This means that we have two key expectations from the productivity function, if we want to achieve an acceptable performance for our system: we expect productivity to be a function of the price, as well as to be able to attribute to the system the volatility observed in real data.



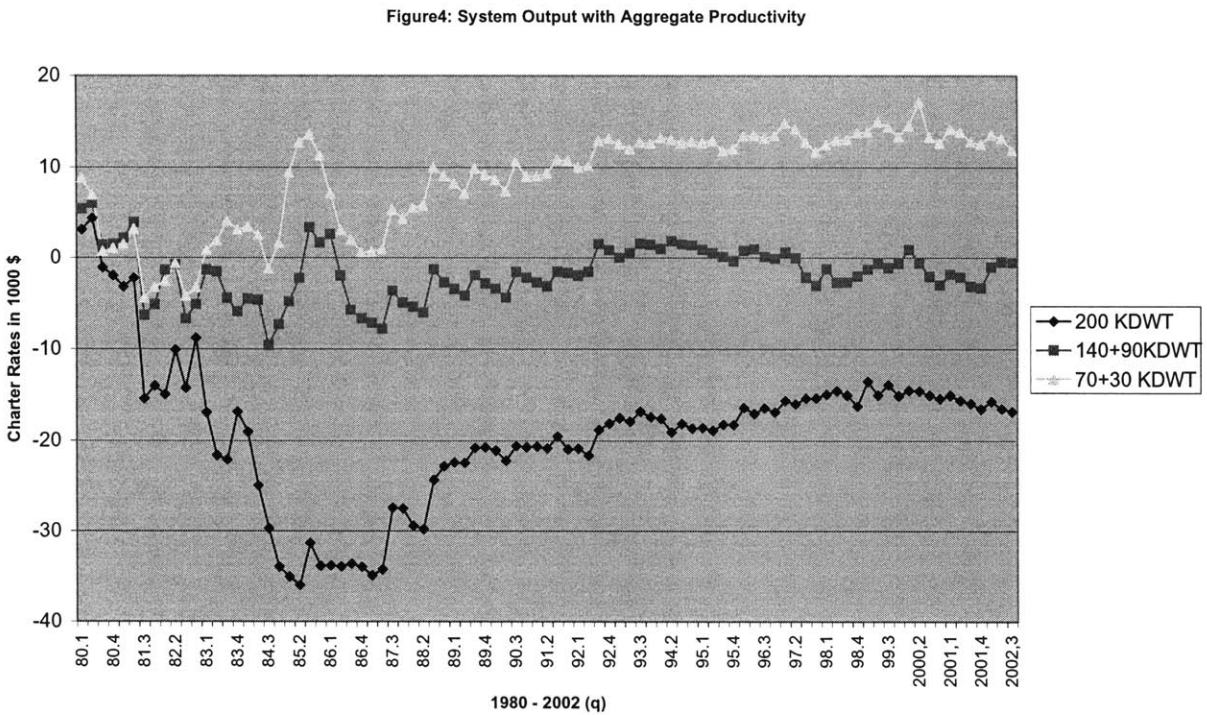


Figure 4: System Dynamics Output: Aggregate Productivity

We shall therefore proceed as discussed in the last step in the algorithm: namely, add a set of exogenous variables that will hopefully “explain” the pattern of the implied productivity.

In order to improve the performance of the system, without abandoning the market clearing approach, we will derive the aggregate average fleet productivity, based on microfoundations with the hope that the structural approach will provide us the necessary insight in identifying the “missing” variable, that will generate a sufficient outcome. As it will turn out there will be one crucial variable that will totally “boost” the performance of the system.

Let us start from explaining and understanding productivity for one specific vessel: On a ship basis, the ship has a non-zero productivity only if it is in a non lay-up status. If the ship is in lay-up or is used for purposes of storage (a recent example is the employment of VLCC’s in the 1991 Kuwait War) then it has zero speed and consequently zero productivity. Once rates are sufficiently high, then the ship has a positive productivity. The speed increases with the prevailing prices, but the loaded days at sea and capacity utilization remain ambiguous. This observation implies that in the region of low rates, only the younger and most efficient ships contribute to the average fleet productivity. At higher rates even the more obsolete and old vessels contribute to the average fleet productivity, which reduces the effects of higher rates on the average speed of the fleet. Due to the adverse effects we expect average productivity to remain relatively stable in the region of high rates. Higher prices **have a positive impact on the optimal speed of each vessel and a negative impact on the quality and average performance of the active fleet.** Therefore, the implied productivity of the system does not possess the necessary volatility we have hoped for and cannot solely account for the volatile pattern observed in prices. In order to model average productivity effectively we have to combine two adverse forces: on the one hand, high rates have to contribute in a positive sense and on the other hand, we must identify the necessary state variable that will account for the negative contribution of high prices on the quality and age distribution of the fleet. We choose tonnage in lay-up as the associated quality state variable for the following reason: High rates induce high productivity and less tonnage in lay-up, whereas low rates reduce speed and potentially the days spent at sea (owners are willing to undertake dry-docking and repair activities in depressed markets), but increase lay-up. These two adverse factors that account for speed, days at sea and fleet quality seem more intuitive

**Table P: Implied Productivity Parameters**

Categories	200K	90-140K	30-70K
theta1	5500	6150	6500
theta2	29050	19000	10300
theta3	2300	2000	1150
Mean Squared Error	6068.936884	3165.770878	2273.250296
Average Error	-0.25072313	-0.198177452	-0.123558086

for modelling productivity. We now choose the following parametric form for the  $P(r_t, Lay)$  function:

$$P(r_t) = \theta_{1,j} \cdot \ln(r_t) - \theta_{2,j} + \theta_{3,j} \cdot Lay \quad (85)$$

We now repeat all the steps of the calibration algorithm. We calibrate the system with simulation methods instead of regressing the implied productivity on the charter rate and lay up, in order to avoid complications, due to endogeneity. The parameters  $\theta$  of the productivity function and the mean squared error and average error between the system output and the observed rate are presented in *TableP*. The results are displayed in Figure 5 and are remarkable indeed. The outputs of the system are marked with arrows. In the periods of low rates, the system output is below the actual market prices, which implies that supply potentially exceeds demand, when the market is in recession. In the period of high rates our forecast “marks” the true prices even in the most brutal and adverse movements. The performance of the system is not only optimized but follows the direction of the actual prices with the utmost precision. We conclude this section with presenting Figure 6 with the implied equilibrium productivity and Figure 7 that summarizes the System Dynamics approach we developed in this Section in an Input-Output setting. The numbers for implied productivity are on a quarterly basis and once multiplied by the factor of four (annualized) they resemble the Stopford [58] data set. In the periods of very low rates the VLCC numbers are counterintuitive, which is potential evidence that supply “overshoots” demand in this region.

Having completed the specification and estimation of the model we will now proceed with the discussion of the results. Although we have achieved a remarkable fit, having derived the equations of the system in closed form,

we are now able to understand the “mechanics” of the system.

Since the system is in equilibrium, average fleet productivity for each category is  $\hat{P} = \frac{DD_t}{AMF_t}$  and using the final formula for productivity, we solve for the rate and plug in the derived productivity. We then obtain the following deterministic equation for the rate:

$$r_t = \exp\left(\frac{1}{\theta_1} \cdot \left(\frac{DD_t}{AMF_t} + \theta_2 - \theta_3 \cdot Lay\right)\right) \quad (86)$$

Taking the partial derivatives with respect to demand  $DD$ , we expect the derivative to be positive; whereas we expect it to be negative with respect to the average merchant fleet, which is the case if and only if  $\theta_1 > 0$ . Taking the partial derivative with respect to the tonnage in lay-up  $Lay$ , we expect the partial derivative to be negative, which requires  $\theta_3 > 0$ . The derived parameters  $\theta$  **are all positive** and verify the requirements imposed by economic theory and intuition. What is particularly interesting is that in the periods of high volatility, the fit provided by the **deterministic** equation is more than 0.93, which implies that a deterministic equation can provide the rich price dynamics, that are very sympathetic to stochastic specifications. This argument verifies the assertion of Chaos Dynamics Theorists, that namely deterministic equations can generate patterns that resemble stochastic processes.

In this section we used the full system approach to derive the equilibrium charter rates. Using demand and some other exogenous variables (operating expenses, oil prices, air transportation, etc.) we have fully determined prices by plugging the newbuilding, scrapping and lay-up modules we derived in the previous sections into our previous equation.

## 5.7 A mixed Busdyn@-GARCH Model

In this section we evaluate the performance of the system within a statistical framework. The results derived in 5.5 and 5.6 correspond to the output of a **deterministic** system, whereas the Generalized Autoregressive Conditional Heteroscedasticity models we derived in 5.2 and estimated in 5.3 correspond to **statistical** models. Both models have displayed a remarkable performance. In this section we address the question, to which extent each model can benefit from the other and proceed with the estimation of “hybrid” models that optimize the performance of our forecast, combining the complex statistical modelling of volatility (uncertainty) with the structural

Figure5: Calibrated System Output 1980-2002(q)

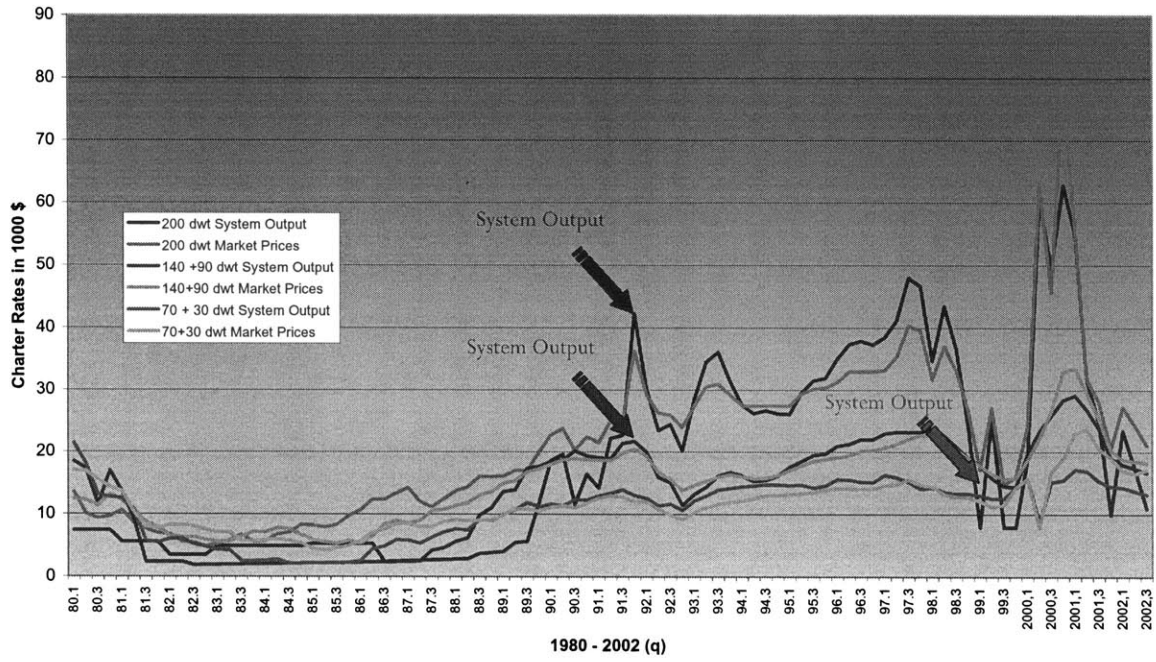


Figure 5: System Dynamics Output: Final Results

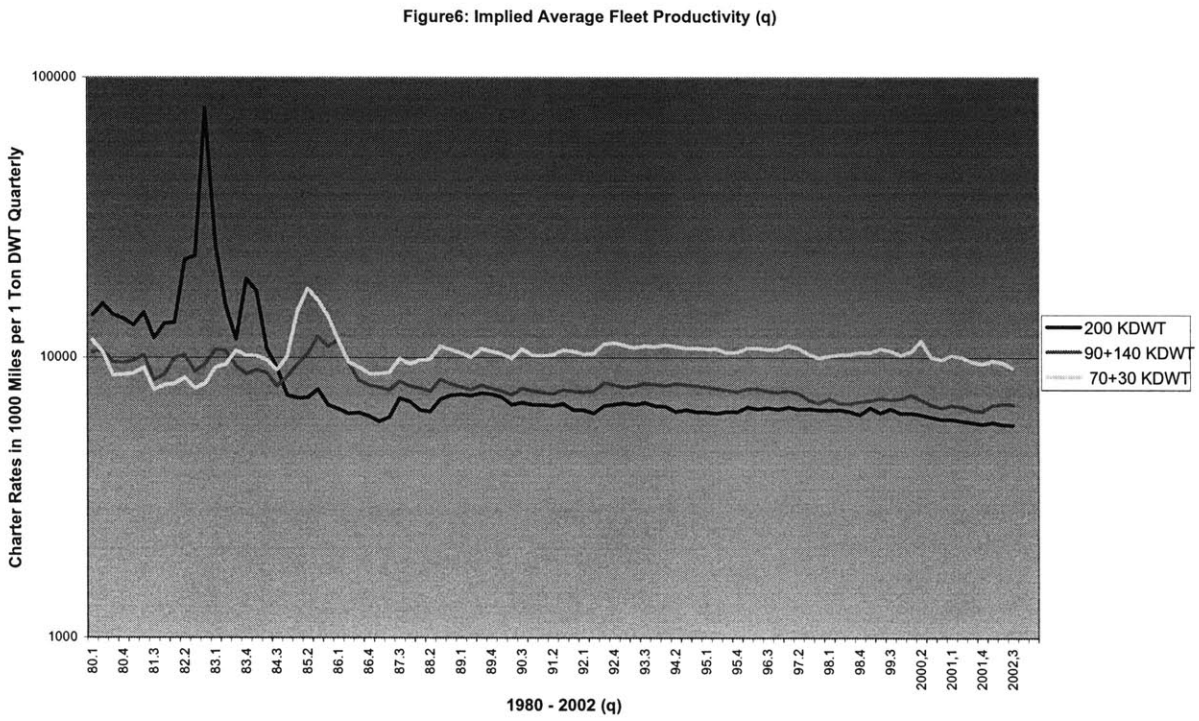
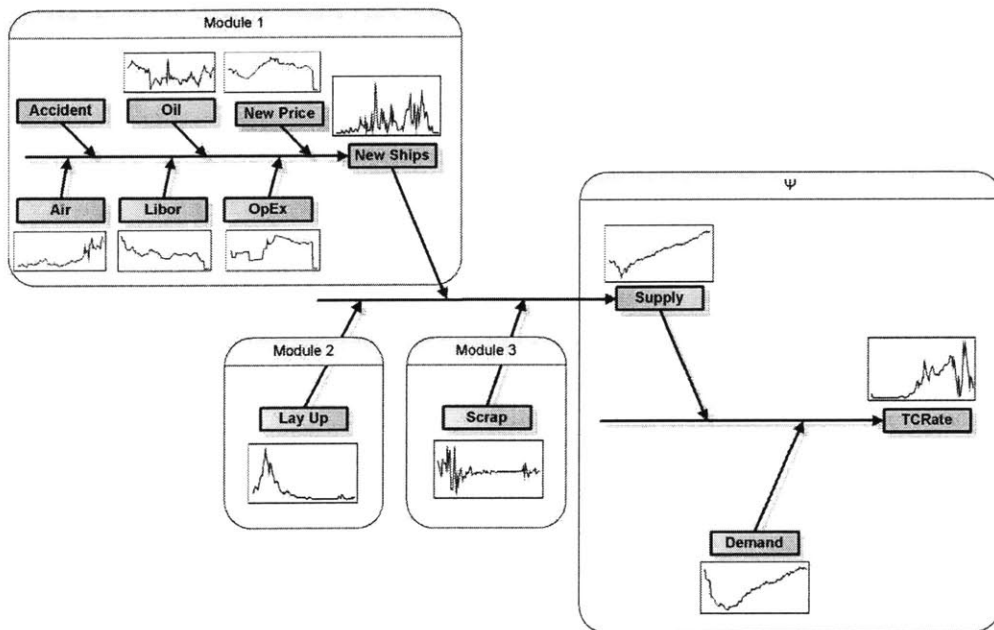


Figure 6: Equilibrium Implied Average Fleet Productivity

Figure 7: Cause and Effect Diagram



**Table XXVII Hybrid EGARCH Full System**

D.tcrate	Coef.	Std.Err.	z	p-0
D.busp	.5947561	.0048782	121.92	0.000
cat	-.0544945	.3609009	-0.15	0.880
cst	89.67948	39.91656	2.25	0.025
arL1	1.605983	.1200491	13.38	0.000
arL2	-.7344997	.1003696	-7.32	0.000
maL1	-1.57367	.130966	-12.02	0.000
maL2	.6588982	.1171024	5.63	0.000
D.busp	.0000316	3.67e-06	8.63	0.000
hetcat	.0001946	.0005558	0.35	0.726
hetcst	.7213303	.2043463	3.53	0.000
earchL1	.2120146	.0515153	4.12	0.000
earchL2	.0765114	.041925	1.82	0.068
earchaL1	.5955742	.0587514	10.14	0.000
earchaL2	.8173896	.056611	14.44	0.000
egarchL1	.0493823	.036764	1.34	0.179
egarchL2	.9088119	.0315344	28.82	0.000
LogL	-3856.066			

output of the supply and demand approach, which allows us to control for exogenous events.

The first step towards the evaluation of our system dynamics outputs is the following: Since the output of the system displayed in Figure 5 (*busp* hereafter) incorporates all economic information on demand and prices, the key assertion is that its should be a sufficient statistic for all the exogenous variables used in the GARCH estimation and specification in *Table XXII*. The output of our system, *busp*, is a sufficient statistic indeed, if it improves the Log Likelihood function, once it replaces demand for transportation *dmd*, oil prices *oil* and the index for air transportation *air*. We perform estimation and specification of the model and report the results in *Table XXVII*.

The results verify our assertion that the output of the system aggregates all **economic information**. The Log Likelihood has been increased with a smaller number of variables, which results in a severe increase in the Akaike



information ratio and the parameter of *busp* displays a huge t-statistic of  $t_{busp} = 121.92$ , which verifies the high impact of the system output on the statistical model. Finally, the category effect appears insignificant here, which is intuitive, since all information aggregate or category specific is aggregated in *busp*. Having estimated the GARCH model with the output of the System Dynamics model as an input to the (GARCH) specification, we have accomplished two diverse, but complementary tasks: on the one hand we have verified that the variable created in the previous two paragraphs, indeed aggregates all economic information and on the other hand this hybrid model takes advantage of the dynamics of any information “left out” by the System Dynamics approach, or simply by imposing statistical structure on the deterministic market clearing model.

We now proceed with imposing some more structure on our hybrid model and repeat estimation of the GARCH model for the logarithm of the time charter rate, as indicated by the exponential specification we derived in 5.6 and display the results in *Table XVIII*. All inputs remain as defined in 5.3.

The mean squared error across each category ranges from 0.143611 to 0.22187 and the average error from 0.00675 to 0.018272, which is less than two percent and is very low, given the small numbers of inputs used. In order to test if any information is “left out” in the residuals we employ white noise tests (which are typical in system identification) and the Portmanteu [59] statistic is  $\chi^{40} = 26.7704$  and does not reject the null, namely that residuals are white noise. Having combined all available forces for the calibration of the system this hybrid GARCH-System Dynamics model has achieved three different tasks:

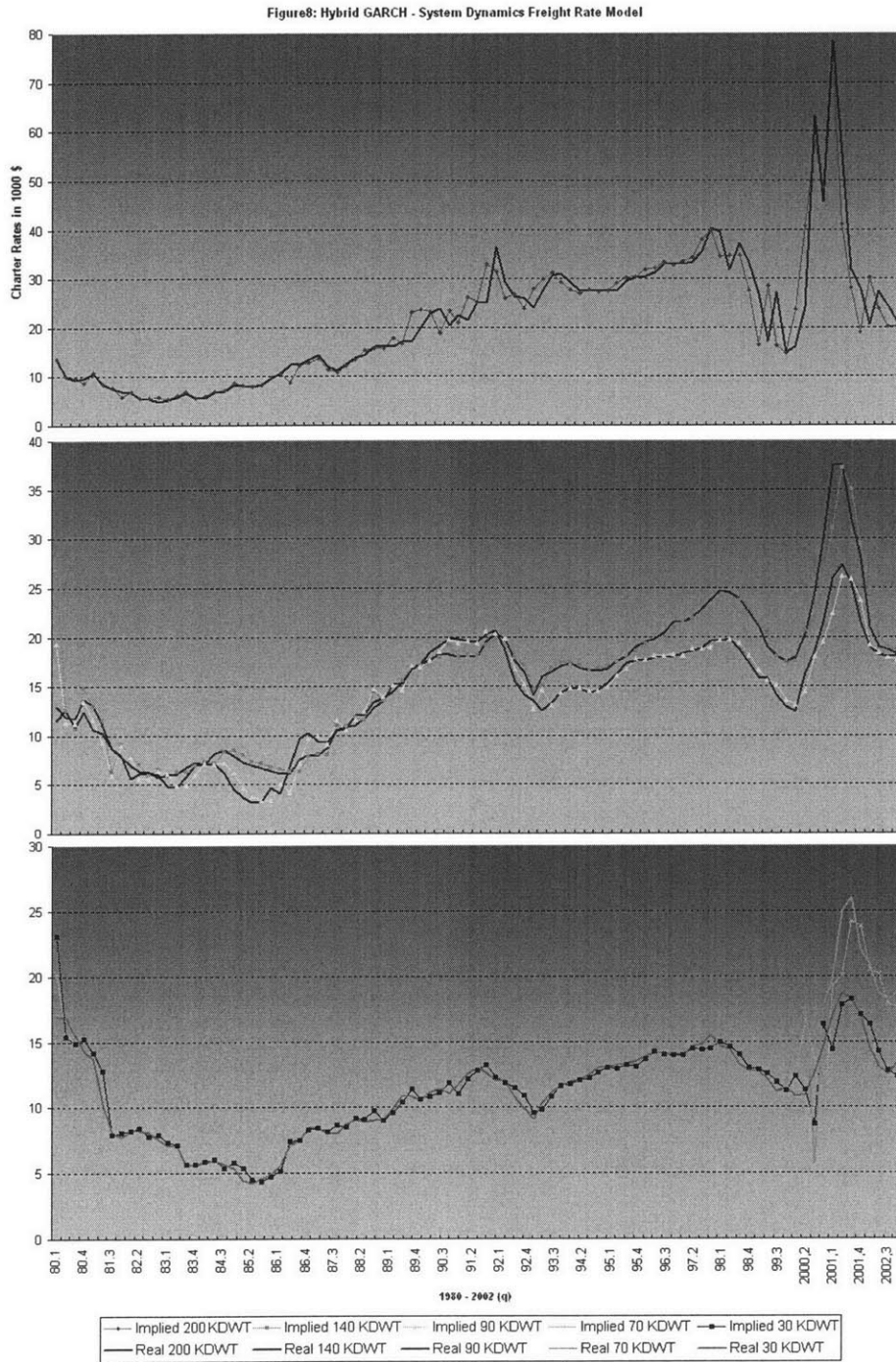
- It incorporates all economic theory and information in a market clearing environment, since it uses as an input the output of a market clearing system.
- It takes advantage of the rich character of GARCH models, by imposing structure on the dynamics of the residuals.
- Finally, we have proposed a hybrid model and a calibration algorithm that aggregates statistical models with engineering type models.

The results of the hybrid model and the actual prices are displayed in Figure 8, which needless to say speaks for its own.

**Table XXVIII Hybrid EGARCH Full System**

D.ln(tcr)	Coef.	Std.Err.	z	p-0
D.ln(busp)	.4394877	.0085786	51.23	0.000
cat	8.68e-07	.000012	0.07	0.942
cst	.0015319	.0016221	0.94	0.345
arL1	.8382046	.5109495	1.64	0.101
arL2	.0170225	.4519416	0.04	0.970
maL1	-.8280828	.5218845	-1.59	0.113
maL2	-.1203292	.5073313	-0.24	0.813
D.ln(busp)	.1340466	.0789613	1.70	0.090
hetcat	.000816	.0007054	1.16	0.247
hetcst	-.3673754	.1639719	-2.24	0.025
earchL1	-.0398744	.0413473	-0.96	0.335
earchL2	.0554082	.0363861	1.52	0.128
earchaL1	.6983358	.057588	12.13	0.000
earchaL2	.8875543	.047151	18.82	0.000
egarchL1	-.0305064	.0193224	-1.58	0.114
egarchL2	.9381737	.0149055	62.94	0.000
LogL	516.61382			

Figure 8: Hybrid GARCH-System Dynamics Output



## 5.8 “Out-of-Sample” Performance Evaluation

All the analysis, identification and estimation has been carried out within the full sample until now. There are two particular reasons supportive to this specific approach: on the one hand our data consists with only 91 observations for each category and on the other hand, we have been mainly interested in assessing the validity of our basic identification assumptions, such as the equality between supply and demand and the exogeneity of the time charter rate for newbuilding and scrapping decisions. Furthermore, we have been particularly interested in the economic interpretation of the structural parameters, which have been in line with Economic Theory and supportive to the integration of the three sub-modules.

Having verified the validity of the market clearing approach, as well as the success of the integrated equilibrium price model, we now address issues interrelated to the ability of the model to generate accurate forecasts. In order to address potential concerns on over-fitting, we use the following training rule: we split the sample and use a fraction of the available observations in order to “train” the system (identify the parameters) and the remaining fraction, in order to generate the forecasts **with the parameters obtained from the “training” sub-sample** and compare the relative performance of the system, with respect to the “full sample” performance.

Since the key input to the Hybrid model we presented in the previous system is the System Dynamics output *busp*, which is the structural equilibrium time charter rate, we perform the training and forecasting approach for the System Dynamics output. We consider several sub-samples (deterministic and random) and perform parameter estimation “within the sub-sample” and forecasting “out-of-sample”. Finally we evaluate the performance of the system by undertaking an adaptive learning approach: namely, we increase in each step the training sub-sample by one observation and decrease the remaining forecasting sub-sample by one observation.

Once we forego the first quarter of observations (which corresponds to a “bear” market) the estimated parameters and the associated “out-of-sample” performance display remarkable stability and appear to converge to the “full sample” parameters and mean squared error. The results are indicative of the stability of the system and provide supportive evidence for the “out-of-sample” ability of the system to track changes, both in direction and magnitude. In Figure 9 we display the estimates of the charter rate, once 60 out of 91 observations are used to calibrate the system. All changes

of directions have been tracked successfully and the “out-of-sample” mean square error does not differ significantly from the one achieved with the entire 91 observations. Results displayed in Figure 9 provide firm empirical evidence that the system is not over-parametrized and that convergence of the system is achieved within a relatively small fraction of the total sample. Results for different ratios of fitting/forecasting data resemble very similar patterns, especially after the first quarter of observations is used for calibration and estimation.

Figure9: Calibrated System Output with 60 Observations

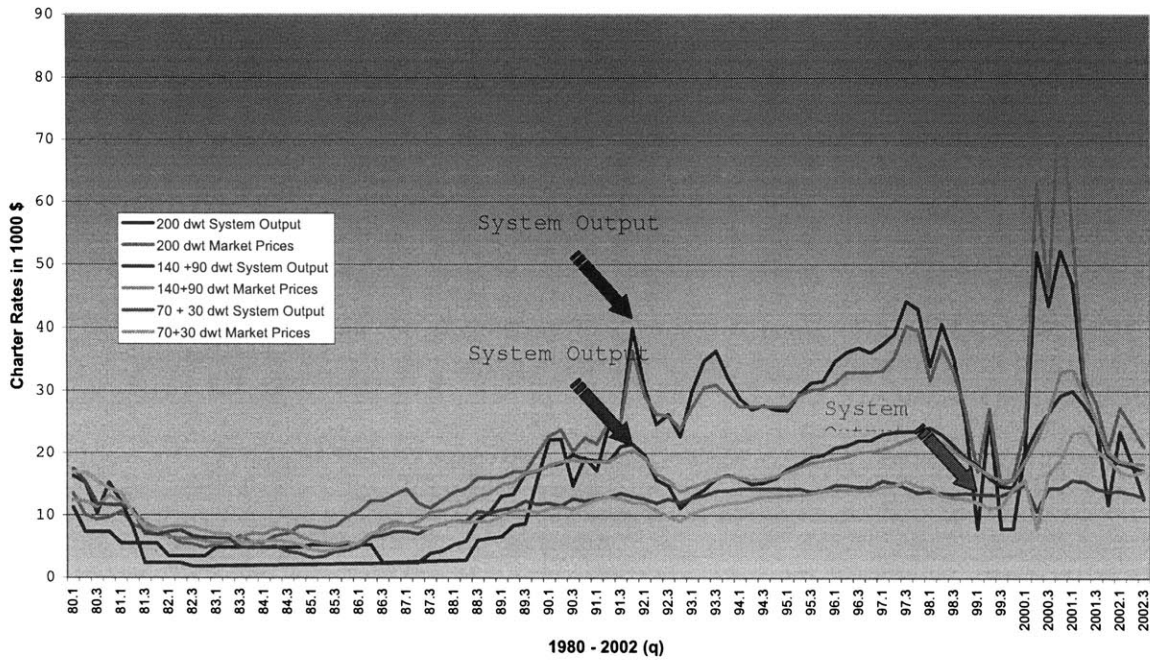


Figure 9: Out of Sample Forecast

## 5.9 A Model for Prices of New Vessels

In this section we address one critical question that has been partially answered, whilst performing the specification and estimation of the Module 3. Namely, *are newbuilding prices exogenous?* By explicitly addressing this question we restore one crucial long-term fallacy of maritime economics. Early authors have claimed that newbuilding prices are a stabilization mechanism for the industry. Once demand is up, time charter rates are up and investment in new vessels picks up, too. Newbuilding prices rise and contribute to the stabilization of the industry. Under complete markets, constructors of new vessels should adjust their prices in order to eliminate any “excess profit” opportunity for investor and make the real option value degenerate and equal to zero. In our model we have claimed that the real option value is non-degenerate, due to subsidization and imperfections in the market for new vessels. Zannetos [64] in his pioneering monograph discussed the destabilizing role of shipbuilders, which contradicts the orthodox economic theory; namely in periods of high time charter rates shipbuilders should respond with quoting higher prices for constructing the vessels. Instead of “devoting all their capacity to shipbuilding, they start employing part of their organization efforts to expansion, thus cutting their current capacity somewhat for the purpose of building future capacity” (Zannetos, [64] p.80). He then concludes by stating: “Prices, however, are neither explosive nor are they perpetually establishing new lows, for reasons we expounded when we analyzed the patterns of behavior...these shifts do not bring about a balance in supply and demand, but are, instead disequilibrating.” Strandenes [57] has addressed this issue formally and claims that the strong presence of labor unions in this market has led to lower flexibility and imperfections. By offering vessels at subsidized prices “demand for new vessels increases other things equal and so do transportation capacities when these vessels are delivered. Subsidization implies that new vessels are sold at lower than optimal price”, for example the price that makes the real option value equal to zero. Strandenes concludes that “this introduces a distortion into the market for ships.” Formally made, the Zannetos-Strandenes argument can be tested by testing the exogeneity of prices of new vessels, which corresponds to testing if the reduced form supply function of new vessels depends on the ordered deadweight. Before proceeding with this task let us restate the main goals in this section.

In this section we perform three tasks:

1. We test the exogeneity of prices of new vessels.
2. We derive a reduced form for the pricing of new vessels.
3. Finally we close the system and make all the statistics relative to shipping investment decisions (newbuilding prices, time charter rates, scrapped tonnage, ordered tonnage and transportation supply) endogenous.

In order to test the exogeneity of prices of new vessels (*new*) we will test whether the ordered deadweight (*dwt*) appears statistically significant in the reduced form of the newbuilding pricing equation. Given a functional form for the prices of *new* we will demonstrate that the ordered deadweight in each period is statistically insignificant, which implies that pricing by shipyards is determined only in terms of production costs and market conditions. This argument was discussed in the specification and estimation of the first module, when we instrumented the price of new vessels, to account for endogeneity in the estimation of the demand for new deadweight in each period. In this section we will estimate the following reduced form for the **supply equation of new vessels**:

$$\ln new = \beta_0 \cdot X + \beta_1 \ln dwt + \epsilon \quad (87)$$

Our assertion is that  $\beta_1 = 0$  and this implies that on the one hand, when estimating the demand equation for the new vessels, there is no endogeneity, due to the price of new vessels, whereas on the other hand, the newbuilding pricing equation is **inelastic with respect to demand for new tonnage**. This is the main reason, why the shipyards are a destabilizing force in the market.

We now proceed with the estimation of the reduced form of the supply function of the shipyards, where *lnn* is the logarithm of *new*, *lnn1* the lag of *lnn*, *ld* the logarithm of the ordered *dwt* and the other variables are as defined in the estimation of the previous two modules. We proceed with the estimation of a linear model with fixed effects for category and instrument for the lag of the exogenous variable, due to autocorrelation, as well as the potential endogeneity of *ld*. Results are displayed in *Table XXIX* and the associated  $R^2$  is very high, which eliminates any concerns regarding weak instruments. The assertion of exogeneity is verified, since the coefficient of the ordered deadweight appears statistically insignificant.



**Table XXIX IV FE Newbuilding Supply Equation**

lnn	Coef.	Std.Err.	z	p-0
lnn1	.8687464	.1139409	7.62	0.000
ld	.0388136	.1255464	0.31	0.757
tcrate	2.50e-06	2.93e-06	0.85	0.393
spoil	.0000619	.001041	0.06	0.953
oil	-.0018181	.0006588	-2.76	0.006
air	-.0001718	.0001634	-1.05	0.293
accident	-.004832	.0302455	-0.160	0.873
const	.4866336	.3260659	1.49	0.136
sigmau=	.03719431		R2within=	0.9537
sigmae=	.06052779		R2between=	0.9991
rho=	.27410513		R2overall=	0.9816

We now repeat estimation and treat the logarithm of the ordered deadweight  $ld$  as exogenous. Therefore we instrument only the lags of the logarithm of the price of new vessels. Results are displayed in *Table XXX* and we finally perform a Hausman specification test, which is  $\chi^2(5) = 0.05$  and verifies the exogeneity of the logarithm of the ordered deadweight in the reduced form of the newbuilding pricing function.

As discussed in the estimation and specification of the first module, the **inelastic** supply with respect to demand, has a strict implication on the demand for new vessels; namely the price of vessels is **exogenous** in the demand function. The exogeneity of prices was verified in the first module and in our previous discussion. We will now perform a final verification of our assertion by using the demand function for new vessels. We estimate the demand function derived in the first module without instrumenting for the endogeneity of prices and then proceed with using the instruments discussed previously for the estimation. We perform a Hausman test that is  $\chi^2(5) = 0.41$  distributed and this is the final verification for the exogeneity of newbuilding prices. Results of the instrumented and non-instrumented estimates are displayed in *Table XXXI*.

Having performed this task, namely the specification, estimation and identification of the three modules, the determination of the transportation supply function has come to an end. Performing this task we have addressed

**Table XXX IV FE Newbuilding Supply Function**

lnn	Coef.	Std.Err.	z	p-0
lnn1	.8845232	.0850922	10.39	0.000
ld	.0118831	.0113928	1.04	0.297
tcrate	3.03e-06	1.56e-06	1.94	0.052
spoil	-.0001076	.0006647	-0.16	0.871
oil	-.0018894	.0005552	-3.40	0.001
air	-.0001421	.0000853	-1.67	0.096
accident	-.0098461	.0188302	-0.52	0.601
const	.4429625	.248965	1.78	0.075
sigmau=	.03132392		R2within=	0.9560
sigmae=	.05900241		R2between=	0.9997
rho=	.2198754		R2overall=	0.9828

**Table XXXI IV FE Newbuilding Demand Function**

lnn	Coef.	Std.Err.	z	p-0
newprice	-.0070655	.0030988	-2.28	0.023
ld1	.283371	.0444305	6.38	0.000
ld4	.0885015	.04217	2.10	0.036
tcrate	.0000407	8.10e-06	5.02	0.000
opex	-.0000131	6.97e-06	-1.87	0.061
lrate	-.0033797	.0044578	-0.76	0.448
tcs	-2.72e-10	9.84e-11	-2.76	0.006
accident	-.0933811	.0599515	-1.56	0.119
const	.184054	.0982438	1.87	0.061
sigmau=	.12783805		R2within=	0.4634
sigmae=	.26003523		R2between=	0.8482
rho=	.194645		R2overall=	0.5185

**Table XXXII FE Newbuilding Demand Function**

ld	Coef.	Std.Err.	z	p-0
newprice	-.0053505	.0015845	-3.38	0.001
ld1	.287755	.0438478	6.56	0.000
ld4	.0867193	.042023	2.06	0.040
tcrate	.000037	5.75e-06	6.44	0.000
opex	.000037	5.75e-06	6.44	0.000
lrate	-.003153	.004438	-0.71	0.478
tcs	-2.34e-10	7.88e-11	-2.97	0.003
accident	-.0742882	.0520459	-1.43	0.154
const	.1493451	.0820473	1.82	0.069
sigmau=	.11224943		R2within=	0.4648
sigmae=	.25968816		R2between=	0.9062
rho=	.15742464		R2overall=	0.5391

some key questions of Economic Theory, we have restored fallacies that have prevailed for decades in the Maritime Economics Literature, derived the Supply Transportation function based on structural foundations and heterogeneous agents and have extended the seminal 1971 Devanney [20] model to account for heterogeneity and actions under uncertainty and irreversibility. This study integrates the research cycle initiated by the seminal monograph of Zannetos [64], almost fifty years ago. Zannetos determined qualitatively the factors that determine the short-run and long-run transportation function, whereas Devanney derived supply and demand for transportation, based on microfoundations. In this study we have proposed aggregate models consistent to the “bottom-up” approach, which on the one hand allow some insight into the mechanics of the supply function and on the other hand provide us a consistent framework to test some key economic hypotheses in this market and determine the stabilizing and destabilizing factors. In the early studies not much attention has been given to the specification of the model; however, any conclusions drawn on statistical inference depend heavily on model selection and specification. Using the “Decisionmetric” approach introduced by Spyro Skouras we have been particular careful and consistent with selecting structural models that are sympathetic to aggregate data and do not fail key specification tests.

Assumptions of **market completeness** and **rational learning** have

eliminated the importance of uncertainty on aggregate decisions, whereas the methods proposed are suitable for performing this exercise in any type of competitive markets (Real Estate markets, Cattle Cycles) . Following Stranden [57] classification of *Real Markets* and *Auxiliary Markets* in the shipping industry, we have completed the task of estimating the dynamics of the Real Markets. We may therefore proceed with a complementary, but essential task; namely the estimation and specification of the Second Hand Market Term Structure that determines Auxiliary Markets.

## 6 A Partial Equilibrium Model for the Valuation of Second-Hand Vessels

Strandenes [57] classifies the market for second hand vessels as an auxiliary market, as it has no impact on the transportation supply function and the real markets we analyzed in the previous three modules. In this section we follow the complete market argument and derive a partial equilibrium model for second hand prices that is not directly related to the previous model, but complementary indeed. Let us now proceed with the specification of the model.

### 6.1 Introduction

After the early supply and demand analysis, which set the foundations of Maritime Economics from a microeconomic or Industrial Organization point of view, very little has been done in using financial tools to identify “pricing links” between the different markets that constitute the shipping industry. Using the terminology of Strandenes [57] our main objectives in this chapter are two: On the one hand we want to price assets that belong to the auxiliary markets in terms of assets that belong to the real markets and on the other hand, we aim to developing a pricing model for second hand vessels in the complete market framework, as introduced at the beginning of our analysis.

As demonstrated in our analysis, the dynamics of the freight rates are determined by the supply and demand for transportation and the same applies for the orderings of new building vessels and scrapping decisions. However, since the second hand vessels do not affect the supply and demand patterns, their value should be determined by their payoffs and the opportunity or replacement cost. In fact, it is now well established that the value of any asset is determined only by its associated payoff. Therefore, the value of a vessel is fully determined by its associated revenues from optimal chartering decisions. This observation will be the leading motivation for our analysis and the link that will allow us to integrate our approach towards the different shipping markets, by using intuition from finance. Shipping economics has suffered from the same ideas that option pricing suffered before the seminal paper by Black and Scholes [12]. Before their paper it was well believed that the value of an option contract should be determined by the supply and demand for such contracts in the market; therefore its price was simply the equilibrium

market price. The same arguments have been used in Maritime Economics. However, it is well established in modern finance that the value of an asset is determined by its risky payoff. This rule applies for both the new vessels, as well as the second hand vessels. The decisions of scrapping the vessels, time-chartering, chartering the vessel under a time charter or bare-boat do not constitute different markets, but simply different policies or “optimal decisions” for an investor that determines the expected payoff from his asset under optimal chartering policies. Using the modern finance approach we shall derive equilibrium prices for vessels in the second hand market, and we shall demonstrate the Real Option (or “asset play” value in the literary vocabulary of maritime economics) hidden in second hand vessels. Even if the market is not transparent and huge transaction costs are associated to each trade, the Real Option value that exists in a complete market framework, may always be considered as a significant pricing benchmark. Since the market for second hand vessels doesn’t depend on supply and demand ideas and given that ships exist in order to provide demand capacity, ideally it should not exist. However, not only it exists, but it is also one of the driving forces of shipping business cycles and shipping investment and financing decisions. This implies that it functions, on the one hand as market for assets and on the other hand (and this is the key idea) as a proxy for the market value of a vessel compared to the replacement cost, given by the price of new vessels. The first part of this observation is not new in maritime economics.

Beenstock and Vergottis [6] came up with a model in order to explain the prices of second hand values. This model, which was a Capital Asset Pricing Model, relied on quadratic utility functions for shipping investors and the assumption that markets are complete. Since then, no other significant effort has been made to understand the financial aspects of the market for second hand vessels and their role in the shipping industry. Without the strict assumptions required in a CAPM type approach, we know that the value of the asset is determined by the value of its expected payoff, for which time charter rates are a sufficient statistic.

Furthermore, decisions in the second hand market depend on the comparison between market values (second hand prices) and new building prices (replacement costs). If these two factors are sufficient statistics for investment/replacement decisions in the second hand market, then they should also be sufficient statistics for the pricing of second hand ships. This was the main intuition in the seminal paper by Marcus [44] et.al. Furthermore, the intuition behind the relationship of second hand prices and new vessels has

close connections to Tobin's q-theory [28].

From an empirical point of view, 10 years later after the "Buy Low - Sell High" approach, Haralambides et.al [34] conducted an excellent econometric analysis for the determination of the factors that affect second hand prices. Once these factors are identified empirically, one has good estimates about the sources of risk involved in pricing the uncertain payoffs. Then, by assuming that we are able to trade continuously in a portfolio that spans the payoffs of the second hand ship (which is the case under complete markets) we may use "arbitrage" arguments to derive the value of the second hand ship, contingent on the factors of risk. **Throughout our entire analysis the assumption of market completeness has reduced the dimensionality and complexity of estimation and has provided valuable "shortcuts" to issues of aggregating individual actions to aggregate data, without depriving our analysis from solid economic foundations.** In the analysis of models of entry and exit (Module 1 and Module 2) the completeness assumption provided excellent empirical results and avoided the cornerstones of heterogeneity and asymmetric information. Therefore, we aim to carry out the same program in this paragraph.

The assumption of completeness is interrelated to the existence of portfolios that replicate the payoffs of second hand ships. If this is the case, we then can construct portfolios that diversify the risks associated to the underlying risk factors. This assumption and its validity will be discussed later on before the specification of the model. As we discussed in the specification and estimation of the entry models, the introduction of continuous time methods and contingent claim valuation methods in shipping is not new: Goncalves [30] used future contracts as an underlying instrument and Dixit and Pindyck [28] derived threshold ratios that trigger investment in the tanker industry.

As we furthermore observe from the empirical analysis in Haralambides et. al. [34], the functional relation between second hand values is highly non-linear. This non-linearity provides significant evidence for a hidden "real option" value in the second hand market asset play. The introduction of contingent claim methods and the justification for these methods is the main idea in our analysis and will lead to closed form pricing formulas for vessels in the second hand market.

## 6.2 The Contingent Claim Valuation Approach

In their seminal paper Marcus et. al. [44] identified the link between prices of vessels in the second hand market, prices of newbuildings and time charter rates, and identified these two risk factors as the main “sufficient statistics” for shipping investment considerations in the shipping asset play. In their excellent empirical paper, Haralambides et. al. [34] conducted an econometric analysis of the prices of vessels in the second hand market and concluded the same results regarding the significance of time charter rates and newbuildings. In a similar econometric analysis Dikos et. al. [27] concluded that newbuilding prices and EBITDA/CAPEX ratios are the main factors that drive prices of vessels in the secondary market and proposed a stochastic model for the depreciation of vessels with respect to these factors.

Maritime economics have based the derivations of the empirical literature on the interrelation of newbuildings, time charters and second hand prices on the basis of supply and demand. Other models for the interaction of these markets have been derived on the basis of Capital Asset Pricing Models. At this point we need to stress that any approach taken on this basis is de facto misleading: Shipping Investors do not have quadratic utility functions, since they potentially accept Net Present Values, below the real option “investment threshold”, for the potential extreme profits they may gain in a bullish market. Furthermore, returns are far away from normal and the market is asymmetric and non-frictionless. Thus, any Capital Asset Pricing Model approach to Shipping (see Beenstock and Vergottis, [6]) is only an application of modern corporate finance theory, (which is anyway rejected in numerous studies for highly integrated and efficient markets) in a very specialized market. On the other hand, we have significant evidence for a highly non-linear relation between second hand prices, newbuildings and time charter rates. One of our goals is to demonstrate that the non-linear pricing relation may be explained by the real option approach to shipping investment decisions. Staying consistent to our basic underlying assumptions of complete markets that allow us to combine solid economic foundations and intuition, without addressing complicated aggregation problems, we shall proceed with the contingent claim valuation approach. Unfortunately, the completeness assumption does not come totally free: Although we avoid complicated aggregation issues, we cannot explain the dynamics of trading volumes in this market, neither why agents trade. Namely, if the value of a real asset is uniquely determined and all agents agree on it, what is the motivation to trade? This



observation opens the door to models of heterogenous expectations or asymmetric information and such models are absolutely necessary, provided we are willing to understand the evolution of trading volumes; this is beyond the scope of this analysis and it is left for further research. In the next two paragraphs we will outlay our model and empirical findings and finally we will wrap up our conclusions and propose topics for further research within this direction. Before proceeding with estimation and specification we need to readdress the limitations of our basic assumption in the specific market and touch upon one more essential assumption that is an absolute necessity for any hope regarding the validity of the completeness assumption.

Trading continuously: How feasible is it in Shipping?

One of the basic assumptions in the risky payoff valuation literature is our ability to trade continuously the asset. Even if we are not able to trade continuously the underlying risk factors, we have to be able to trade the asset we want to evaluate. For example, when valuing an option on a stock we are able to trade continuously on both the underlying stock and the option. Due to obvious reasons it is impossible to trade continuously in second hand ships. However, it suffices that there exist enough instruments in financial markets that allow us to replicate the risky payoffs of the asset. For example, shares of shipping companies listed on stock markets as well as bonds of shipping companies may provide us some very good instruments, which may allow us to replicate the payoff of ships in the second hand market. Trading continuously is not the important issue in the pricing formulas. The derived pricing bounds would be exact if we could find portfolios that could replicate the freight risk and newbuilding risk. Even if this is not the case, still the derived pricing formulas are an indicative pricing benchmark. On the other hand, had we been able to replicate the payoffs of ships by other instruments, then ships wouldn't really need to be traded for capital gains from a financial point of view. Thus there is some hidden value, in not being able to replicate the payoffs of a vessel exactly and perhaps this hidden value is interrelated to the informational asymmetry between bankers and owners. Bankers lend on the same rate, regardless if the owner is hedged against freight rate risk or credit risk. Not being able to replicate the payoff of the vessels is interrelated to disclosing information; therefore by assuming continuous trading, we are always in the safe side in the terms of our valuation analysis.

### 6.3 A Two Factor Valuation Model

Valuation in an incomplete market.

Let us now determine the value of the second hand vessels as a function of the capital expenses associated to a new vessel (the price of the vessels plus the overheads incurred when ordering a vessel) and the ratio of time charter earnings and capital expenses. Then if  $F(CX, r, t)$  stands for the price of a vessel at time  $t$ , with remaining life  $T - t$ .

$$Price = F(CX, r, t) \quad (88)$$

Hereafter  $r$  will stand for EBITDA/CAPEX and  $CX$  will stand for the price of the new vessels, capital expenses added. We propose the following model for the evolution and the dynamics of  $r$  and  $CX$ :

$$dCX = \mu(CX, t)dt + \theta(CX, t)dZ^c \quad (89)$$

$$dr = v(r, t)dt + \sigma(r, t)dZ^r \quad (90)$$

$Z^c, Z^r$  are two independent Brownian motions defined on the standard filtration. We now assume that the price of the vessels in the second hand market is a function of these two risk factors, namely:  $F(r, CX, t)$

The empirical findings in Haralambides et. al. [34] suggest that the second hand pricing function should have the following form:

$$F(r, CX, t) = X(CX, t) \cdot Y(r, t) \quad (91)$$

Since the value of the vessel in the second hand market is a function of these two state variables, we may use the multi - dimensional form of Ito's Lemma and assuming that one can trade continuously in second hand vessels we can derive the following differential equation (see Yue-Kuen Kwok [43] for a more detailed derivation):

$$F_t + 0.5\theta^2 F_{cc} + 0.5\sigma^2 F_{rr} + (\mu - \lambda_c\theta)F_c + (v - \lambda_r\sigma)F_r - rF + rCX = 0 \quad (92)$$

We have made the standard assumptions that the risk free portfolio yields the EBITDA/CAPEX ratio and that we are allowed to trade continuously

values in the second hand market. Although this assumption may seem unrealistic due to the huge transaction costs in this industry it should hold for shares of shipping companies listed on organized markets. Thus there exist assets that allow us to replicate continuous trading strategies in the second hand market. There is one more significant observation related to our pricing differential equation: Having used as state variables the capital expenses to invest in a new vessel and the EBITDA/CAPEX ratio, we are allowed to model the payoffs received from chartering a ship continuously, simply as the product of these two variables. Finally the two terms  $\lambda_c, \lambda_r$  that appear in the pricing differential equation are the market price of risk and correspond to the Girsanov transformation of the specification of the two processes with respect to the local martingale measure. In this setting we have two factors of risk and one asset. The market is therefore incomplete (see Biais et. al. [11]) since there are more risk factors than traded assets and an infinite number of (no-arbitrage) local martingale measures exist. The prices of risk in the above model are simply determined by the market.

If we now plug into our equation the separable empirical form we derive the following two differential equations:

$$Y(X_t + 0.5\theta^2 X_{cc} + (\mu - \lambda_c \theta) X_c - rX) = 0 \quad (93)$$

$$X(Y_t + 0.5\sigma^2 Y_{rr} + (v - \lambda_r \sigma) Y_r + r(CX/X)) = 0 \quad (94)$$

If we set  $X(CX, t) = CX$  we obtain the following equation:

$$\lambda_c = \frac{\mu - rCX}{\theta} \quad (95)$$

If the evolution of the prices of new vessels are a simple log - Ornstein - Uhlenbeck process the above specification is reduced to  $\lambda_c = \frac{\mu_c - r}{\theta_c}$ , and it is sensitive to technological advances that affect the mean of the prices of new vessels. Technological advances that affect the market price of risk may be the explanation for the formation of two patterns of depreciation curves in the bulk industry for data from 1976 until 2002 (Figure 10).

Having specified the market price of risk for a new vessel investment that is consistent to the specification  $X(CX, t) = CX$  we now may derive the following equation for  $Y$ :

$$(Y_t + 0.5\sigma^2 Y_{rr} + (v - \lambda_r \sigma) Y_r + r) = 0 \quad (96)$$

We have now a complete characterization of the second hand price function and once we specify the terminal conditions of this set of differential equations we have a theoretical model that integrates prices of new vessels, prices of vessels in the second hand market, the demolition market and time charter rates and is consistent to the empirical findings, as well as our analysis in the previous chapters. Having identified the two explanatory variables (factor risks) in the industry we will be able to extend these results in the non continuous trading case in the form of good deal versus bad deals and relative pricing. Before proceeding with the empirical results, it is worth mentioning that the EBITDA/CAPEX ratio is the inverse of the expected investment recovery period and is similar to the P/E ratio which is a common risk factor for shares. EBITDA/CAPEX is specified exogeneously in this industry, due to the competitive nature of the industry. Although one could argue that the resulting EBITDA/CAPEX is an output of the equilibrium due to the demand and supply for transportation, as well as the investment decisions of the players in this market, since bulk shipping is an extremely competitive market, this process may be considered as exogeneously specified. In their seminal paper Hansen et. al ([33]) consider an exogeneously “dividend ratio” process for robust control in a Ramsey-type model. Introducing the EBITDA/CAPEX as a sufficient statistic to characterize the uncertainty of investment decisions in this industry has close links to q-theory. EBITDA/CAPEX is not only an inverse P/E ratio and an approximate measure of the required capital recovery period, but an equivalent q-ratio. EBITDA is a statistic for the market value of the asset, whereas CAPEX is a proxy for its replacement or construction cost. Since no agent can acquire sufficient power to control this market, instead of deriving the q-ratio as an output of a dynamic model we specify it exogeneously. Finally, the specification of time charter rates as a risk factor has been a drawback for the understanding of shipping investment dynamics, due to the fact that it is not invariant to size, type and cost parameterizations, whereas EBITDA/CAPEX is cost and size invariant. Furthermore, time charter rates are only a proxy for the market value of the asset and not the renewal value. Equivalently, given the rent for a real estate property you cannot conclude if you should invest or not, unless you are given the construction costs at the specific time period. We shall now proceed with the empirical findings regarding the above results.

## 6.4 Empirical Results

There are several difficulties in constructing precise tests for the above model. First of all the market prices of risk  $\lambda$  are not observed in the market and possibly change over time. Furthermore the number of data is limited and restricted to specific ages of vessels, whereas in the above model a continuum specification of vessel prices is required. However we can test still the above specification. As implied by the above model the depreciation of vessels, or the ratio:

$$D(r, t, T) = \frac{CX_t - F(CX, r, t)}{CX_t(T - t)} = \frac{1 - Y(r, t)}{T - t} \quad (97)$$

We observe that in this model the term structure of depreciation does not depend on the price of new vessels and since it has to preserve positivity we make the following exponential specification for  $D(r, t, T) = \exp(A(t, T) - rB(t, T))$ . We will now test our model by using annualized depreciation data. For two different categories of tankers and using data from 1993-2002 we shall plot the depreciation against the EBITDA/CAPEX ratio for three different ages: 5, 10 and 15 years. The dispersion of the observed data around the main trend will be due to the time variation of the market price of risk. We are now going to fit the empirical model for the depreciation curves with true data. We are going to carry out the following program: For a fixed age  $t = 5, 10, 15$  and economic life  $T = 25$  we are going to fit the depreciation curves implied by our two factor model with respect to EBITDA/CAPEX and for different categories of ships from the tanker industry and the dry bulk industry. We have used data from five consulting firms and we have carefully ruled out any inconsistencies among the different sources. As a proxy for the long term time charter ("risk free freight rate"), we have used the one year time charter rate and as operating expenses we have used an estimate from different sources. With these two inputs we calculated the EBITDA/CAPEX ratio and given the prices for new buildings and vessels in the second hand market we calculated depreciation. By fixing the age of the ship at  $t = 5, 10, 15$  years we are able to collect data from 1993-2002 for the tanker sector and from 1976-2002 for the dry bulk sector. For each month we observe the prevailing EBITDA/CAPEX ratio and the depreciation ratio for ships five, ten and fifteen years old for the ships in different categories.

Fitting the observed data into the exponential depreciation curves, namely:  $D(t, T) = \exp(A(t, T) - rB(t, T))$  is equivalent to fitting the depreciation

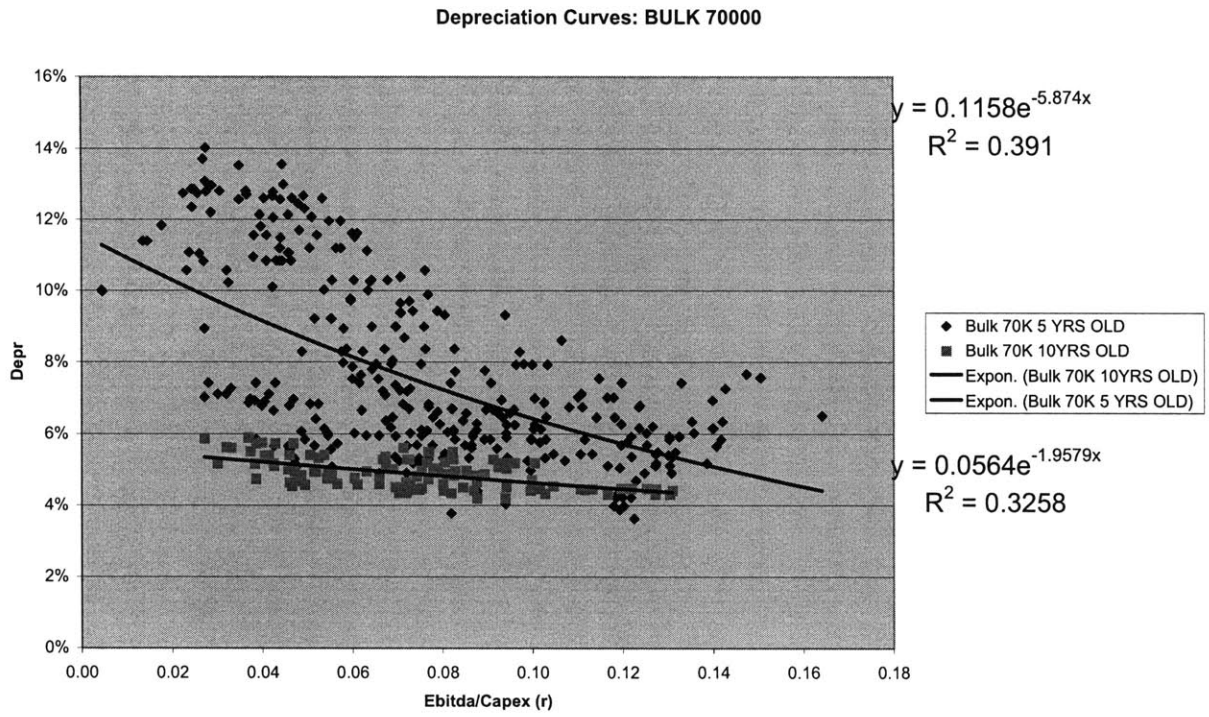


Figure 10: Depreciation Curves: Bulk 70000

function for each type of ship and age with respect to the prevailing ratio. In the case of the tanker industry and specifically for VLCC's and SUEZMAX this type of exponential fitting has yielded an  $R^2 = 0.90$  and the characteristics of the observed depreciation curves are consistent to our model. The derived curves and the depreciation curves are plotted in Figures 11 and 12 respectively.

Following the same procedure for the category of SUEZMAX we achieve a very high fit and consistency of our model with market data. The observed non - linearity implies strong evidence for the hidden real option or asset play value in the prices of second hand vessels.

## **6.5 Conclusions: The Market Price of Shipping Investment Risk and Future Research Directions**

There are several assumptions that may seem strong regarding our previous discussion. Most of them, such as the assumption of the same interest rate for borrowing and lending, or of an arbitrage portfolio that yields instantaneously the one process may be relaxed. Making the setting more realistic might result in a system of forward - backward differential equations and in advanced computational complications. However the strongest assumption remains the one of continuous trading that seems unrealistic, especially in a thin and illiquid market such as the market for second hand vessels. For our good luck we can cut corners to this problem once we have identified the factors that determine the value of the asset and the payoff it generates, by introducing the optimization analogous problem. This problem is far more general and applies to identifying good and bad deals for the pricing of risky payoffs. Dixit and Pindyck [28] and Cochrane [18], in his seminal paper, have first addressed this problem. Intuitively we are interested in determining "good deals" and "bad deals" for risky payoffs, given we have identified the factors that determine the payoff and the value of the asset. The specification of the risky payoff allows on the one hand the modelling of the payoff of the asset ship and simultaneously its value as an asset traded in the second hand market. We shall now proceed with the general setting of the problem. In order to be in line with our setting and our empirical findings let us assume that the value of the vessel is determined by the following two factors: The one factor is the ratio of EBITDA/CAPEX, which may be considered as a proxy to the required investment recovery period and is close to the P/E

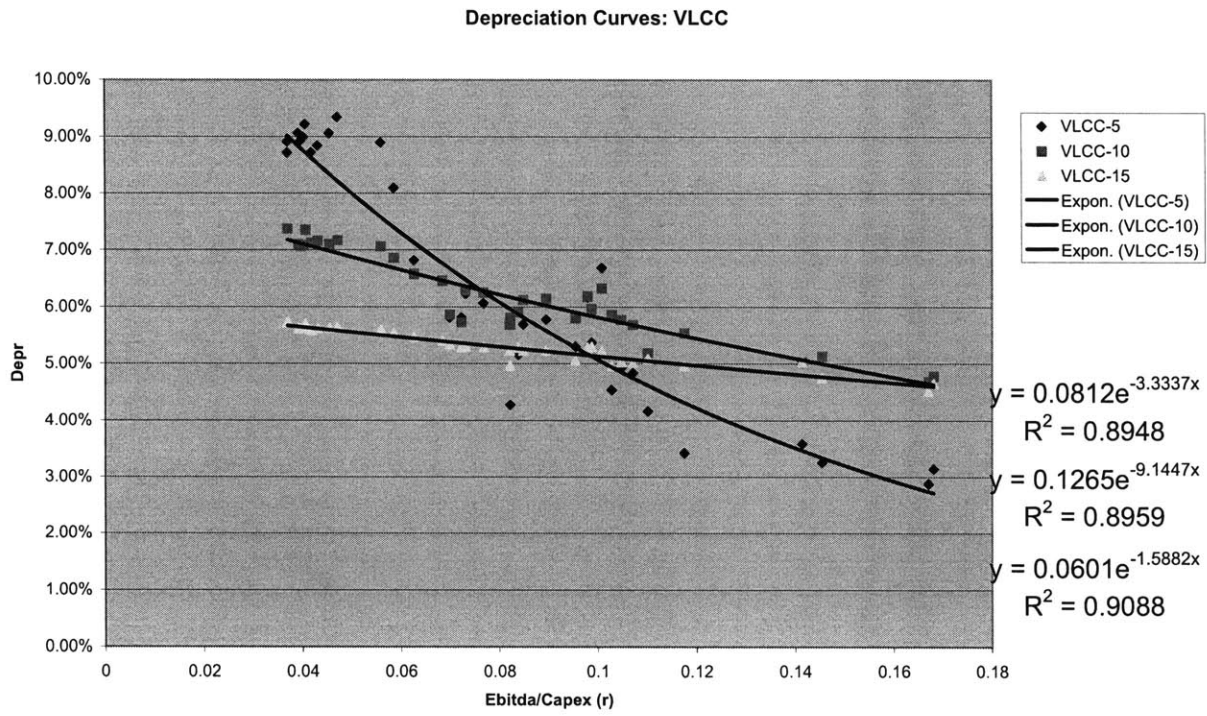


Figure 11: Depreciation Curves: VLCC



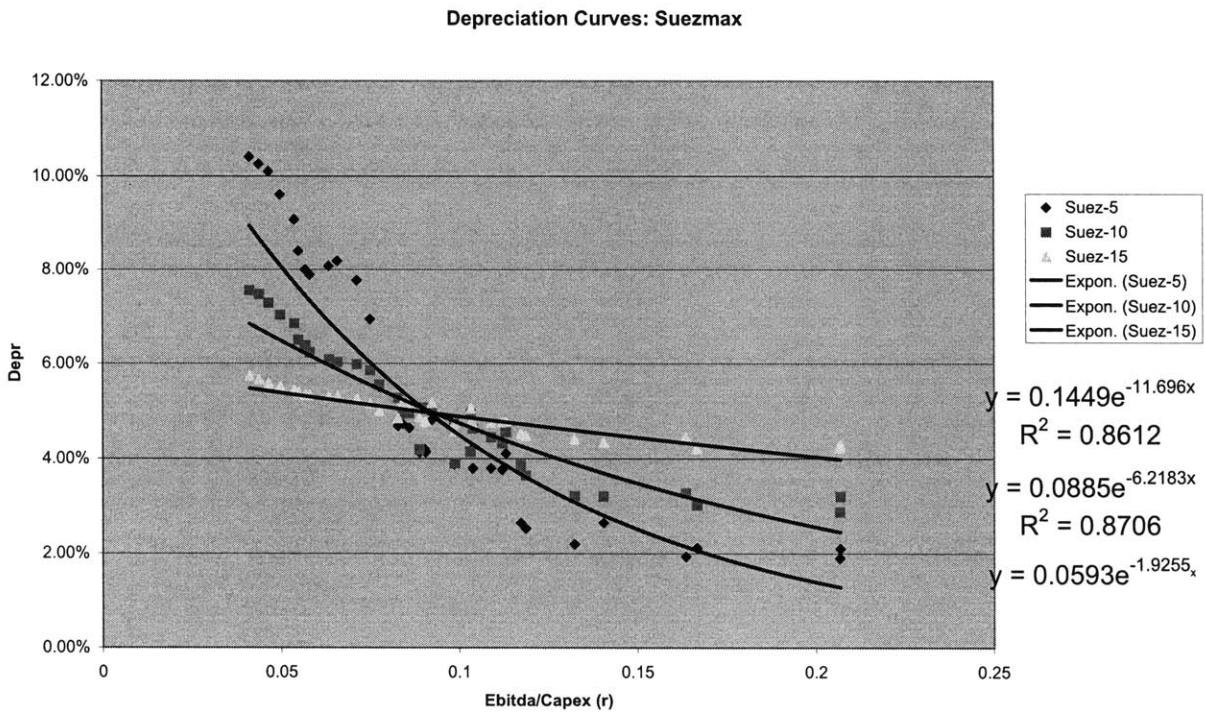


Figure 12: Depreciation Curves: Suezmax

ratio that is a common factor for stock returns. The reason why freight rates are not a good factor (to the contrary of the beliefs of shipping economists) is because it is not scale or type invariant. The second driving factor is the price of new vessels. This process incorporates new technical advances as well as the economic conditions (or political conditions, such as subsidies). For example a productivity improvement will result in a decrease of the drift term of the process, whereas an increase in political uncertainty will be reflected on a higher volatility term. Having specified these two factors, the payoff of a ship is simply the product of these two factors and shall be denoted by  $x_s^c = r \cdot CX$  and the terminal payoff or scrap value shall be denoted  $x_T^c$ . Then the problem we are interested in solving is stated in Cochrane [18] as following:

$$F_t = \min E^P \int_{s=t}^T \frac{\rho_s}{\rho_t} x_s^c ds + E^P \left( \frac{\rho_T}{\rho_t} x_T^c \right) \quad (98)$$

The problem is to specify a discount factor process  $\rho_s$  that minimizes the above equation, namely the discounted value of the payoffs and the scrap value of the vessel. The expectation is taken under the P-dynamics (statistical dynamics) of the process. However, from the risk neutral valuation theory we can restate the minimization problem under the equivalent martingale measure (a consequence of the absence of arbitrage) as following:

$$F_t = \min \exp(-r(T-t)) E^Q \int_{s=t}^T x_s^c ds + E^Q(x_T^c) \quad (99)$$

This is the equivalent risk neutral formation of the problem: If continuous trading were possible and the underlying assets were traded then the martingale measure would be uniquely defined and the market price of risk processes would be unique. However, since continuous trading is not possible and the market is incomplete the market prices of risk processes are not uniquely defined. The above risk neutral specification of the problem has the advantage that if we extend the underlying processes beyond diffusions, we have analytic specifications for the moment generating function of the wider class of affine processes. Thus, there are advantages when the problem is posed under the Q-dynamics, especially when one includes jumps in the processes. The solution of the above problem for a wider class of processes than the ones considered by Cochrane [18] remains still an open and essential problem since it allows the valuation of risky payoffs in incomplete markets, where continuous trading might not be possible. The extension to the dif-

ferential characterization of the 'good deal' bounds for wider processes than Ito [28] diffusions is essential to the valuation of risky payoffs in incomplete markets.

Before concluding, there is an important comment to be made: In our empirical derivations we stacked pairs of (EBITDA/CAPEX, Depreciation) observations in a graph. We observed however that at different times snapshots for the same EBITDA/CAPEX different depreciation values were documented. This implies strong evidence for a time varying market price of risk. Unfortunately, if we do not make some assumptions about the nature of the market price of risk, we cannot find the closed form solution to the depreciation curves and we cannot extract the time varying risk from market data. We are faced with an open loop problem: If we do not specify some characteristics for the market price of risk, we cannot extract it. This implies that we are not only questioning our assumptions about the model but also about the market price of risk. An alternative approach to this philosophical problem that limits substantially our ability to make any inferences on the time varying prices of risk can be overcome in a robust control setting, as the one introduced in the seminal work of Hansen et. al. [33].

## 7 Conclusions

### 7.1 Empirical Limitations

Before proceeding with a discussion of the main conclusions of this Thesis, as well as some topics for further research we shall discuss some of the limitations of our analysis, particular due to the nature of this industry and the data available. <sup>21</sup>

In all three modules we have derived models that are consistent to the notation of partial or general equilibria. However, the character of the data is illiquid and the time charter rates quoted are averages, mainly based on the time charter rates quoted by modern ships, since older ships are usually not reported. Furthermore, there is a term structure charter rates, with the spot market exhibiting persistently higher volatility than the time charter volatility. Due to the unavailability of data on the term structure, it has not been feasible to introduce term structure decisions in our analysis.

Furthermore in all markets, (especially the Sale and Purchase market) there are unreported transactions, which implies that there might be a significant selection bias when performing an econometric analysis in these markets.

Finally, there are significant policy issues which are clearly not included in our analysis. Governments can create uncertainty through the prospect of policy change. This is particularly relevant in the Tanker Industry, since the potential phase out of all mono-hull tankers is suggested and discussed. Expectations of **shift of policy** can have a powerful impact on entry and exit decisions. Accidents and the proposed phase out of tanker vessels clearly affect the newbuilding and scrapping process by introducing a jump in the time charter process and the price of new vessels, which clearly violates the assumption of market completeness and distorts the value of the option to wait. Furthermore, tax credit policies and uncertainty about the enactment of stimulus policies and packages have a profound impact on the investment and production process. Although it is possible to model such events as in Dixit and Pindyck ([28] p.303) this task is left for further research. [25]

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<sup>21</sup>This section draws heavily on a personal communication of the author with the President of Marsoft, Dr. Arlie Sterling. I once more express my thanks and appreciation to Marsoft for all the support.

## 7.2 Summary of Results

This Thesis has been devoted to the derivation of the Transportation Supply Function for the Tanker sector, based on quarterly data from 1980-2002. We have followed precisely the seminal monograph of Zannetos [64], where many of the qualitative arguments made by Zannetos have been proved quantitatively, based on theoretical foundations. Whilst performing this task we have restored some of the oldest fallacies in Maritime Economics. Finally we have identified the stabilizing and destabilizing forces in the process of time charter rate formation.

There are three main markets surrounding agents in the Tanker Industry. The first one is the Real Market that determines the transportation supply function. The transportation supply function is determined by entry, exit and lay-up decisions, which have been analyzed in Chapters 3, 4 and Paragraph 5.1. The issue of interrelating these three different actions that determine the supply of transportation capacity, as well as the necessary assumptions, have been derived based on the classical model by Devanney [20]. The calibration of the system has been performed in Chapter 5, where both statistical and deterministic price models have been derived and compared.

The second one, is the Auxiliary Market for second hand vessels, which has no impact on the supply and demand process. Therefore we may consider the price process for this particular market as exogenous and derive a partial equilibrium model for second hand prices. This task has been successfully performed in Chapter 6.

The last one is the Risk Sharing Market, where the term structure of time charter contracts is determined. The theoretical framework for undertaking this task is exogenous to both the Real and Secondary Market. The market for contracts satisfies the need for risk sharing among agents and has been addressed in the recent work by Adland [3].

## 7.3 Applications of the Model in Policy and Business

During the estimation and specification of the submodules that constitute the supply function we have performed the interim task of addressing several assertions of Economic Theory. The particular structure of the tanker market industry (perfect competition, “the ship is the firm”) has provided us with a unique framework for the empirical testing of the Real Option markup hypothesis and other count models of entry and exit, derived in an equilibrium

framework. Although several questions of the utmost importance have been thoroughly addressed, we have basically employed Economic Theory, in order to reduce the dimensionality and complexity of the system and in some sense, these two tasks (of reducing the dimensions of the problem and test theory) have been interrelated. Advanced econometric methods have not only served the task of identification; they have also provided us with a *consistent* tool for simultaneously testing theory and the power of each submodule, helping us choose the specification that “squeezes out” all information contained in the data. Once we have chosen a specific class of aggregate models, any empirical test has been conducted on the conditional knowledge that this model is a valid approximation of reality within an admissible subclass of models.

From a theoretical point of view we have accomplished far more beyond our initial tasks. The ultimate goal of this project has been the development of models that will allow policy makers and investors to improve the quality of their decisions. This has been the applied goal and results in 5.7 have (hopefully) justified our initial expectations to undertake the derivation of a Devanney-type model with aggregate data, based on the “Bottom-Up” approach.

Policy makers may employ the model in order to simulate the effects of policies on the market. Although (following Lucas’s critique) new policies will have a profound impact on the value functions of entry and exit and consequentially, on the aggregate models of entry and exit, it is really doubtful if they will have a significant effect on the aggregate Lay-Up and productivity function. It therefore becomes apparent that policy simulations can be performed within this framework. For example, there is significant uncertainty on the impact of the new European Union “phase out” policies on the tanker industry. By specifying the effects of the proposed regulations on the scrapping and newbuilding functions the system will generate the equilibrium prices, the price of new vessels, as well as the capacity required to restore equilibrium in the market. Given these estimates, regulators may then conduct a more efficient and quantitative assessment of their proposed regulations and measure consumer surplus, social welfare or even the loss of the “option to wait” before imposing new regulation. Overall, this model provides policy makers with a quantitative tool that allows them to simulate the effects of their policy and assess the short term and long term effects of different policies on time charter rates, the dynamics of prices of new vessels and the long term stability of the tanker industry.

On the other hand, investors will have different objectives than policy

makers. The General Equilibrium (5.2-5.3) approach provides them some additional insight into the effects of economic factors on the parameters of statistical models, whereas the System Dynamics approach (5.5-5.7) is a consistent tool that allows them to project their expectations regarding future demand patterns, on future prices and evaluate alternative demand patterns. Since the only exogenous required input to the system is demand, each owner has to have some a priori belief on future demand, which once inserted in the system will generate market clearing rates, prices of new and second hand vessels, as well as fleet capacity and productivity. These forecasts will improve the ability of investors to evaluate business decisions and narrow down uncertainty in terms of their ability to predict demand within an acceptable level of tolerance, rather than extrapolating their forecasts (and the associated uncertainty of the forecast) on all the inputs and outputs of the system.

## 7.4 Topics for Further Research

In terms of the time charter rate dynamics we have not touched upon any issues of the term structure of charter rates. This has been done in an advanced statistical framework by Adland [3], who identifies and estimates alternative specifications for the stochastic specification of time charter rates. In some sense Adland's work is complementary to the work undertaken in this Thesis, since it addresses the issue of the term structure of charter rates. One drawback of Adland's approach is that he imposes no economic structure on the problem. A utility based framework seems a promising candidate for resolving this issue. However, from the view of economic theory there should be no difference whether supply is quoted in spot rates or the time charter rate equivalent. However, due to risk preferences and uncertainty a utility based approach to the term structure seems an interesting topic for further research. Given the structural process  $S_t$  for the time charter rate equivalent of the spot rate and  $F_t(T)$  the time charter rate at time  $t$ , with "maturity"  $T$ , the expected utility from employing the ship in the spot market should be equal to the utility acquired from fixing the ship.

$$dS_t = \mu_S(S_t)dt + \sigma_S(S_t)dB_S^t \quad (100)$$

$$dF_t(T) = \mu_{F_t(T)}(F_t(T))dt + \sigma_{F_t(T)}(F_t(T))dB_F^t \quad (101)$$

$$EU\left(\int S_t dt\right) = U(F_t(T)) \quad (102)$$

And in a competitive equilibrium the process  $S_t$  has to be derived endogenously for  $j = 1, N$  competitive agents:

$$\int_t^T S_s ds = \int_J F_{t,T}^j \mu(dj) \quad (103)$$

However, the issue of the term structure can only be addressed once a structural process has been specified that brings markets to equilibrium, as is the case in this Thesis. Once this process is either *apriori* or structurally specified and issues of risk sharing are specified, then the competitive equilibrium time charter term structure may be easily derived. This task is left for further research in the field and it completes the trilogy of markets in Maritime Economics.

Many unanswered questions also remain about dynamic entry, exit, temporary suspension, duration of chartering and capacity choice decisions both on a firm specific level, as well as on an aggregate level. In this Thesis we have imposed Economic assumptions that have reduced the parametric space of the model. Complete markets and reduced value functions in a partial equilibrium setting have been very helpful towards the derivation of the modules in the previous chapters.

On a firm specific level a dynamic analysis of firm specific choices seems necessary for the determination of the variables that agents take into consideration when forming the decisions, as well as a comparative tool of performance evaluation. The choices of entry, exit, duration of the contract and capacity choice can all be addressed on a firm-specific level, given data from a panel of firms. Given the associated profitability of the firms, studies of **performance evaluation** seem challenging.

On an aggregate basis it still remains open to forgo the **independence of actions** assumption and consider the Full Dynamic Programming Problem as introduced by Devanney [20]. This will allow the simultaneous derivation of optimal policies. It then remains open to determine aggregate equilibrium models on an integrated framework. Standard approaches to this problem as in Pakes *et.al.* [7] seem inappropriate, because on the one hand the market has a satisfactory proximity to perfect competition and on the other hand the number of agents is very big in this market.



Entry, exit, duration of commitment and temporary suspension are all discrete choice decisions which can be addressed by using the artillery of modern econometrics, simply by replacing the associated utility functions by value functions. It seems challenging indeed to carry out a dynamic analysis both on firm specific data, as well as on aggregate data in a general equilibrium framework.

# A Glossary

## Chapter 3

- $\lambda$ : intensity of the Poisson process  $P(\lambda)$
- $P_{eff}$ : probability of action of the most efficient operator
- $V_n, I_n$ : value and investment cost of a project
- $\pi_{invest}$ : probability of entry
- $V_{opt}$ : excess Real Option value of entry [28]
- $mup$ : the Real Option markup [28]
- ships: number of vessels ordered each quarter (source: *Marsoft*)
- dwt: tonnage of new ships ordered each quarter (source: *Marsoft*)
- $\ln\pi$ : the log of  $\pi$
- NLLS: Non Linear Least Squares
- PQMLE: Partial Quasi Maximum Likelihood
- NB: Negative Binomial
- OLS: Ordinary Least Squares
- const: constant of the regression
- $ship_k$ : lags of ships of order  $k$
- tcrate: one year time charter rate (source: *Marsoft, Clarksons, Roar Adland* [3])
- newprice: the price of new vessels (source: *Clarksons*)
- accident: a dummy for the *Erika* accident
- lrate: the FED lending rate (source: *Datastream*)
- $V_{opt, lag}$ : lags of the Real Option value

- opex: operating expenses (source: *Clarksons, Marsoft, etc.*)
- VV:  $V_{opt}^2$
- tcs:  $tcrate^2$
- dwg: a deadweight dummy variable
- lnn: logarithm of *newprice*
- oil: prices of crude oil (source: *Datastream*)
- spoil: Standard and Poor's oil price index (source: *Datastream*)
- air: Standard and Poor's index of air transportation (source: *Datastream*)

#### Chapter 4

- $\pi_{0exit}$ : probability the most efficient operator does not exit the market
- $V_{stay,scrap}$ : the value to stay in the market or scrap, respectively
- $scr$ : aggregate scrapped tonnage each quarter (source: *Marsoft*)
- $scrk$ : lags of  $scr$  of order  $k$
- $crt$ : capital replacement time calculated in equilibrium
- $tci, opi$ :  $tcrate$  and  $opex$  category weighted indexes
- ARMA( $p,q$ ): Auto Regressive Moving Average process of order  $p$  and  $q$
- D2SLAD: Double Two Stage Least Absolute Deviations Estimator
- AR( $p$ ): ARMA( $p,0$ ) process
- 2SLS: Two Stage Least Squares Estimator
- TARARCH: Threshold Auto Regressive Conditional Heteroscedasticity process
- (E)GARCH: (Exponential) Generalized Conditional Heteroscedasticity process
- QR: Quantile Regression

#### Chapter 5

- $lay$ : aggregate tonnage in lay-up (source: Personal communications)
- $layk$ : lag of  $lay$  of order  $k$
- $itci$ : inverse of  $tci$
- $fleet$ : total fleet in tonnage (source: *Marsoft*)
- QMLE: Quasi Maximum Likelihood Estimator

- $D$ : takes first difference
- $arLk$ : coefficient of the Auto Regressive term of order  $k$
- $het_y$ : coefficient of the conditional heteroscedasticity variable  $y$
- $earchLk$ : coefficient of the *EARCH* term of order  $k$
- $dmd$ : demand for tanker transportation capacity (source: *Marsoft*)
- $DD$ : equals  $dmd$
- $busp$ : the forecasted time charter rate from the System Dynamics output

## B Appendix B

Let  $X$  be a random variable with Poisson distribution; namely:

$$X \sim P(X = x|\lambda) = \exp(-\lambda) \frac{\lambda^x}{x!}$$

The associated Moment Generating Function of the Poisson distribution is:

$$M_x(t) = \exp(\lambda(\exp(t) - 1))$$

If  $d$  is an integer then  $Y = d \cdot X = \sum_{j=1}^{N=d} X_j$ , where  $X_j \sim P(\lambda)$ , *in.i.d.*.

Then the Moment Generating Function of  $Y$  is the following:

$$M_y(t) = E \exp(-t \sum_{j=1}^d X_j) = \prod_{j=1}^d \exp(\lambda(\exp(t) - 1)) = \exp(\lambda \cdot d(\exp(t) - 1))$$

This Moment Generating Function implies that  $Y \sim P(\lambda \cdot d)$

The above derivation can be generalized for the case where  $X_j$  are *in.i.d.* distributed with  $X_j \sim P(\lambda_j)$ .

Then, following the same argument:

$$Y = \sum_{j=1}^d X_j \sim P(\sum_{j=1}^d \lambda_j)$$

Now let  $B_j, j = 1, N$  denote *in.i.d.* Bernoulli random variables with  $B_j \sim B(p)$ . Then the Moment Generating Function of  $Y$  is:

$$\begin{aligned} M_y(t) &= E \exp(-t \sum_{j=1}^N B_j) = E \exp(\prod_{j=1}^N \exp(-tB_j)) = E_N E_{Y|N} \exp(\prod_{j=1}^N \exp(-tB_j)|N) \\ &= E_N ((1-p) + p \exp(t))^N \end{aligned}$$

Now set  $\beta = (1-p) + p \cdot \exp(t)$  and:

$$E_N \beta^N = \sum_{k=0}^{\infty} \beta^k \lambda^k \frac{\exp(-\lambda)}{k!} = \sum_{k=0}^{\infty} (\beta \cdot \lambda)^k \frac{\exp(-\lambda)}{k!} \exp(-\lambda \cdot \beta) \exp(-\lambda \cdot \beta) = \exp(\lambda(\beta-1))$$

Combining the previous two results we get the following specification for the Moment Generating Function:

$$M_y(t) = \exp(\lambda \cdot p \cdot (\exp(t) - 1))$$

This implies that

$$Y \sim P(\lambda \cdot p)$$

## C Appendix C

$$r_t = \exp\left(\frac{1}{\theta_1} \cdot \left(\frac{DD_t}{AMF_t} + \theta_2 - \theta_3 \cdot Lay_t\right)\right) \quad (104)$$

$$AMF_t = AMF_{t-1} + New_t(r_t, x_t) - Scr_t(r_t, x_t) - Lay_t(r_t, x) \quad (105)$$

$$Lay_t(r_t, x) = \frac{\alpha_L}{r_t^2} + \beta_L \cdot x_t \quad (106)$$

$$New_t(r_t, x_t) \sim P(\lambda(r_t, x_t)) \quad (107)$$

$$\ln(Scr_t(r_t, x_t)) \sim ARMA(2, 4) \quad (108)$$



## D Appendix D

We assume  $n$  heterogenous agents, who consider exiting the market. Given the assumption of **independent actions**, each of them solves his own Dynamic Programming problem and determines his optimal threshold of exit, as well as his own value function  $V_{jt}$ , where  $j$  stands for the  $j$ -th agent and  $t$  stands for time. Each agent determines his value function from choosing optimally to remain in the market and operate the vessel, which will be denoted  $V_{jt,stay}$  hereafter and his associated value function from optimally deciding to exit the market as  $V_{jt,exit}$ . We assume that each agent assigns a Markovian specification to the process, which implies that all value functions are determined by the variables at time  $t$  and the parameters of the process. We furthermore assume that the number of vessels each agent scraps follows a Poisson process with intensity  $\lambda_{jt}$  and the **probability of no exit** for each agent is:<sup>22</sup>

$$p_{jt,0-exit} = \exp(-\lambda_{jt}) \quad (109)$$

By assuming that the risk premia offered by shippers (observed by the owners, but not by the econometrician) or scrappers belong to the family of Extreme type errors, the above probability is also equal to:

$$\exp(-\lambda_{jt}) = \frac{\exp(V_{jt,stay})}{\exp(V_{jt,exit}) + \exp(V_{jt,stay})} \quad (110)$$

This specification implies that the probability of zero exit (or the probability to remain in the market) is a monotonic function of  $V_{jt,stay}$ ; the corresponding value derived from market presence. Solving for the intensity  $\lambda_{jt}$  we get the following equation:

$$\lambda_{jt} = \ln(\exp(V_{jt,exit}) + \exp(V_{jt,stay})) - \ln(\exp(V_{jt,stay})) \quad (111)$$

Hereafter we suppress the time index  $t$  and set:  $z_j = V_{j,exit} - V_{j,stay}$ ; then the first order Taylor expansion for  $\lambda_j$  has the following form:

$$\lambda_j = \ln 2 + \frac{\exp(z_j)}{1 + \exp(z_j)} \cdot z_j \quad (112)$$

or:

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<sup>22</sup>It seems interesting to investigate if we can derive this specification in a utility-based structural framework.

$$\lambda_j = \ln 2 + p_{exit,j} \cdot z_j \Rightarrow \lambda_j = \ln 2 + p_{exit,j} \cdot V_{j,exit} + p_{stay,j} \cdot V_{j,stay} - V_{j,stay} \quad (113)$$

Now we observe that the expected value of operating or exiting this market optimally is:

$$E_j[V] = p_{exit,j} \cdot V_{j,exit} + p_{stay,j} \cdot V_{j,stay} \quad (114)$$

Plugging into our previous equation we get the following specification for  $\lambda_j$ :

$$\lambda_j = \ln 2 + p_{exit,j} \cdot z_j \Rightarrow \lambda_j = \ln 2 + E_j[V] - V_{j,stay} \quad (115)$$

The following specification of the intensity is valid as long as  $\ln 2 + E_j[V] - V_{j,stay} \geq 0$ , which implies that the specification for the aggregate intensity  $\lambda$  is the following<sup>23</sup>:

$$\lambda = \ln 2 \cdot n + \left( \sum_{j=1,n} \ln 2 + E_j[V] - V_{j,stay} \right)^+ \cdot \left( \sum_{j=1,n} \ln 2 + E_j[V] - V_{j,stay} \right) \quad (116)$$

Taking a closer look we observe that  $E_j[V]$  corresponds to the value of owning a second hand vessel for a **risk neutral** investor. Since an organized market exists for second hand vessels we assume that under risk neutrality  $E_j[V]$  is the same for all agents and it corresponds to the market or second hand price of the vessel. It includes the value of operating the vessel and the option to wait and therefore exceeds  $V_{j,stay}$ . Our final assumption is the following:

$$plim \sum_{j=1}^n \frac{V_{j,stay}}{n} = \widehat{V_{stay}} \quad (117)$$

which implies that heterogenous beliefs converge to an average, which is invariant to the number of agents, namely to the value an agent would assign if he had perfect knowledge of the process. This implies that heterogenous beliefs for the value function converge to the unique value function that corresponds to a rational expectations equilibrium. Convergence to a competitive equilibrium requires convergence of beliefs to the equilibrium process. Persistent deviations from equilibrium would either result in breaks in the intensity, or under the prisma of complete markets, in arbitrage opportunities. The

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<sup>23</sup> $(x)^+ = \max(0, x)$

intuition behind this assumption is that otherwise some players could persistently outperform the market, by taking advantage of the inability of other agents to converge towards the true process. The above specification implies that to first order at least, the mean conditioned on the number of agents is multiplicative in the number of agents  $n$  and coincides with the specification of the complete market model. This implies that the source of extra volatility needed is either due to the remaining terms of the approximation or the dynamics of the population  $n$ . The basic claim of our model is that **heterogenous beliefs do not distort the multiplicative mean specification, at least in the long run**. The only extra source of volatility is now due to the evolution of agents.

One more implication from the above specification is that there could be breaks in the intensity of the Poisson process of aggregate scrapping data, arising from disequilibrium and heterogeneity. We obtain the following specification for the intensity, for these values that result in an indicator function equal to one:

$$\lambda_{bear} = \ln 2 \cdot n + \sum_{j=1}^n [E_j[V] - V_{j,stay}] = (\ln 2 + (\overline{E}[V] - \widehat{V}_{stay})) \cdot n \quad (118)$$

In a “bullish” market the indicator function is “to first order” equal to zero, since the value of remaining in the market is high enough to offset any expected value added by the option to scrap. This is a rather simplistic approach, which however provides us with a good motivation for considering a Poisson process with **structural changes**, as a result of the interaction of heterogenous agents.

To complete our model specification we have to determine the intensity of the Poisson process for the number of the  $n$  heterogenous agents that is mainly determined by capital replacement decisions and physical depreciation, as well as a reduced form for  $\overline{E}[V] - \widehat{V}_{stay}$ . At this point we should note that if one of the assumptions of our model fails, the population dynamics are exogenous and cannot be uniquely determined in equilibrium.

Regarding the specification of the dynamics of the population of agents  $n$ , we assume  $n$  follows a Poisson process with intensity determined by the total existing tonnage and the ordered tonnage for new vessels. This specification captures the effect of **capital replacement**, as well as physical **depreciation**. A high number of pending orders implies a higher number of

scrapped tonnage, due to capital replacement purposes, whereas the higher the existing tonnage, the higher the effect of physical depreciation.

The above specification manages to capture the three different effects that contribute to the scrapping process: The number of agents interested in potential scrapping activity due to capital replacement and physical depreciation are determined by the existing fleet and the pending orders, whereas the pure exit decision is determined by the payoffs and risk-adjusted returns in this market. More specifically

$$n \sim P(\mu_n)$$

with  $\mu_n = \exp(X'\beta)$ , where  $X$  are the following explanatory variables: Pending orders for new vessels (*ord*), the total tonnage of the existing fleet (*fleet*) and the ratio of the price of a new vessel (*newprice*) divided by the annualized net earnings (*ebitda*), having assumed a log-normal process. The last variable *crt* is similar to an inverse  $P/E$  ratio and gives an approximation to the time needed to recover the capital.

Regarding the specification of  $\lambda$  we assume the following reduced form, that ensures non-negativity:

$$\lambda = \exp((X'\alpha) \cdot (X'\alpha)^+) \quad (119)$$

And combining both we have the following specification for the intensity of the **aggregate quarterly scrapped tonnage**:

$$\lambda_{t,t+T} = \exp(\ln(\kappa) + X'\beta + X'\alpha \cdot (X'\alpha)^+) \quad (120)$$

The above specification resulted from the interaction of heterogenous agents and implies that there is a structural change in the process, depending on the market conditions. Our basic claim however remains: to first order at least, agents heterogeneity does not distort the multiplicative in  $n$  conditional mean specification. Before proceeding with the estimation of a Poisson model with a structural break we shall discuss the following variation on the previous model.

Let us now reconsider the solution in 4.2 that will result in the same multiplicative specification of the intensity without implying the existence of breaks. We assume  $n$  heterogenous agents with **exponential utility** and we suppress the index  $j$  hereafter. We assume that each agent has a value  $V^{eq}$  for which he is willing to scrap his vessel or sell it in the second hand

market. The utility from this value is then equal to the expected utility from remaining in the market and operating the vessel:

$$-\exp(-V_{eq}) = EU(V) = p_{exit}U(V_{exit}) + p_{stay}U(V_{stay}) \Rightarrow \quad (121)$$

$$\exp(-V_{eq}) = \frac{\exp(V_{exit})}{\exp(V_{exit}) + \exp(V_{stay})} \cdot \exp(-V_{exit}) + \frac{\exp(V_{stay})}{\exp(V_{exit}) + \exp(V_{stay})} \cdot \exp(-V_{stay}) \Rightarrow \quad (122)$$

$$\exp(-V_{eq}) = 2 \cdot \exp(-\lambda) \cdot \exp(-V_{stay}) \Rightarrow$$

$$\lambda = \ln 2 + V_{eq} - V_{stay} \quad (125)$$

This result is interesting: the intensity determined by an agent with an exponential utility coincides with the intensity we derived previously by using a first order approximation. Since there exist organized markets for the second hand price of vessels, we assume that  $V_{eq}$  is the price of the vessel in the market and it is the same for all agents. Furthermore, by assuming:

$$plim \sum_{j=1}^n \frac{V_{j,stay}}{n} = \widehat{V_{stay}}$$

we obtain the same specification for the aggregate intensity; namely the conditional mean is **multiplicative** in the number of agents.

The key conclusion of this simple model of heterogenous agents is that under the existence of organized markets and convergence of beliefs, **investor heterogeneity** does not have a significant impact. In section 4.3 we demonstrate that unlike investor heterogeneity, the evolution of the population of the number of agents  $n$  is crucial to the specification of this model.

Before concluding this section we present the results from estimating the Poisson model with a structural break in the intensity of the Process. It is well known that if the separation function (the function that assigns each observation to a specific regime) is known in advance, then we may simply estimate the model by separating the data. If the separating function is unknown or endogenous, then estimation can become complicated, especially given the small number of observations available in our case.

**Table D1 Appendix D**

Model	PQMLE (Boom)	PQMLE (Recession)
scr1	-.0834 (.0781)	.0287 (.0385)
scr2	-.0280 (.0864)	.0983 (.0269)
tci	-.000141 (.000055)	-.0000971 (.000028)
opi	.0002791 (.000258)	.0003061 (.000059)
crt	-.6250 (.2461)	.0036 (.0046)
cons	8.037 (4.417)	.1969 (.3411)
R <sup>2</sup>	.0892	.2497

We assume that the separation variable is  $crt$  which is the Marshallian rate of return and corresponds to an estimate of the capital replacement time. We estimate the model for  $crt < 10$  (boom period) and for  $crt > 10$  (recession period). We then perform a generalized *Chow* test. Results are displayed in *Table D1*. The generalized *Chow* test is a special case of the Hausman [36] specification test. Under the null that coefficients are equal in both regimes, we obtain efficient and consistent estimators, when imposing the restriction of equality, but inconsistency under the alternative, under which our restriction is invalid. If we estimate the model taking into account the two regimes, then our estimation is consistent, but inefficient under the null. Thus, the generalized *Chow* test is a special case of the Hausman specification test and in our case it is a  $\chi(6) = 22.78$ , which clearly rejects the equality of coefficients in both regimes. One major limitation of this test is that it is very sensitive to the *a priori* knowledge of the separation function.

The results are displayed in *Table D1*. By inspecting the residuals it becomes apparent that very little has been gained by assuming a structural break, whereas the main deficiencies of the specification are still present. This finding provides additional motivation to our key conclusions in Chapter 4.

## References

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