Options on Shipbuilding Contracts

by

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ABSTRACT

Analysis of investment projects and strategic decisions using option theory has gained wide acceptance among corporate finance scholars and professionals. In the shipping and shipbuilding industries, option analysis is still in its infancy, and few professionals are familiar with option valuation tools. At the same time, practically all shipbuilding contracts contain option elements, the value of which most industry players do not know how to calculate. Newbuilding options give shipowners closing newbuilding contracts a right, but not an obligation, to enter into additional newbuilding contracts, with predetermined terms, at a later date.

This thesis presents a general introduction to option theory as it applies to traded financial securities. This framework is extended to newbuilding options. Characteristics of the newbuilding markets are given, and fundamental stochastic processes that can describe newbuilding prices are introduced. Based on these stochastic processes, closed-form formulas for calculating the value of newbuilding options are presented. Actual observations of shipbuilding prices are analyzed in the context of the stochastic models. The results of this analysis are discussed as they apply to the option formulas and to the practical aspects of the newbuilding option framework. Recommendations are given on how to analyze real cases in which newbuilding options appear.

Thesis Supervisor: Henry S. Marcus
Title: Professor of Marine Systems

Biography of Author

Morten W. Høegh was born in Oslo, Norway in 1973. Upon completion of the Norwegian Certificate of Secondary Education at Oslo Katedralskole in 1992, Mr. Høegh entered the Norwegian Army to complete the mandatory national service. He was selected for the Military Russian Program at the Defense Intelligence and Security School, and here he studied Russian language and was trained as an officer. Mr. Høegh graduated as Best Cadet from the program in December 1993, and went on to complete another six months of Russian studies at the University of Bergen.

Mr. Høegh was admitted as a freshman to the Massachusetts Institute of Technology in 1994. He selected Ocean Engineering as his undergraduate major, and was accepted as a dual-degree candidate in Ocean Systems Management in his junior year. He is expected to graduate in June 1998 with a Bachelor of Science-degree and a Master of Science-degree in OE and OSM, respectively. Mr. Høegh was awarded the Ocean Engineering Prize for Undergraduate Research and Academic Accomplishment in 1997.

Mr. Høegh volunteered as a host and interpreter for the Russian delegation at the Winter Olympics in Lillehammer, Norway in 1994. His internships have led him to work for a shipping company in St. Petersburg, Russia, and for an investment bank in London, UK.

Mr. Høegh is fluent in Norwegian, English and Russian.

Acknowledgements

I would like to thank my thesis supervisor, Professor Henry S. Marcus, for accepting my idea to undertake this thesis project and for giving valuable help and guidelines during the course of the project. His enthusiasm for the shipping industry serves as great motivation for all students in the Ocean Systems Management program, and I hope that I will be able to bring some of it with me in my future professional career.

I also owe gratitude to Professor Nicholas M. Patrikalakis and Mr. Fred Baker of the Ocean Engineering Design Lab at MIT. I am thankful for the opportunity to access the computer facilities in the laboratory.

Finally, I would like to thank all those who have assisted me in one way or another throughout this project. They include many shipping and shipbuilding professionals who have had the patience to share valuable information and practical insight into the subject matter of this thesis, as well as fellow students who have helped me with theoretical aspects of the project. By not mentioning any names, I do not run the risk of forgetting anybody. Still, you know who you are, and I extend my sincere gratitude.

Morten W. Høegh, May 8, 1998

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Chapter 1 Introduction

A financial option represents a claim on a set of assets. Its payoff, and thus its value, depend on and are derived from the price of the underlying assets. Hence options are called derivative securities. Financial option pricing theory has experienced rapid growth since the early 1970s. Black and Scholes published in 1973 the closed-form formula which calculates the value of an option based on a limited set of parameters[1]. The Black-Scholes formula revolutionized and initiated the explosive growth of the financial derivatives business. There is currently trading of options related to financial securities such as stocks, bonds, currencies, futures, indices and some commodities. Financial engineering, the science of combining basic and derivative instruments to form risk management tools, has emerged from the foundation of option trading. A general rule states that any set of contingent payoffs - that is, payoffs which depend on the value of some other asset - can be valued as a mixture of simple options on that asset[2]. Clearly, option theory is one of the single most important fields of applied financial economics that have been developed over the past few decades. This was confirmed when the 1997 Nobel Prize in Economics was awarded to Myron Scholes and Robert Merton for their publications in 1973 on option valuation[3].

Option theory has been extended to project valuation and capital budgeting. The term real option is used in conjunction with investment projects that generally are characterized by significantly uncertain and asymmetric future payoffs. Real options arise whenever a

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[1] See Black and Scholes (1973) for details

[2] Brealey and Myers (1996), p. 568

[3] Fischer Black, who died in 1995, was mentioned in the award. The Nobel Prize is not awarded

project has uncertain benefits or costs, and there is an opportunity to modify, delay, expand, or abandon the project contingent upon information gathered in the future. Real options allow managers to add value to their firms, by amplifying good fortune and mitigating loss. Most companies traditionally rely on net present value (NPV) or internal rate of return (IRR) techniques for project valuation. These methods do not deal adequately with future uncertainty, and they can not be used to predict optimal timing of investments. The NPV rule states that all projects with positive NPV should be undertaken. In reality, it is often optimal to delay a project, resulting in a higher NPV. The inherent flexibility of a project is not captured by NPV valuation. On the other hand, real option theory includes the value of flexibility in the project valuation. The notion of project flexibility also has strategic implications. A project that is analyzed within a real option framework contains certain reactive flexibilities - the option to invest, wait or divest in response to new information. Even more important are the proactive flexibilities associated with the project - the flexibility to take action in ways that will enhance the value of an option once acquired[4]. Uncertain and volatile future payoffs from a project are no longer considered purely value reducing. By identifying option elements and proactively managing risk, a decisionmaker might conclude that a more uncertain project is more valuable than a less risky project. Thus, increasing a project's risk can be value enhancing. Real option analysis is becoming widely accepted for valuation of R&D projects - projects that require a limited up-front investment that can lead to significantly larger future investment opportunities, and for valuation of natural resource projects -

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posthumously.

[4] Leslie and Michaels (1997)

projects for which the value depends on an underlying commodity, while the investments required for extraction are independent and do not affect the value of the commodity[5].

The more uncertain a project is, the less adequate is NPV valuation, and the more relevant is real option analysis. However, it is not possible to value real options directly using the theory of financial options. There are some important differences:

- Financial options are standardized, securitized contracts between two parties, while real options are unique projects held by individual firms.
- Financial options are written on underlying assets that are traded in well developed, liquid markets.
- Typically, financial options are short-lived (duration less than 6 months), while real options are long-lived (6 months to 25 years).
- Exercising a real option may be a strategic decision with significant operational consequences, while exercising a financial option is usually a strictly financial transaction.

1.1 Options in Shipping

Significant volatility and cyclicality characterize the shipping and shipbuilding markets. Factors such as freight rates, ship prices, exchange rates, interest rates, stock prices, oil prices, operating costs, technical performance, accidents, liability claims, taxes and political conditions are all highly uncertain. This has only to a limited degree led to development of standardized and traded derivative instruments. There are, naturally,

[5] Faulkner (1996) and Nichols (1994) describe on real options in R&D valuation. Leslie and Michaels

options on publicly traded shipping stocks, and there is some trading of options on BIFFEX freight futures[6]. Real options appear in two categories in shipping. One category includes options that are agreed on an ad-hoc basis between two parties. Examples are[7]:

- Newbuilding option. Upon signing a newbuilding contract, a shipowner gets an option on one or more additional vessels at pre-agreed terms, to be declared at a later point in time.
- Option to purchase secondhand vessels.
- Charterer's purchase option. A charterer has the right to purchase a ship at a pre-agreed price at expiration of a time-charter contract.
- Charterer's time charter option. A charterer has the right to extend a time charter contract at expiration of the original charter.
- Charterer's spot charter option. A charterer has the right to fix a vessel for another voyage upon completion of the original voyage.

The other category of real options appears in situations that are characterized by significant flexibility, and that are equivalent of holding an option. However, they do not involve a counterpart to the option. Examples of this category are[8]:

- Decisions relating to laying-up of ships, and subsequent re-activation.
- Decisions to extend a ship's lifetime, or alternatively to scrap it.

(1997) discuss real options in oil exploration.

[6] Wijnolst and Wergeland (1997), pp. 554 and 558

[7] Stray (1991), pp. 3 - 5

[8] This is the main focus of Gonçalves (1992). See also Stray (1991), pp. 91 - 97

The highly uncertain nature of the industry presents industry players with tremendous opportunities for proactive risk management. Familiarity with option theory and methodical application of risk management techniques can lead to strategies that maximize value and optimize the exposure to risk according to individual preferences. Real option theory assists a decisionmaker in exploiting and valuing flexibility, and analysis of real options determines and develops optimal operational strategies. In parallel, the financial markets produce vital information for these decisions, and present an opportunity to engineer the desired risk profile for the firm through various financial instruments. Understanding fundamental option theory is vital in both cases to ensure successful application, and as a result the skilled shipping professional will have a competitive advantage.

Many shipping industry players will argue that they have a "gut feeling" of what an option is worth, and that this intuition will be closer to the fair value than any theoretically based option valuation techniques ever will be. This argument can not be omitted. There is no reason to believe that analytic models can replace experience. The ability to be able to build an understandable model is more useful than precise estimates of option value. However, financial expertise can be used to support the knowledge and intuition of experienced shipping professionals, and give insight into the mechanics of option value and into how important variables affect option prices.

Some option contracts are difficult to understand, and misperceptions can have unexpected effects on the deal and on the risk exposure of a shipping company. There have been cases of shipping companies that sell off the entire market upside by engaging in long time charters with options written to the charterer, and that subsequently are left with the entire downside, should the market collapse. These are some of the potential benefits of using a formal option pricing models for valuing contracts and projects with option elements:

- A professional familiar with option theory has the opportunity to construct complex contracts that the counterpart does not fully understand, and therefore misprices. There are examples in which players "give away" option in order to secure a deal, without realizing that the entire payoff structure changes. Thus, the skilled professional might enjoy "a free lunch".
- Options can be combined with other assets and securities to tailor specific risk profiles. Options are used both for hedging and speculation, and enable players to trade away or secure risk. In view of this, the paper market for derivative securities complementing the underlying freight and vessel markets in shipping is expected to grow in the future.
- Complex contracts with option elements allow the contracting parties to negotiate in terms of implicit volatility and price uncertainty, rather than in terms of absolute prices. This will enable players to close deals based on less available information.

1.2 Review of Previous Research[9]

As early as the mid-1970s, financial economists realized that the option framework can be extended from securities theory to other aspects of corporate finance, and that the

[9] See Bibliography for complete references.

results of the groundbreaking work by Black, Scholes and Merton on option valuation can be applied to a range of situations. Myers[10] establishes the similarity between holding options and holding claims to a company's balance sheet. He first introduces the term real option. Concurrently, discrepancies of the discounted cash flow method in project valuation are evident. The DCF method implicitly assumes that assets are held passively by a company. The only method that adequately accounts for timing flexibility and value added by management is the real option approach. Trigeorgis points out in several papers that:

Strategic NPV = Static NPV + Value of options from active management

Recently, two thorough texts on real options have been published, Investment under Uncertainty (1994) by Dixit and Pindyck, and Real Options: Managerial Flexibility and Strategy in Resource Allocation (1996) by Trigeorgis. They combine the mathematical and economic foundation of real option theory with examples of typical investment decisions from specific industries. Both rich in equations, they combine intuitive explanation and rigorous derivation of their conclusions. According to these two books, examples of real options are: Option to defer a project, time-to-build option (staged investment), option to alter operating scale (expand, reduce, contract, shut down, restart), option to abandon, option to switch inputs or outputs, growth options, and interacting options.

[10] This was published in Myers, S. C. "Determinants of Corporate Borrowing". Journal of Financial Economics. November 1977. See Brealey and Myers (1996), Chapters 20 and 21 for more.

The Norwegian Centre for Research in Economics and Business Administration completed in 1992 a project called "Optimal Strategies under Uncertainty in Shipping Markets". Various publications on options in shipping have resulted from this project. Bjerksund and Ekern (1992 (a) and (b)) derive differential equations for freight revenues, under the assumption that freight rates are stochastic and behave according to the so-called Ornstein-Uhlenbeck process. This process assumes that the rates fluctuate stochastically around a constant mean. Furthermore, equations are developed for valuation of time charter contracts, futures on time charter contracts, and options on time charter contracts.

Andersen (1991) analyzes the spot and time charter markets for panamax bulk carriers. Based on extensive data, input variables for the Ornstein-Uhlenbeck process in this particular market are calculated. The main application of the statistical analysis is to calculate the value of an option on a three-month time charter. The sensitivity of this value to the parameters is shown. Andersen extends his work to calculate vessel value based on freight rates and operating costs.

Stray (1991) performs a similar study for VLCCs. However, the markets for these two types of vessels are distinct, such that the quantitative results are vastly different. Stray establishes that the market parameters are not stable over time, and that the VLCC market in general is more volatile and has a stronger tendency for mean-reversion. A sensitivity analysis is presented here as well.

Næss (1990) focuses on the decision whether to operate or lay up a ship given uncertain freight rates, using a real option framework in which there is no immediate counterpart. He determines guidelines for finding the optimal strategy and valuing the optimal strategy under different assumptions for the stochastic nature of freight rates.

Dixit and Pindyck include in their book one example from the shipping industry that is similar to the topic of Næss' work. This example uses continuous-time contingent claims analysis to derive a system of differential equations, for which the numerical solution determines the rate level at which a ship should be laid up, or mothballed, and the rate level at which it should be reactivated. A sensitivity analysis is performed to establish how these rate levels depend on the one-time cost of mothballing, reactivation cost, annual maintenance costs, annual operating costs and freight rate volatility.

Gonçalves (1992) extends this notion to chartering and ship investment decisions. The optimal chartering decision does not only answer the employment or lay-up questions, but also determines the type of employment to accept - spot or time charter. He compares, using both continuous- and discrete-time contingent claims analysis, spot and time charter, respectively, with no employment. Subsequently, spot and time charter are held up against each other to find the optimal strategy. A similar analysis is performed for the various investment alternatives: sale, purchase, ordering and scrapping. Guidelines for optimal chartering and investment policies are outlined. He concludes that a ship with lower operating and maintenance costs and lower costs to move in and out of lay-up is a more valuable ship, and that a shipping company with more flexible operations and management creates more value.

1.3 Scope of Thesis

As the title indicates, this thesis focuses exclusively on option elements in newbuilding contracts. Newbuilding options are encountered frequently in the shipping industry, and their features are relatively transparent and homogenous, such that it is meaningful to apply a framework of analysis that is close to the one used for financial options. Very few shipping and shipbuilding professionals feel comfortable with the concept of newbuilding options, and most industry players are not able to proceed beyond realizing that newbuilding options can represent significant value, and that this value is transferred from shipyards to shipowners without proper consideration.

From a starting point of general theory based on options on publicly traded stock, the thesis discusses models that can describe the process determining newbuilding prices. These models are compared with observations of actual newbuilding price data, and serve as a foundation on which option valuation formulas are developed. Lastly, issues related to the specific application in the context of shipbuilding contracts are discussed.

There are no previous studies that focus specifically on newbuilding options, and thus this project should complement and not duplicate previous shipping-related work on option analysis.

1.4 Overview of Subsequent Chapters

Chapter 2 offers a general introduction to the theory of stock options. A fundamental definition of the notion of an option is given and discussed, and various general properties of options are analyzed. The methodology that is used for arriving at an exact formula for option valuation is presented, and finally the famous Black-Scholes formula is discussed. This chapter is equivalent to an introductory chapter on option theory in any basic textbook in finance.

Chapter 3 offers a discussion of stochastic processes, and in particular focuses on stochastic aspects of asset price formation. Two possible models for the ship newbuilding price process are presented in detail. One is the so-called geometric Brownian motion, which is based on constant exponential growth. In this model, the instantaneous return from holding an asset is lognormally distributed, and only the current price affects the future price development. The other model is the Ornstein-Uhlenbeck process, which assumes that prices revert to a long-term equilibrium value and that future prices are subject to normally distributed disturbances from the expected value. In this model, prices are expected to decay exponentially from the initial value towards the long-term equilibrium level.

Chapter 4 presents an analysis of actual past price data and tests whether these data conform to the two pricing models from Chapter 3. The results show that neither offers a good description of the newbuilding market, but that aspects of both are present in the true pricing process.

Chapter 5 develops two formulas for valuation of newbuilding options. One is based on the geometric Brownian motion model. This formula is essentially the same as the Black-Scholes model for stock options, but it has been adjusted to account for the fact that newbuildings are not a traded asset. The other formula is based on mean-reversion and includes similar adjustments. From the same price data, estimates for the input parameters needed for the two option formulas are calculated and assessed qualitatively, and four base case newbuilding options are defined. The value of these options is calculated, and extensive sensitivity analyses are performed in order to understand the mechanics of the option formulas, and in order to establish the main drivers of option value.

Chapter 6 discusses the results of the previous chapters in the context of the shipping and shipbuilding industries. Issues and concerns derived from interviews with industry players are presented from the point of view of shipyards, shipowners and intermediaries, such as shipbrokers and consultants. Practical guidelines for analysis and assessment of the value of newbuilding options are also discussed.

Chapter 7 offers concluding remarks, and presents suggestions for possible future research extending from this project.

Chapter 2 Option Theory[1]

A fundamental definition of an option is:

> "A right, but not an obligation, to take some action now, or in the future, for a pre-determined price."

Each part of this definition requires careful explanation. "A right, but not an obligation" means in practice that the action specified by the terms of the option will be exercised only if advantageous to the holder, leading to asymmetric returns. From this, it follows that there must be an intrinsic value in the option, corresponding to an up-front acquisition cost. The action is either to buy or sell an underlying asset. An option usually involves a limited timeframe, or duration, and specifies the points within the timeframe at which the option can be exercised. After the limit, the option expires worthless if not exercised. The pre-determined price associated with exercising the option is independent of the acquisition cost, and these two parameters should not be confused.

Valuation of options emerged as a new field within finance theory in the early 1970s. It became evident that traditional valuation methods such as the discounted cash flow (DCF) method does not allow for flexibility in the investment project under consideration[2], and that utility theory and the **capital asset pricing model** (CAPM)[3] do not deal adequately with uncertainty in future cash flows. Decision tree theory was developed to enable analysis of flexible alternatives, creating a structured approach to

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[1] This chapter is an introduction to basic stock option theory, based largely on Chapter 20 of Brealey and Myers (1996), Bookstaber (1991) and Satty and Troccolo (1994).
[2] Brealey and Myers (1996), p. 573, and Kulatilaka and Marcus (1992)
[3] For more on the theory of CAPM, see Brealey and Myers (1996), Chapter 8

decisions after observation of prior outcomes. However, it became clear that DCF valuation can not be used in decision trees because the degree of uncertainty changes as observations and decisions are made through time. In the context of a decision whether to exercise an option, DCF does not work because the discount rate changes with changes in the value of the underlying asset. Option valuation theory grew out of this challenge, and a framework was developed that effectively avoids dealing with the uncertainty of future payoffs.

Valuation of options on publicly traded stock was the first application of the new valuation framework. This has now developed into an industry of its own. Every day, stock options worth billions of dollars are traded on the world's option exchanges. The analogy between financial options and real investment projects was identified at an early stage, but only recently it became common to analyze and value the option element of an investment project. Thus, it is appropriate to present a thorough discussion of options traded in financial markets, to state universal characteristics of all options in the context of stock options, to derive the most common formula used to value options, and from this basis, to extend the theory to real options and shipping-specific options.

2.1 Types of Stock Options

There are two types of stock options:

- A **call option,** or simply a **call,** gives its owner the right to buy a stock for a specified **exercise,** or **strike** price, on or before a specified **exercise date**.

- A **put option**, or a **put**, gives its owner the right to sell a stock for a specified strike price on or before a specified exercise date.

In addition to the fundamental difference between calls and puts, constraints on the possible points in time at which exercise is allowed provide another classification of options[4]:

- **European** options can only be exercised on the expiration date of the option contract.
- **American** options can be exercised any time on or before the expiration of the option contract.

All possible combinations of puts and calls, and of European and American options, are traded and available to investors in standardized contracts.

Before introducing the mechanics of the cash flows associated with the various types of options, it is important to distinguish between the payoff from an option and the value of an option. The value of holding an option will generally exceed payoff, and the two concepts should not be confused. Payoff is the cash flow derived from immediate exercise of the option. The value of an option represents the present value of expected future cash flows that the owner of the option will receive. This is analogous to the value concept for any financial asset. Note again that option value can not be calculated by the DCF method.

[4] The terms European and American options are a result of traditions, and do not indicate any geographic classification of traded options. Options that can be exercised at distinct points in time before exercise, but not at any point in time, are called Mid-Atlantic or Bermudan options.

2.2 Payoff Structures

If exercised, the holder of a call option buys the underlying stock for a fixed, pre-determined price K. At the time of exercise, the price of the stock is denoted as S. The holder gets stock worth S dollars in exchange of K dollars, resulting in a net position S-K. If unexercised, the payoff from the option is zero. As exercise of the option is at the discretion of the holder, it will only occur if the payoff from exercising the option is positive. Thus, the payoff from a call option is always the maximum of either 0 or S-K. This gives the following **position diagram** for a call option. Payoff is shown as a function of the stock price at the time of exercise:

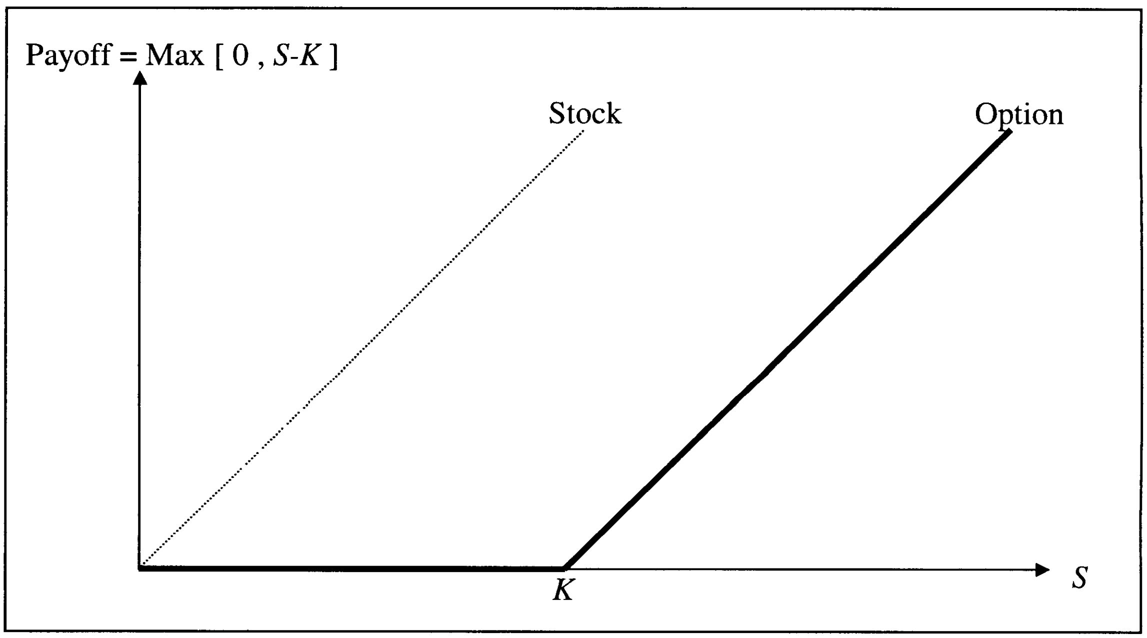

Figure 2.1: Position Diagram for Call Option

In this figure, the bold line is the payoff. For a stock price smaller than the exercise price, the option should not be exercised, and the payoff is zero. As S increases and exceeds K, the option should be exercised and the payoff increases with the stock price in a one-to-one relationship.

Similarly, it is possible to determine the payoff from a put option. If exercised, the holder of a put option sells stock for a pre-determined price *K*. At the time of exercise, the stock is worth *S* dollars. The holder receives the strike price of *K* dollars in exchange of stock worth *S* dollars, resulting in a net position of *K-S* dollars. If not exercised, the payoff from the option is zero. Again, as exercise of the option is at the discretion of the holder, this will only happen if the payoff from exercising the option is positive. Thus, the payoff from a call option is always the maximum of either 0 or *K-S*. This gives the following position diagram for a put option:

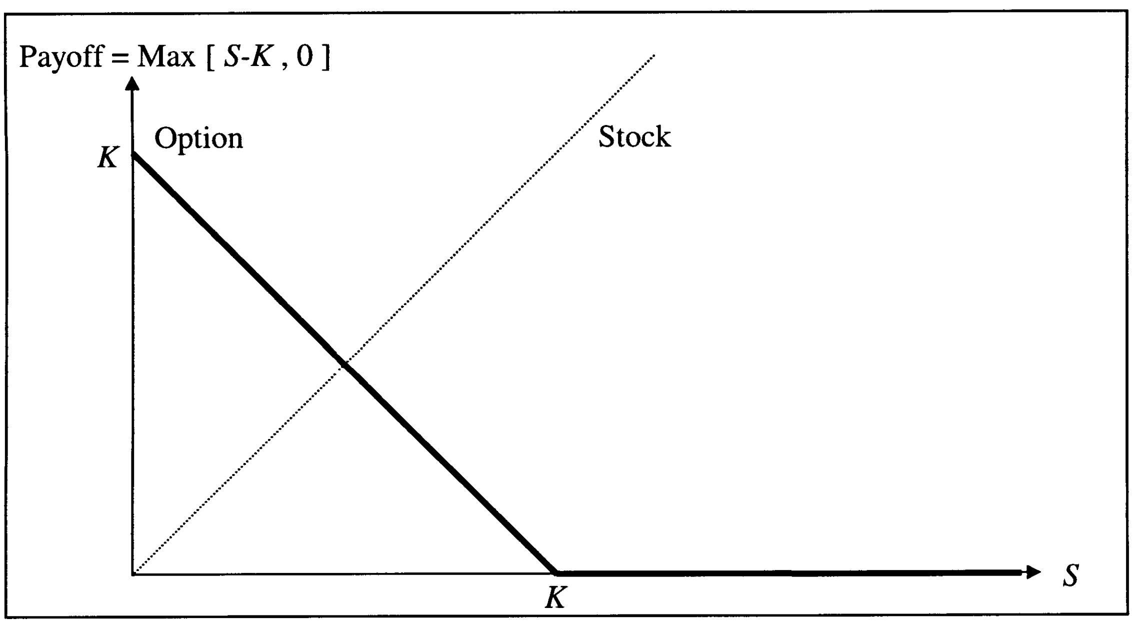

Figure 2.2: Position Diagram for Put Option

This figure shows that for low stock prices ($S<K$), the payoff from a put option decreases in a one-to-one manner as S increases. When S exceeds K, the option should not be exercised and the payoff is zero.

There are always two parties to an option contract. The buyer, or **holder**, of an option is said to be **long** in the option. The seller, or **writer**, of an option is said to be **short** in the option. It is important to note that the option to exercise always rests with the holder; the writer simply has to act according to the holder's decisions.

The position diagrams for short positions in a call option and a put option are as follows:

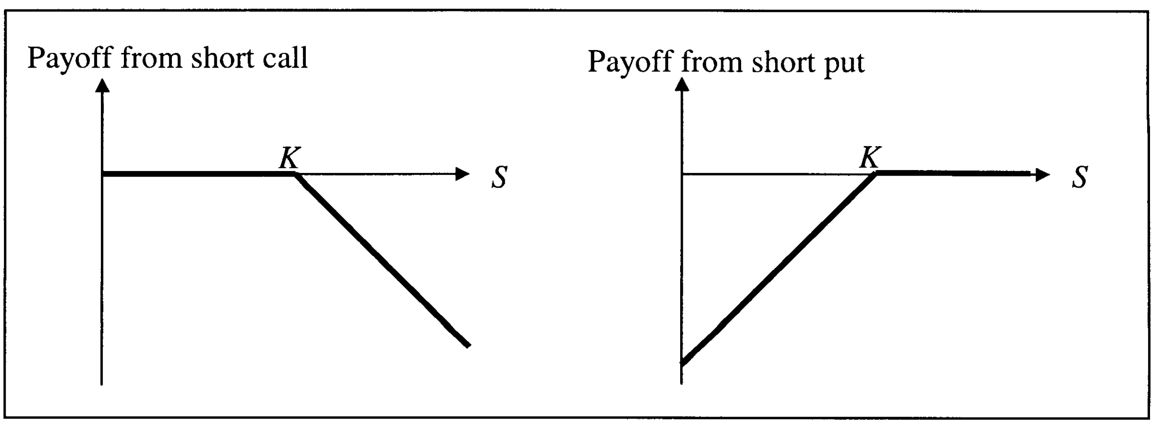

Figure 2.3: Position Diagrams for Short Call and Short Put

This figure shows graphs that are symmetric around the horizontal axis when compared to the long positions in the two types of options.

It is important to note that when comparing the short and the long side of an option, whether a call or a put, it is clear that due to symmetry, the sum of the gain to one party is exactly equal to the loss incurred by the other party. This has led to the notion of option investments as a zero-sum game. It is useful only when comparing payoffs from isolated option contracts, not when options are held in combinations with other options or the underlying asset itself as risk-management instruments.

An option that will generate a positive payoff if exercised immediately, is referred to as being **in the money**. Similarly, an option that will lead to a negative payoff, and therefore should not be exercised, is **out of the money**. If the current stock price is equal to the strike price ($S=K$), the option is **at the money**.

2.3 Determinants of Option Value

An option represents intrinsic value, because it entitles the holder to obtain the payoffs described above. How much should an investor be willing to pay to acquire this opportunity? In order to arrive at an exact formula for option value, it is necessary to identify certain important characteristics and relationships influencing the value.

From the position diagrams in Section 2.2, it is possible to determine the value of options at expiration, or the immediate payoff of an American option if it is exercised early. As long as there is time remaining until expiration of an option, immediate payoff may not reflect the full value. This can be illustrated by the following example:

> Consider an American call option that is at the money ($S=K$), with time remaining until expiration. Immediate exercise payoff is zero. Positive payoff might be

obtained by waiting, if the stock price increases. The worst outcome of waiting is payoff of zero, the same as for immediate exercise.

In this case, there is only upside, and no downside. This example can be extended to other option structures, and the conclusion from all cases is that the value of an option always exceeds the payoff from immediate exercise, which thus is the lower limit of option value. There is value simply in waiting.

The upper limit of option value is the value of the underlying asset, i.e. the stock price. The reason for this is that upon exercise, the holder of the option receives the value of the stock less the exercise price, which is greater than or equal to zero. If the stock price ends up below the exercise price, the option is worthless while the stock is still a valuable security. Another way to express the upper limit of the value of a call option is to recognize that owning a share is equivalent to holding a call option with strike price zero and infinite time to maturity.

Thus, the option value will always be in the shaded range below:

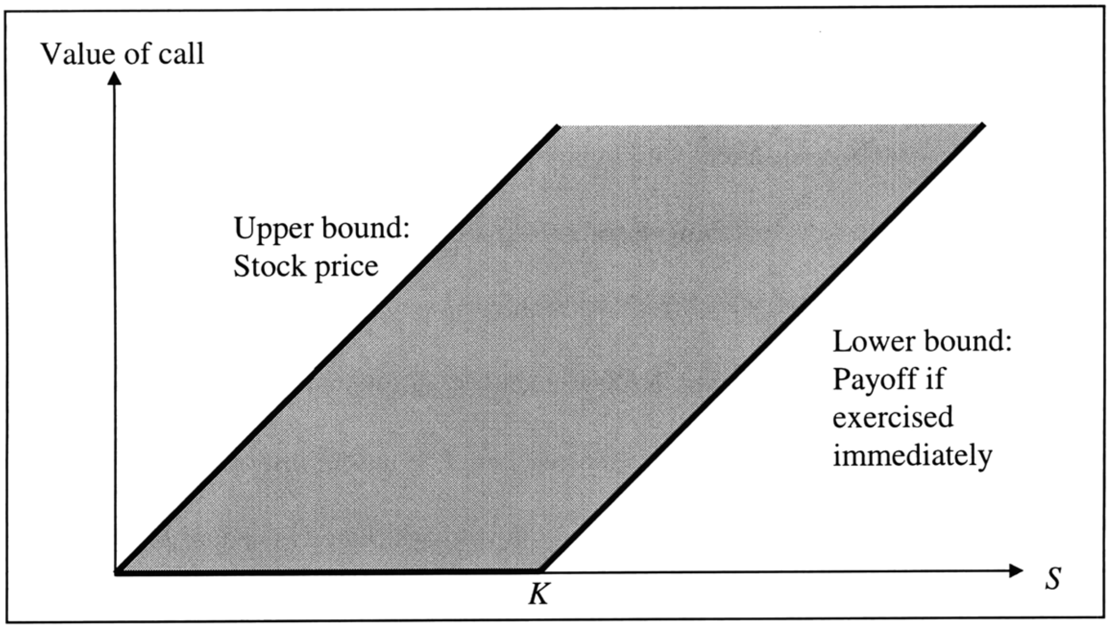

Figure 2.4: Boundaries of Option Value

The value of a call option will always be confined to the shaded region. In addition, the value obeys the following general principles:

- The value of a call option increases as the price of the underlying stock increases, if the exercise price is held constant. Two parallel factors contribute to this behavior. A higher stock price means that there is a higher probability of the option being in the money at expiration. Secondly, a higher stock price means that the payoff on exercise, the difference between S and K, will be higher. Thus, option value is strictly increasing in S.
- When the stock is worthless, the option is worthless. A stock price of zero means that there is no possibility the stock will ever have any future value. If so, the option is certain to expire unexercised and worthless, and therefore it is worthless today.

- When the stock price becomes large, the option value approaches the stock price less the present value of the exercise price, discounted at the risk-free interest rate. The higher the price, the higher the probability that the option will eventually be exercised. If the stock price is high enough, exercise becomes a virtual certainty. If an option is certain to be exchanged for a share of stock, the stock is effectively owned at the present time. The only difference is that the payment for the stock does not occur until later. In this situation, buying a call is equivalent to buying the stock, but financing part of the purchase by borrowing. The amount implicitly borrowed is the present value of the exercise price, and the value of the call is equal to the stock price less the present value of the exercise price. This argument extends further. An investor who is acquiring stock by way of a call option is buying on credit. Only the purchase price of the option is paid today. The delay in payment of the remainder is particularly valuable if interest rates are high and the option has a long maturity. This can be generalized to all options, not only to those that have a very high probability of exercise. The value of an option increases with both the risk-free interest rate and time to maturity.
- The option price always exceeds its minimum boundary value as long as there is time left before expiration. It was established above that the payoff from immediate exercise is the lower boundary of option value. A "live" option is always worth more than a "dead" option, because there is always a non-zero probability that the share price will increase in the future, leading to a higher payoff.
- For a stock that pays dividends, the owner of the stock, and not the owner of any option written on the stock, receives the dividend. Dividend theory states that

immediately after a dividend payment, the stock price will fall by an amount equal to the dividend[5]. This reduces the price of a call option on the stock. Generally, increasing dividends lead to a lower call option value.

- A given percentage change in the price of the underlying stock always leads to a higher percentage change in the value of any option or derivative asset. When buying a call, the investor is taking a position in the stock but putting up less money compared to buying the stock directly. This makes the option riskier than the underlying stock.
- The value of an option increases with the variance in the price of the underlying stock. One of the most important determinants of the difference between the call value and the immediate exercise payoff is the likelihood of substantial movements in the stock price. More volatile movements in the price of the underlying stock lead to higher option values. The following example illustrates this notion:

  Consider two options, A and B, with the same exercise price, stock price and time to maturity. The current stock price equals the exercise price for both options. The only difference between A and B is that the price of stock A is much harder to predict than the price of stock B at expiration of the options. For both stocks, a normal distribution of the future stock price is assumed. This means that both stock prices have a 50 percent probability of increasing, resulting in the options being in the money at expiration. Similarly, there is a 50 percent probability that the stock prices decrease, leaving the options worthless. However, the probability of a large payoff from the option on stock

[5] Dividend policy is discussed in Brealey and Myers (1996), Chapter 16

A is greater than the same probability for the option on stock B, because stock price A is more volatile. Option A has more upside potential, and is more valuable.

The following figure projects the probability distribution of the future stock prices of the two stocks A and B on to a position diagram for which the current stock price *S* equals the strike price *K*. The figure illustrates how option value increases with volatility. The distribution of stock A is more spread out and has a less clearly defined peak. The probability of having a relatively large *S* at expiration is higher for stock A compared to stock B. Subsequently, call A is more valuable than call B.

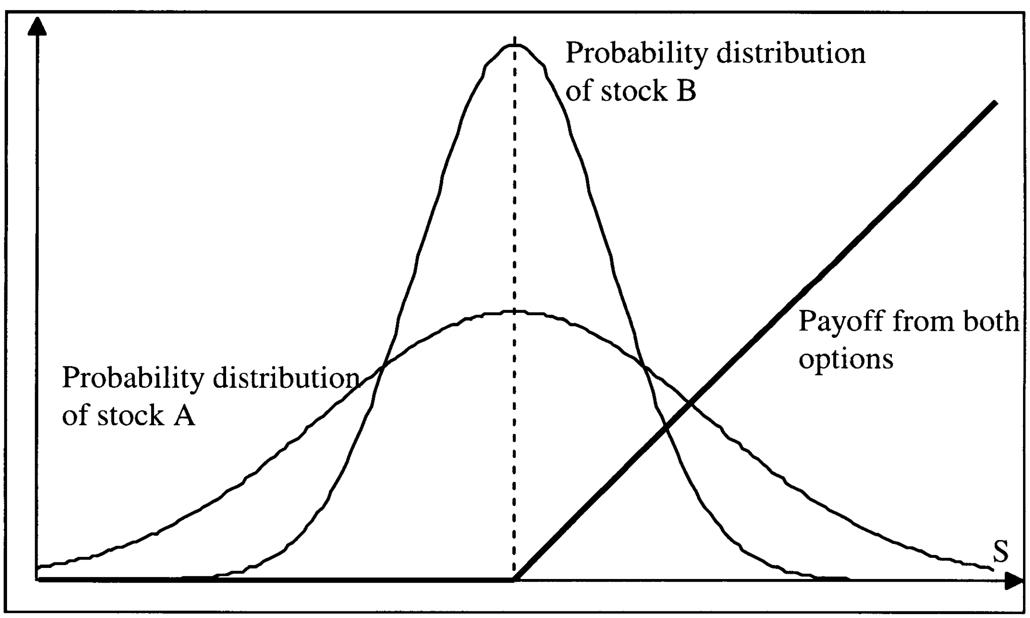

Figure 2.5: Volatility and Option Value

In accordance with the principles discussed above, the following figure plots the value of options on two stocks that have different volatility, but other parameters being equal, for varying stock price *S*. The direction in which option value moves with increasing volatility, time to maturity and interest rate is indicated. Note how the value of the calls is confined to the region between the upper and the lower bounds.

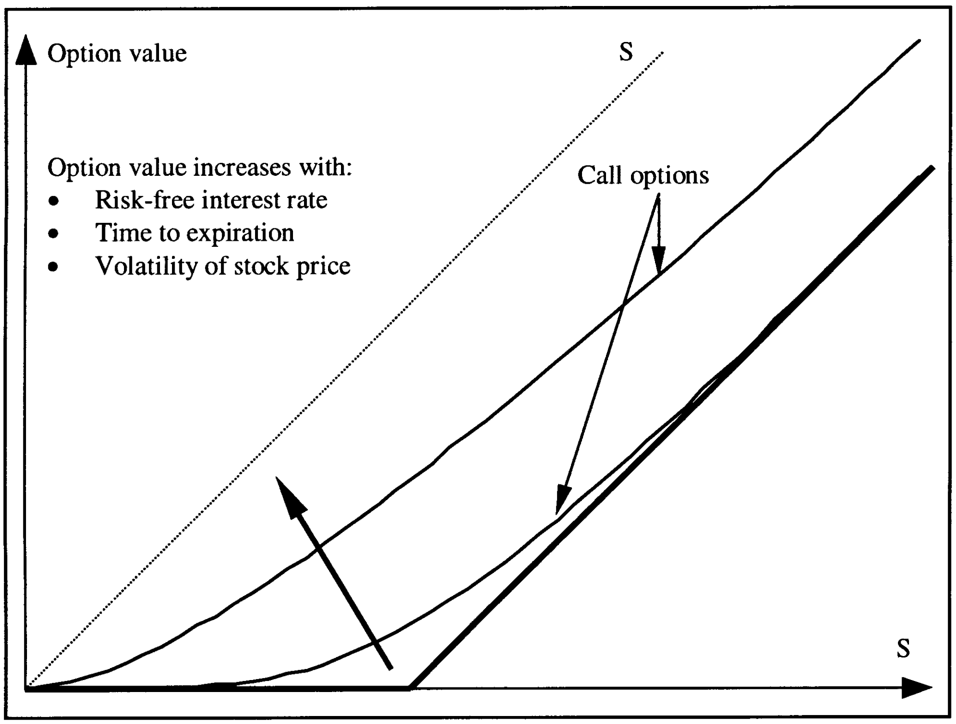

Figure 2.6: Examples of Call Option Value Functions

As a summary, the following table lists the variables on which option value depends for both calls and puts. The relationships for put options can be derived through a similar set of arguments as those given for call options.

Increase in variable	Symbol	Change in value of call	Change in value of put
Stock price	S	Positive	Negative
Exercise price	K	Negative	Positive
Interest rate	r_f	Positive[a]	Negative
Time to expiration	t	Positive	Positive
Dividends	D	Negative	Positive
Volatility of stock	σ	Positive[a]	Positive

[a]The *direct* effects of increases in r_f or σ on the value of a call option are positive. There may also be *indirect* effects. For example, an increase in r_f could reduce stock price S. This in turn could reduce option price. An increase in σ could also lead to lower stock price due to increasing required rate of return as a result of the higher risk.

Table 2.1: Variables Determining Option Value

2.4 The Put-Call Parity

An American call option can not be worth less than its European counterpart. This intuitive argument follows from the fact that an American option has all the features of a European option, as well as the additional flexibility that allows its holder to exercise before maturity. In addition, an American option can not be worth less than its immediate exercise value. For a non-dividend-paying stock, the American call option is always worth more than its immediate exercise value. This implies that an American call on a non-dividend paying stock should never be exercised prior to maturity. If the owner wants to terminate the position in the call option, the option should be sold rather than exercised early. Furthermore, this argument can be extended to state that an American call on a non-dividend paying stock is just as valuable as its European counterpart, and one common method of valuing the two options can be applied.

When a stock does pay dividends, early exercise of American options may be optimal in order to capture the cash flow from the dividend, which otherwise is foregone and remains with the owner of the stock on which the option is written.

European put options tend to be worth less than immediate payoff for small values of the current stock price S, and for large values of time to expiration. The reason is that upper limit of a put option is limited to K (for $S=0$), and when S falls, the probability that the put option will be in the money at expiration approaches one. Thus, the value of the option is approximately equal the present value of $K-S$, while the immediate payoff is $K-S$. The present value is less than the nominal value. When the option value of a European put drops below the immediate payoff, early exercise of its American counterpart is optimal, as the cash flow derived from exercising the option will be available for reinvestment.

It is possible to construct an interesting and useful relationship between the stock, call and put values for options of the European type. Consider the following two investments, for which the payoffs are tabulated below:

- Buy stock and buy put option
- Buy call and buy government bond, i.e. lend money at the risk-free interest rate

Payoff	$S<K$	$S>K$
Stock	S	S
Put	K-S	0
Total	K	S
Call	0	S-K
Bond	K	K
Total	K	S

Table 2.2: Investment Combinations of Call, Put, Stock and Bond

The payoffs at expiration of these two combinations of assets are identical. Thus, the cost of buying a share of stock and a put option on that share with strike price K and time to maturity t is equal to the cost of buying a call with the same terms and lending the present value of the strike price K. This identity is known as the **put-call parity** for European options. More formally, it is expressed as:

$$S + p = K \cdot B + c \tag{2.1}$$

where:

- c denotes the call value[6]
- p denotes the put value
- B denotes the present value of a $1 face value zero-coupon government note

[6] As a convention, European options are denoted by lower-case letters, while American options are denoted by upper-case letters.

The put-call parity can also be displayed graphically:

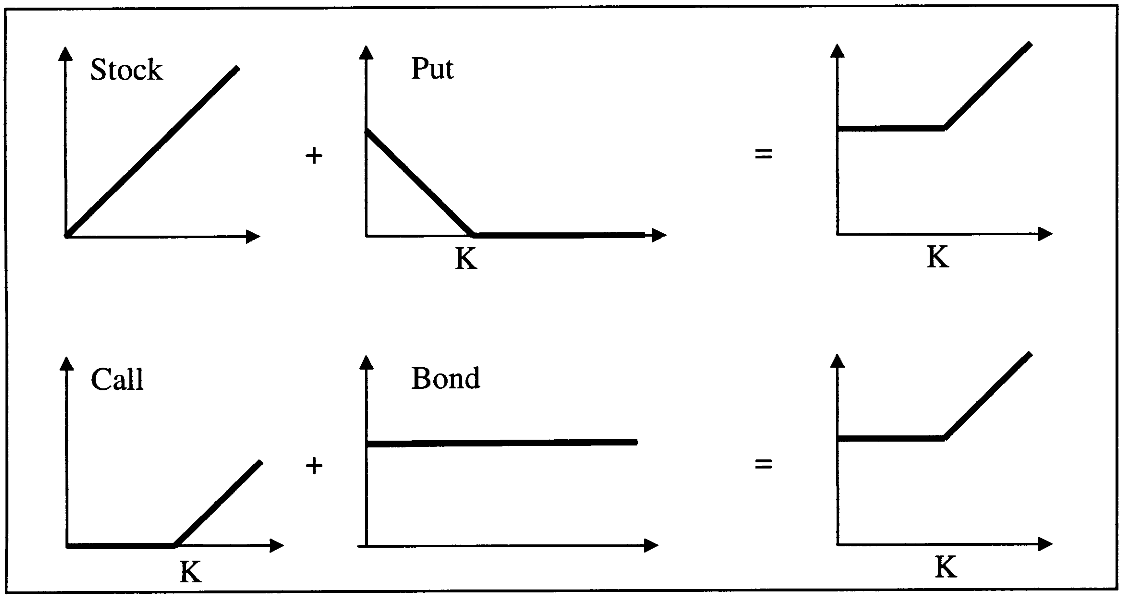

Figure 2.7: Graphical Representation of Identical Investments According to the Put-Call Parity

In order to reflect the foregone dividends, the put-call parity for European options on dividend paying stock is:

$$S + p = K \cdot B + c + PV(D_e) \tag{2.2}$$

where:

- $PV(D_e)$ denotes the present value of expected dividends declared and paid before expiration of the option.

2.5 Option Pricing Methodology

In the previous two sections, the variables that determine option value are presented along with the directions in which they influence value. These qualitative statements need to be extended to find an exact option-valuation model. This section describes the general approach that served as the starting point in the search for a closed-form option valuation model.

The traditional way of valuing investment projects is the discounted cash flow method (DCF). It consists of two steps:

- Forecasting expected cash flows
- Discounting cash flows at the risk-adjusted **opportunity cost of capital**

This method is not useful in option valuation. The first step can be done, but it is messy, as the expected cash flows are a function of the price of the underlying stock, and changes as the stock price changes. The second step is impossible to perform because there is no unique appropriate discount rate. Every time the stock price moves, the probability of being in the money at expiration changes. This changes the risk of the option. For instance, when the stock price of the underlying asset increases, the value of the option increases and the risk decreases. Accordingly, continuous adjustment of the discount rate is required. The riskiness of an option can even change over time without movements in the stock price, as the option approaches expiration and positive payoff becomes increasingly more or less certain.

To overcome the problem of changing the discount rate, it is necessary to set up an option-equivalent investment by combining the underlying stock and borrowing at the risk-free interest rate. This method effectively implies that investors are risk-neutral and have linear utility for wealth. In this case, only the risk-free rate of interest is needed to produce a discounted option value.

An example illustrates the option-equivalent approach:

Consider a 12-month call option on stock XYZ with exercise price \$120. Today's stock price is also \$120, so the option is at the money. The risk-free one year interest rate is 6%. Although unrealistic, XYZ stock can only do two things over the next 12 months, either the stock price falls by 20% to \$96, or the stock price increases by 25% to \$150. If the stock price falls, the call option will expire worthless, but if the stock price increases, the call will be worth \$150 - \$120 = \$30. These are the only possible payoffs from the option.

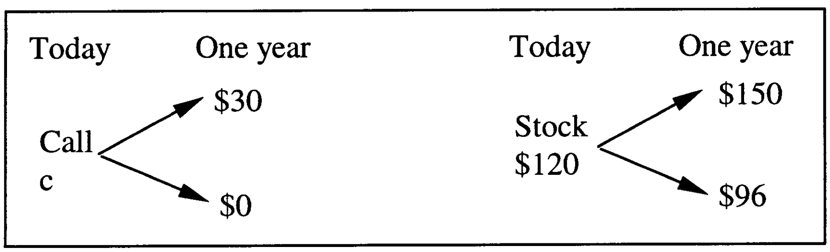

Figure 2.8: One-Period Binomial Tree

Having established the payoffs, it is useful to introduce the concept of **option delta** or **hedge ratio**[7]:

$$\text{Option delta} = \frac{\text{Spread of possible option prices}}{\text{Spread of possible share prices}} = \frac{30-0}{150-96} = \frac{5}{9}$$

It is possible to replicate the investment in a call option by purchasing exactly the option delta fraction of a share, in this case $\frac{5}{9}$, and borrowing the balance at the risk-free rate such that the payoff at expiration is exactly equal to the option payoff. In this example, $\frac{5}{9}$ of a share is worth either \$53.33 or \$83.33 at expiration. The option payoff is either \$0 or \$30. Thus, the difference of \$53.33 is the borrowed amount to be repaid (with interest) at expiration. The present value of this loan is $\frac{FV}{1+r_f} = \frac{\$53.33}{1.06} = \$50.31$. As the payoffs at expiration are identical for the call option and for the option equivalent investment constructed by borrowing and purchasing stock, the value of both investments must be identical. Thus, the value of the call option described in this example is:

$$\text{Value of call} = \text{value of } \frac{5}{9} \text{ of a share - \$50.31 bank loan}$$

$$c = \frac{5}{9} \cdot \$120 - \$50.31 = \$16.35$$

This example not only illustrates a method to value a simple option, but also how an investment in the option can be replicated by a levered investment in the underlying asset. Furthermore, it can be shown that if the probability of a higher stock price in the future period is balanced such that the expected return from holding the stock is equal to the risk-free rate, the investment in the option equivalent of delta shares and the bank loan will yield the same return, equal to the risk-free rate. For this reason, this approach is also known as the **risk-neutral valuation** method, since it does not require information about the risk preference of the investor. The same approach can be used for valuing put options. The put option delta δ_p and the call option delta δ_c are related as follows: $\delta_p = \delta_c - 1$

[7] Brealey and Myers (1996), pp. 574 - 575

2.6 The Black-Scholes Formula

The trick in pricing any option is the same as in the above example - set up a combination of a long position in the stock and a loan that will exactly replicate the payoffs from the option. If the stock and the loan can be priced, so can the option. This concept is completely general. The example above used a simplified version of the **binomial method**. The possible changes in the next period are reduced to two, an "up" move and a "down" move. This simplification is acceptable if the time period is very short. A large number of such small moves are accumulated over the lifetime of an option. After each period, the degree of leverage and the option delta of the option equivalent investment need to be adjusted to ensure that the payoff at expiration is exactly equal to that of the call option.

Fisher Black and Myron Scholes successfully generalized the binomial method into a differential equation that reflects a situation in which the stock price can change continuously and for which there is a continuum of possible stock prices at expiration. The result of their work is the famous Black-Scholes formula, which is a closed-form solution to the differential equation. Since its publication in 1973[8], the Black-Scholes model has become widely accepted and used in financial economics. Furthermore, its practical significance is confirmed by thousands of traders, who every day apply the formula to value derivative assets worth billions of dollars.

The Black-Scholes formula for a European call option is as follows:

Value of call option = [delta x share price] – [bank loan]

$$c = N(d_1)S - N(d_2)Ke^{-r_f t} \tag{2.3}$$

where:

- c is the value of the call option
- S is the current stock price
- K is the exercise price
- r_f is the risk-free interest rate
- t is the time until expiration, or the number of time periods until expiration
- σ is the standard deviation per period of the continuously compounded rate of return of the stock price
- $N(\bullet)$ is the cumulative unit normal probability distribution function
- $$d_1 = \frac{\ln(S/K) + (r_f + \frac{\sigma^2}{2})t}{\sigma\sqrt{t}} \tag{2.4}$$
- $$d_2 = d_1 - \sigma\sqrt{t} \tag{2.5}$$

The derivation of the Black-Scholes formula for European puts substitutes the original call formula into the put-call parity, and solves for p.

Although the Black-Scholes formula looks complicated and messy, it proves to be an elegant and useful formula that can be programmed easily into a commercial spreadsheet

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[8] Black and Scholes (1973)

application or a calculator. The derivation of the Black-Scholes formula is not relevant to this thesis, but it is important to examine carefully the various assumptions underlying the formula[9]:

- The financial markets for stocks, bonds and options are frictionless. This means that there are no transaction costs or taxes, and no restrictions on short sale, that all shares of all securities are infinitely divisible, and that borrowing and lending at the same rate is unrestricted. This allows continuous trading and eliminates all riskless arbitrage opportunities.
- The option is of the European type. It can only be exercised on its expiration date.
- The risk-free short-term interest rate is constant over the life of the option.
- The standard deviation is constant over the life of the option.
- The underlying asset pays no dividends over the life of the option.
- The price of the underlying stock follows a stochastic diffusion Wiener process[10] of the form $dS = \mu S dt + \sigma S dz$, where:

  μ is the instantaneous expected return on the stock

  σ is the standard deviation of stock returns

  dz is the differential of a standard Wiener process with mean 0 and variance dt

  This assumption implies that the stock price follows a random walk through time. The instantaneous change $\frac{dS}{S}$ of the stock price is a random process with expected

[9] Trigeorgis (1996), pp. 83 - 84
[10] See Section 3.1

growth rate μ. The process is known as geometric Brownian motion[11]. Chapter 3 discusses stochastic processes in detail.

Several of these assumptions can be relaxed by adjusting the original Black-Scholes formula. The two most important adjustments provide means to value options on dividend-paying stocks and American-style options:

- Suppose the stock pays dividends at a rate of δ. Then, the Black-Scholes formula changes to[12]:

$$c = N(d_1)Se^{-\delta t} - N(d_2)Ke^{-r_f t} \tag{2.6}$$

  where these variables change to:

$$d_1 = \frac{\ln(S/K) + (r_f - \delta + \frac{\sigma^2}{2})t}{\sigma\sqrt{t}} \tag{2.7}$$

$$d_2 = d_1 - \sigma\sqrt{t} \tag{2.8}$$

- The value of an American option on non-dividend paying stock is equal to the value of its European counterpart. If there are dividend payments, the value of the American option can be found by the following approximation[13]. Suppose there is one discrete dividend payment during the life of the option. First, calculate the difference between the present values of the exercise price on the day the dividend is paid and on the expiration date. If the difference is greater than the dividend, the option should not be exercised early. If it is smaller, proceed with calculating the value of a European option expiring on the day the dividend is declared. Compare this with the value

[11] See Section 3.2

calculated with the Black-Scholes formula using the terms of the American call as inputs. The value of the American call is equal to the higher value of the two. Similarly the higher value indicates which action is optimal, early exercise or waiting until maturity.

Having developed a thorough framework for understanding financial options, it is possible to approach and analyze projects and situations in shipping that contain option elements.

[12] This modification was published in Merton, R. C. "The Theory of Rational Option Pricing". Bell Journal of Economics and Management Science. No 4. Spring 1973

[13] This approach was developed by Fischer Black, and is described in Hull (1997), pp. 252 – 253.

Chapter 3 Stochastic Processes

Any variable whose value changes in an uncertain way over time is said to follow a **stochastic process**. Stochastic processes describe the probabilistic evolution of the value of a variable through time. It is fundamental in option theory to identify and understand the stochastic process of the underlying asset. Although the approach is general, different stochastic processes lead to vastly different results for option valuation. The better the understanding of the underlying process, the better is the ability to quantify future uncertainty, and thus to value contingent claims.

Stochastic processes can be classified as **continuous time** or **discrete time**. A discrete-time is one where the value of the variable can change only at certain fixed points in time, whereas a continuous-time stochastic process is one for which changes can take place at any time. Stochastic processes can also be classified as **continuous variable** or **discrete variable**. In a continuous-variable process, the underlying variable can take any value within a certain range, whereas in a discrete variable process, only certain discrete values are possible[1].

Although stock prices are quoted neither continuously in time nor in infinitesimal increments, the results derived from a continuous-variable, continuous-time model prove to be the most versatile and useful for various applications. This chapter analyzes the fundamentals of continuous-variable, continuous-time stochastic processes, and examines

[1] Hull (1997), p. 209

the two most common processes that can be applied to shipping markets and to the stock market. Although not discussed here, due to their conceptual simplicity, discrete-variable, discrete-time processes are often used to illustrate important concepts underlying uncertain processes.

3.1 Markov, Wiener and Ito Processes. Ito's Lemma

A **Markov** process is a "memoryless" stochastic process where only the present state of the process is relevant for predicting the future[2]. The only relevant piece of information is the current value. The past history of the variable and the way in which the present has emerged from the past are irrelevant. Stock prices are usually assumed to follow a Markov process. This property is consistent with the weak form of market efficiency. The weak form of market efficiency implies that all information is contained in the past history of stock prices. It is competition in the marketplace that ensures that weak-form efficiency holds[3].

Furthermore, stock prices are assumed to follow a so-called **Wiener process**. The Wiener process can be regarded as having the simplest form of variability, or **white noise**, added to the path followed by a variable. A Wiener process is a Markov chain, and in addition it is characterized by two other properties. First, its increments are independent in non-overlapping time intervals, and secondly the increments are normally distributed for finite intervals. The variance of a Wiener process grows linearly with the length of the time

[2] Hull (1997), p. 209
[3] Brealey and Myers (1996), p. 329

interval[4]. The behavior of variable z, which follows a Wiener process, can be understood by considering changes in its value, Δz, in small intervals of time, Δt. The value of Δz is given by:

$$\Delta z = \varepsilon\sqrt{\Delta t} \tag{3.1}$$

where ε is a random variable with a standardized normal distribution. The mean of Δz is zero, and the standard deviation of Δz is $\sqrt{\Delta t}$. In the limit as Δt goes to zero, the relationship becomes

$$dz = \varepsilon\sqrt{dt} \tag{3.2}$$

This differential expression represents **stochastic calculus**.

Another more general class of stochastic processes is the **Ito process**, named after the famous mathematician K. Ito who published important discoveries in the field of stochastic calculus in the 1950s. A number of commonly observed stochastic processes originate in the Ito process. It is a generalized Wiener process for which a variable x has an expected drift rate of a per unit time and variance rate of b^2 per unit time. The values of the parameters a and b depend on the underlying variable x and time t. Both the expected drift rate and the variance rate of an Ito process can change over time[5]. Algebraically, it can be written as:

$$dx = a(x,t) + b(x,t)dz \tag{3.3}$$

where dz is the Wiener process introduced above.

[4] Dixit and Pindyck (1994), pp. 63 - 65

The value of a derivative, or contingent claim, depends on and is a function of the price of an underlying asset. Given uncertainty in future prices of the underlying asset, it is therefore necessary to understand how functions of stochastic variables behave mathematically. **Ito's Lemma** is an important result for functions of stochastic variables. Suppose the value of a variable x follows an Ito process (Equation 3.3). Ito's lemma shows that a function G, which depends on x and t, is described by the following differential[6]:

$$dG = \left(\frac{\partial G}{\partial x} a + \frac{\partial G}{\partial t} + \frac{1}{2} \frac{\partial^2 G}{\partial x^2} b^2 \right) dt + \frac{\partial G}{\partial x} b dz \tag{3.4}$$

where dz is the same Wiener process as before. Thus, G itself also follows an Ito process, with drift rate $\frac{\partial G}{\partial x} a + \frac{\partial G}{\partial t} + \frac{1}{2} \frac{\partial^2 G}{\partial x^2} b^2$ and variance rate $\left(\frac{\partial G}{\partial x} \right)^2 b^2$. Ito's lemma is an extremely powerful tool for valuing contingent claims of various claims of various kinds, and it was the departing point from which Black and Scholes developed their famous formula for valuation of stock options. As soon as one has established the relation between the claim and the underlying variable, Ito's lemma can be applied, and the rest is non-trivial algebra. A proof of Ito's lemma is beyond the scope of this thesis[7].

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[5] Hull (1997), p. 215
[6] Hull (1997), p. 220
[7] See Appendix 10A of Hull (1997) for proof of Ito's lemma.

3.2 Geometric Brownian Motion

The most widely used model for stock price behavior[8], and one process that has been used to model newbuilding prices and secondhand ship values over time[9], is **geometric Brownian motion**. In financial economics, the underlying rationale of this process is motivated by the valuation of a security itself. The investment associated with holding a security needs to provide a sufficient return; otherwise the investor will look for alternative investments. Geometric Brownian motion assumes that the drift term grows geometrically over time. The expected change in value is proportional to the value of the variable. Over time, the variable is expected to grow exponentially. The motivation for the assumption of proportional growth is obvious from the following analogy:

> Consider two stocks that have identical characteristics, except that one is priced at \$100 and the other at \$20. Investors will require the same return (in percent) from both stocks, independent of the magnitude of the stock price. Thus, the expected return in dollars from the more expensive stock is five times greater than for the less expensive stock.

Mathematically, geometric Brownian motion for discrete time intervals can be expressed as:

$$\Delta S = \mu S \Delta t \qquad (3.5)$$

where μ is the expected rate of return from holding the asset.

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[8] Dixit and Pindyck (1994), p. 72

[9] See Stray (1991) for empirical conclusions regarding geometric Brownian motion for vessel prices.

The geometric character of the process also extends to the uncertainty, or volatility, of the value of the variable. Geometric Brownian motion assumes that the variance of the percentage return is the same regardless of the value of the variable. If σ^2 is the variance rate of the proportional change in the value of the variable, the variance of the actual change in the value is $\sigma^2 S^2 \Delta t$. Relating this back to the framework of the Ito process, the instantaneous differential describing geometric Brownian motion is[10]:

$$dS = \mu S dt + \sigma S dz \tag{3.6}$$

where μ is the expected rate of return and σ is volatility.

Dividing through by the value of the variable S yields:

$$\frac{dS}{S} = \mu dt + \sigma dz \tag{3.7}$$

The right-hand side is normally distributed with mean μ and standard deviation σ. When integrating the left side of the equation, the underlying variable S does not appear, but instead its logarithm, $\ln S$. This implies that the logarithm of the underlying variable is normally distributed, and not the underlying variable itself. Therefore, S is said to be lognormally distributed[11]. The probability density function of a lognormal random variable is skewed to the right, with no probability of negative values, as shown in the following figure.

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[10] Hull (1997), pp. 215 - 216
[11] Dixit and Pindyck (1994), p. 71

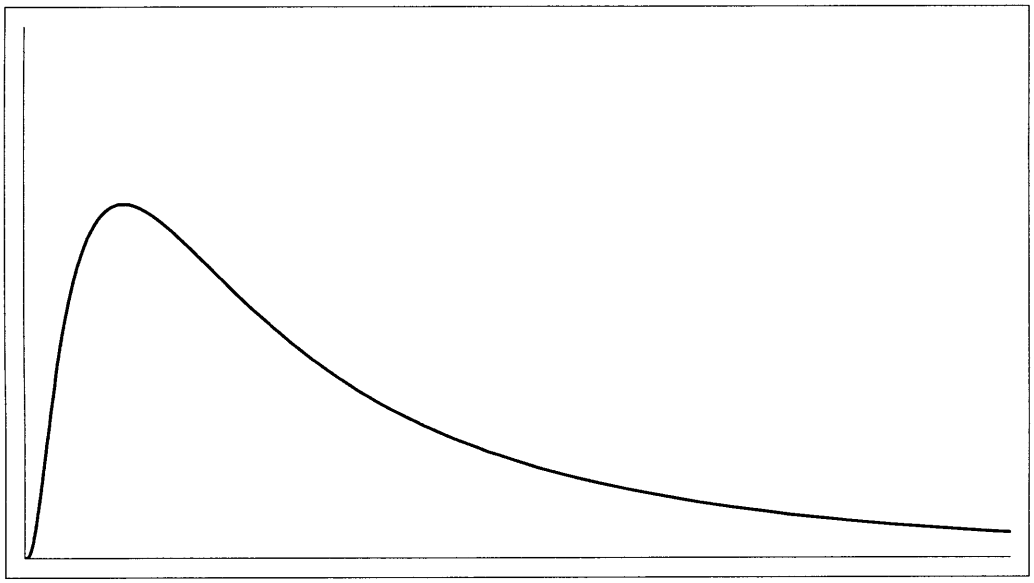

Figure 3.1: Lognormal Probability Density Function

The process followed by $\ln S$ can be derived using Ito's lemma. Let

$$G = \ln S \tag{3.8}$$

Since

$$\frac{\partial G}{\partial S} = \frac{1}{S}, \quad \frac{\partial^2 G}{\partial^2 S} = -\frac{1}{S^2}, \quad \frac{\partial G}{\partial t} = 0$$

it follows from Ito's lemma (3.4) that

$$dG = \left(\mu - \frac{\sigma^2}{2}\right)dt + \sigma dz \tag{3.9}$$

G follows a generalized Wiener process with constant drift rate $\mu - \frac{\sigma^2}{2}$ and constant standard deviation σ. The value of G at time t is $\ln S_t$. Its value at time T is $\ln S_T$. The change during the time interval T-t is therefore $\ln S_T - \ln S_t = \ln\left(\frac{S_T}{S_t}\right)$. This change is normally distributed with mean $\left(\mu - \frac{\sigma^2}{2}\right)(T-t)$ and standard deviation $\sigma\sqrt{T-t}$ [12].

Integrating (3.9) and generalizing the resulting equation yields the following expression for the stock price S at time T:

$$S(T) = S(t)e^{\left(\mu - \frac{1}{2}\sigma^2\right)(T-t) + \sigma Z(T-t)} \tag{3.10}$$

Here, $Z(T\text{-}t)$ is a stochastic function that is normally distributed with mean 0 and standard deviation $\sqrt{T-t}$.

The expected value of $S(T)$ is:

$$m = E[S(T)] = S(t)e^{\mu(T-t)} \tag{3.11}$$

and the variance is:

$$\sigma_S^2 = Var(S(T)) = (S(t))^2 e^{2\mu(T-t)}\left(e^{\sigma^2(T-t)} - 1\right) \tag{3.12}$$

where $S(t)$ is the initial value at time t[13].

[12] Hull (1997), pp. 221 - 222
[13] Dixit and Pindyck (1994), pp. 71 - 72

An example showing geometric Brownian motion and its expected value is plotted below:

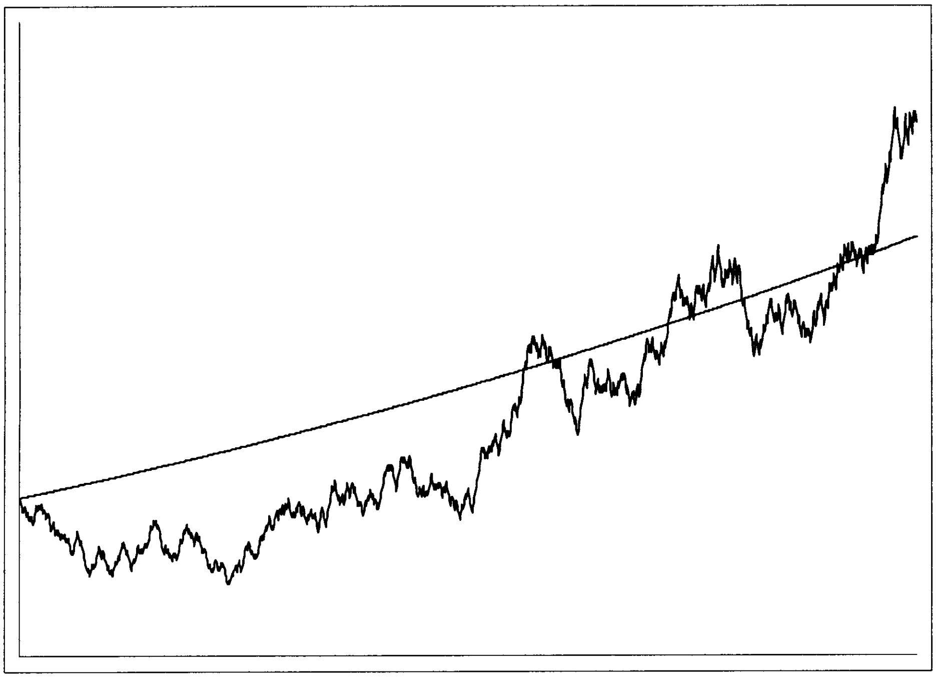

Figure 3.2: Example of Geometric Brownian Motion

3.3 Mean Reversion

The alternative to analyzing how a security itself moves through time, as for geometric Brownian motion, is to focus on the price process of an underlying commodity, and view the security as being dependent on it. When doing so in a shipping context, the value of a vessel is the security, while the spot freight rate is the commodity price. The market for spot freight voyages shares some characteristics with markets for commodities such as metals, grain or oil. There are suppliers and demanders in the market, and the price of the commodity represents a significant risk to all.

If the price in a commodity market rises, suppliers get an incentive to increase their supply, and the commodity will eventually fall in price to a level where providing additional supply is no longer attractive. In shipping markets, contracting of new vessels increases substantially during good periods, and comes to a halt during bad periods. This affects the freight rates, which will fluctuate and tend to be pulled towards a natural long-term level, at which the market is in balance. This spot freight rate process feeds back to the price process of vessels, for both newbuildings and secondhand ships.

One stochastic process that describes this pattern is the **elastic Brownian motion,** or the **Ornstein-Uhlenbeck process**. Mathematically, it is given by:

$$dS = k(\alpha - S)dt + \sigma dz \qquad (3.13)$$

where α is the **long-term equilibrium level**, or mean, of the variable S, and k is the **gravity factor**, or **speed of adjustment-factor**, describing the rate at which the variable reverts to the mean. As before, σ is the standard deviation and dz is the increment of a standard Brownian motion.

For the Ornstein-Uhlenbeck process, the drift term is positive if the value of variable S is below the long-term mean, and vice versa. The probability of a higher price in the next time increment is larger than the probability of a lower price. The probability distribution is symmetric and Gaussian only when the current price equals the long-term mean. Thus, the Ornstein-Uhlenbeck process satisfies the Markov property, but it is not a Wiener process as the increments of the process are not independent and normally distributed, but instead depends on the difference between current value and the long-term equilibrium level[14].

The speed of adjustment-factor k determines the strength of the mean-reverting tendency. When interpreting k, note that

$$T = \frac{\ln 2}{k} \tag{3.14}$$

corresponds to a "half time" T, after which the expected future value of the variable is half way between the initial value $S(t)$ and the long term mean α.

The value of variable S described by the stochastic process in (3.13) can not be expressed in a closed form, but rather through the following stochastic integral[15]:

$$S(T) = e^{-k(T-t)}S(t) + \left(1 - e^{-k(T-t)}\right)\alpha + \sigma e^{-k(T-t)} \int_t^T e^{k(T-t)} dz \tag{3.15}$$

The expected value of an Ornstein-Uhlenbeck process is:

$$m = E[S(T)] = e^{-k(T-t)}S(t) + \left(1 - e^{-k(T-t)}\right)\alpha \tag{3.16}$$

and the variance is:

$$\sigma_S^2 = Var(S(T)) = \frac{\sigma^2}{2k}\left(1 - e^{-2k(T-t)}\right) \tag{3.17}$$

[14] Dixit and Pindyck (1994), p. 74

An example showing a mean-reversion process and its expected value is plotted below:

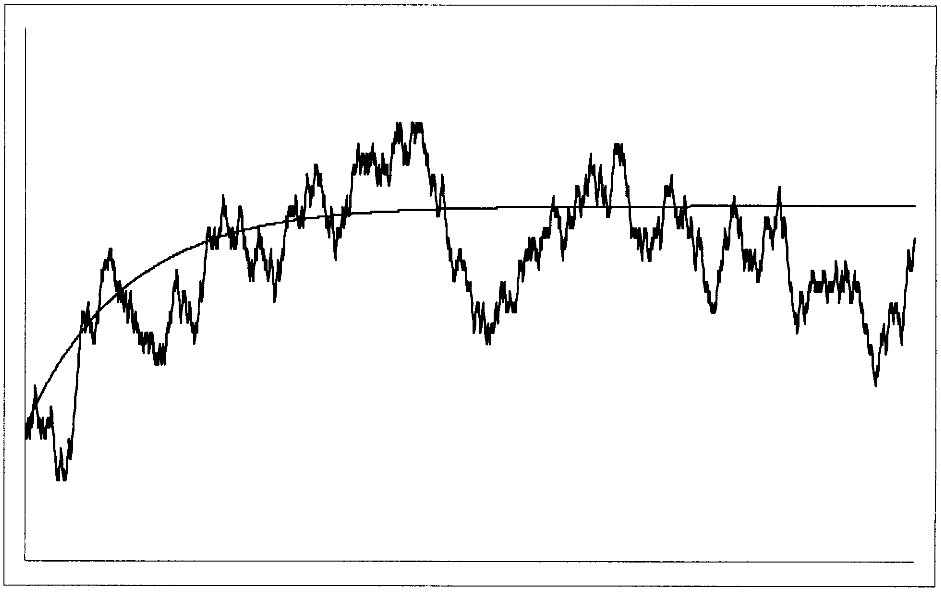

Figure 3.3: Example of Mean-Reversion Process

[15] Bjerksund and Ekern (1992 (b))

Chapter 4 Market Models and Data

In view of the discussion of stochastic processes in Chapter 3, it is necessary to establish whether the market for newbuilding vessels is best modeled through geometric Brownian motion or through a mean-reverting process. A well justified choice of model and carefully calculated parameter values are fundamental in contingent claims analysis. Otherwise, decisionmakers will regard option valuation as nothing more than an interesting theoretical game, useless in investment decisions.

A time series of past newbuilding prices can be examined and tested to establish which of the two models, if any, provides the more accurate description of the price process. However, the availability of meaningful data is limited. It is not possible to observe a prevailing newbuilding price at any given point in time; instead observation must be based on actual contracts concluded. Even for the most common and typical vessel categories, contracts are entered on an infrequent basis. Each contract usually contains unique specification elements, and the price is not always disclosed publicly. Ideally, years of data covering hundreds, if not thousands, of observations are needed to determine with any degree of confidence the type of stochastic process and the relevant parameter values. Furthermore, the boundaries of the time period chosen for the econometric analysis can influence the resulting outcome. Accordingly, there are many pitfalls to avoid in the analysis of newbuilding price data, and any conclusions derived will in their very nature be weak[1].

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[1] Dixit and Pindyck (1994), p. 77

4.1 Data Sources

For the purpose of analysis, shipbuilding price data from three different sources were obtained. H. Clarkson & Co. Ltd., a London-based shipbroker, provided a time series of monthly nominal newbuilding prices for the major types of bulkers and tankers, covering the period between January 1976 and February 1998. R.S. Platou Shipbrokers a.s. in Oslo provided quarterly price data for the same types of vessel, covering Q1 1970 to Q4 1997. Marsoft, Inc., a consulting and market forecasting company in Boston, specializing in the shipping industry, similarly provided quarterly data covering Q1 1980 to Q4 1997. The reason why it was decided to focus on bulkers and tankers is that these vessel categories collectively account for more than half of the total global shipbuilding activity and that bulkers and tankers are relatively homogenous in terms of technical specifications. Furthermore, both the underlying freight market and the second-hand vessel market for these ship types are considered relatively liquid and efficient, and this characteristic can be extended to some degree to the newbuilding market as well.

Figure 4.1 shows a plot of three indices, calculated from the newbuilding price data provided by Platou, Marsoft and Clarkson, respectively. Each vessel category is given equal weight, and the indices are rebased such that the initial value in 1970 is equal to 100[2].

[2] Within the data collected from Clarkson and Platou, there are some discrepancies in terms of when observations for certain vessel categories start. When developing the indices, new categories were included in the indices on a pro-rata basis from the time of the first observation. Furthermore, for aframax, suezmax and VLCC tankers, these two companies distinguish between single hull and double hull vessels. In the indices, single hull vessels are included up to 1990, while double hull vessels are used from 1990 and onwards.

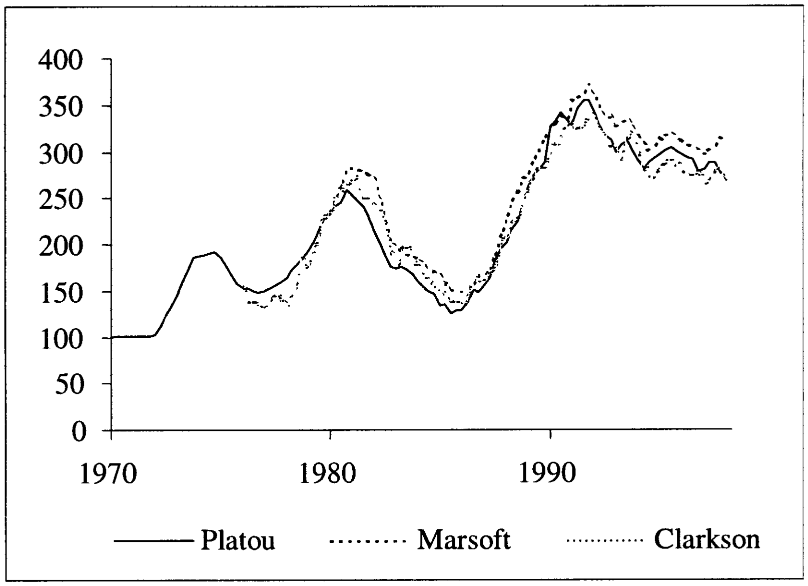

Figure 4.1: Newbuilding price indices 1970 - 1998

The three data sources all have in common that the price observations were manipulated when they were recorded in order to produce homogeneous time series of price information. Records of actual newbuilding contracts concluded in the global shipbuilding market were collected, and an average price for each vessel category was calculated for each period. The data were adjusted for differing vessel specifications and other unique terms in each contract. In developing the time series, it was attempted to produce the price of the typical ship throughout time[3]. In some periods, there were no contracts entered for a specific vessel category. In these cases, a price was estimated from quotes and from trends observed in contracts concluded for other vessel categories.

[3] The deadweight tonnage of a typical vessel within a category has been steadily increasing. The analysis has not been adjusted to account for this.

Thus, the time series are not based on raw observations in the market, and the analyzed data do not reflect the true pricing process for newbuildings. The quarterly time series are more heavily influenced by being calculated from the average of many observations, while the monthly time series from Clarkson provides a better indication of the true pricing process. In view of this, the conclusions drawn from the data analysis are inherently weak. Still, it is possible to arrive at indirect conclusions that are meaningful when evaluating newbuilding options.

4.2 Test of Geometric Brownian Motion

As established in Section 3.2, geometric Brownian motion is a Markov process. The natural logarithm of the ratio between prices in subsequent periods should not depend on the values in prior periods. Testing the null hypothesis through regression can establish whether the data conforms to the geometric Brownian price process.

The following regression was performed on all the newbuilding price time series:

$$\ln\left(\frac{S_t}{S_{t-1}}\right) = a + b\ln\left(\frac{S_{t-1}}{S_{t-2}}\right) + \varepsilon_t \tag{4.1}$$

where ε_t is the error, expressed as the difference between the predicted value and actual value at each point in time. The ordinary least squares method was used to determine the parameters a and b.

In this test, if the null-hypothesis holds, b is equal or close to zero. Even if b is non-zero, the null-hypothesis can not be rejected if the standard deviation of the parameter value is significant in comparison. The calculated t-ratio for a parameter estimate, which is equal the value of a parameter divided by the standard deviation, is useful in determining the consistency of the results. For a large number of observations, or degrees of freedom in the statistical material, a t-ratio exceeding 1.960 indicates that the null-hypothesis can be rejected on a 95% confidence level, while a t-ratio of 1.645 corresponds to a 90% confidence level[4].

Appendix A.1 contains all the results of the regression analysis. This is a summary:

	Clarkson[a]		Platou[b]		Marsoft	
	b	t-ratio	b	t-ratio	b	t-ratio
Mean	0.15410	2.29658	0.53936	6.54555	0.57517	6.04876
Minimum	0.04579	0.65263	0.31875	3.46659	0.39063	3.60523
Maximum	0.23438	2.83400	0.71016	10.37222	0.69383	8.06535

[a] Excludes aframax, panamax tanker and VLCC double hull data, for which there is a limited number of observations

[b] Excludes handysize and VLCC double hull data, for which there is a limited number of observations

Table 4.1: Regression Analysis to Test Geometric Brownian Motion

These results do not confirm the null-hypothesis explained above, as the values of b can be determined to be non-zero with a high degree of confidence. Thus, a geometric Brownian model for newbuilding prices is not supported by the analyzed data. There is evidence that the current value depends not only on the previous value, but also on values preceding the previous value. In other words, the data show auto-correlation tendencies. However, there is a clear distinction between the quarterly data from Platou and Marsoft, and the monthly data from Clarkson. The value of the coefficient b is significantly lower for the Clarkson data. As the numbers become less affected by averaging over longer

[4] Hogg and Tanis (1993), p. 684

periods of time, the logarithm of the percentage price development seems to become less dependent on its lagged value. Furthermore, the *t*-ratio for the Clarkson numbers decreases by more than the square root of the change in duration of each interval. The monthly Clarkson data fluctuate more than the quarterly, and one should be able to justify that this trend is likely to be even stronger for more frequent observations of newbuilding price data. Therefore, although the analysis *a priori* does not support the null-hypothesis, it is not possible to reject entirely the geometric Brownian price process.

Geometric Brownian motion is the most widely accepted model for the stochastic behavior of stock prices and other financial securities. Performing the same null-hypothesis regression as above for monthly values of the Dow Jones Industrial Average and Standard & Poor's 500 indices for the period between January 1984 and February 1998 yielded a value of b of -0.010 and -0.014, respectively. In both cases, the standard deviation was significantly larger than the parameter value. Therefore, it is possible to conclude that the stock market data confirm the null-hypothesis. For the same period, the average value of the b parameter for the Clarkson data was calculated as equal to 0.350. This is another indication that geometric Brownian motion is not a very good model of the newbuilding price process as observed in the collected data.

4.3 Test of Mean-Reversion

The mean-reversion price process described in Section 3.3 is, contrary to the geometric Brownian process, not a Wiener process. The probability distribution of future values of the variable is not symmetric, as the current distance from the long-term equilibrium level skews the distribution in the direction of this mean value. The probability distribution of future values is symmetric only when the current value of the variable is equal to the mean. Doing a null hypothesis regression similar to the one for geometric Brownian motion is meaningless because data conforming to a mean-reversion process should not satisfy the null-hypothesis. In fact, developing a test for mean-reversion is rather complex due to the dependency due this asymmetry, and no literature describes a test that establishes whether mean reversion is a good description of the stochastic process[5].

Instead, it was assumed that the data indeed are mean reverting. This assumption made it possible to perform a regression analysis that determines the key parameters in the Ornstein-Uhlenbeck process, the long-term equilibrium level α and the speed of adjustment-factor k. The mathematical expression for this regression is:

$$S_t - S_{t-1} = \alpha k - kS_{t-1} + \varepsilon_t \qquad (4.2)$$

The variability in the calculated parameters, as expressed through the t-ratio, as well as the comparison between the calculated value of α compared to the average value of the prices in the time series subsequently indicate the consistency of the model.

The results of the regression analysis are tabulated in Appendix A.2. A summary is given here:

[5] Dixit and Pindyck, p. 77 - 78

	Clarkson[a]		Platou[b]		Marsoft	
	k	*t*-ratio	*k*	*t*-ratio	*k*	*t*-ratio
Mean	0.01246	1.41176	0.02817	1.53914	0.01302	0.63100
Minimum	0.00385	0.68650	0.01901	1.21158	0.00769	0.48023
Maximum	0.03532	3.69221	0.05036	2.11442	0.01914	0.79256

[a] Excludes aframax, panamax tanker and VLCC double hull data, for which there is a limited number of observations

[b] Excludes handysize and VLCC double hull data, for which there is a limited number of observations

Table 4.2: Regression Analysis to Determine Mean-Reversion Parameters

There are two significant results. Firstly, the *t*-ratios are generally low, and they are consistently smaller than 1.96, which corresponds to a 95% confidence level. Accordingly, the speed of adjustment-constants are not calculated with a high degree of certainty. This means that the *k*-values either change significantly during time, or that the simple model for mean-reversion does not accurately describe the newbuilding price process. Secondly, the *k*-values are surprisingly low. Considering the notion that the speed of adjustment constant corresponds to the half time of the process, these values correspond to a half time on the order of several decades. A process with such a low speed of adjustment-constant has a very weak mean-reversion tendency, and as the analyzed data cover a period of 25 years or less, this tendency would not be observable. Figure 4.1 shows clear tendencies of cyclicality and reversion, but these are not captured in the regression analysis of the mean-reversion model.

If the time span of the data series is sufficiently long, the average value of the prices during that period should not differ significantly from the calculated value of the long-term equilibrium level in the mean-reverting process. In order to verify this, these two averages were compared:

	Clarkson[a]	Platou[b]	Marsoft
	Difference	Difference	Difference
Mean	22.78%	26.70%	32.60%
Minimum	-2.17%	17.67%	8.04%
Maximum	49.67%	38.02%	54.26%

[a] Excludes aframax, panamax tanker and VLCC double hull data, for which there is a limited number of observations

[b] Excludes handysize and VLCC double hull data, for which there is a limited number of observations

Table 4.3: Percentage Difference Between Average Price and α

The difference between the average value of the newbuilding prices and the calculated value of α is too large to be explained simply by the length of the time period. Changing the starting date and the end date of the analysis still leads to differing results. This fact is another indication that the mean-reversion model does not fit well to the actual price process.

In addition to these empirical observations, it is possible to argue that the mean-reverting model fundamentally can not describe any economic process. Over time, the mean, around which the variable fluctuates, has to increase due to inflation. This fact extends to analyses over limited periods in time. The choice of starting date and end date inevitably affects the resulting outcome, not only because the distance of the first observation from the mean is unknown prior to the analysis, but also because the very nature of the price process dictates that the mean evolves through time.

4.4 Conclusion on Price Process

It has been established that neither geometric Brownian motion nor mean-reversion serve as accurate models of the newbuilding price process. Both are mathematically simple, but at the same time they represent fundamentally opposite processes. A variable governed by geometric Brownian motion is expected to grow exponentially at a constant rate, and only the current value affects the next value in the time series. The Ornstein-Uhlenbeck process fluctuates around a constant mean value, and the previous disturbances to the variable affect its future probability distribution. The true newbuilding pricing process is located somewhere between these two extreme models, and it can not be expressed in a neat analytic expression. The expected value will grow over time, and values in the time series more than one step back affect the future value of newbuilding prices. When proceeding with option valuation in Chapter 5, option values are calculated for the two different models. In Chapter 6, the price process is discussed further in a practical industry context, and guidelines as to how to perform adjustments in order to relate the results to the actual environment in which the options apply, are given.

Chapter 5 Valuation of Ship Newbuilding Options

A ship newbuilding is a commodity, and using the technically correct term, a newbuilding contract is a forward contract on a new ship. The owner promises to pay for a new vessel that is delivered at a specified date in the future. Therefore, a newbuilding option is a call option on a forward contract. However, the timing element of newbuilding forward contracts is irrelevant because there is always a delay between entering into a contract and delivery of a ship due to the construction time. This is independent of whether a contract concerns a fixed number of ships, or whether it is an option.

The similarities of the contract specifications between a call option on publicly traded stock that pays no dividends and a ship newbuilding option are striking:

Call Option on Stock	Ship Newbuilding Option
Current stock price *S* Exercise price *K* Time to expiration *t* No dividends	Current newbuilding price *S* Exercise price *K* Time to expiration *t* No convenience yield or cash flow from operations
Value of call option *c*	Value of ship newbuilding option *c*

Table 5.1: Similarities Between Call Option on Stock and Ship Newbuilding Option

In this chapter, option valuation formulas for the two fundamental stochastic processes will be analyzed. First, it is necessary to make an important distinction between commodities such as ships, and financial securities.

5.1 Market Price of Risk

The term **traded security** is used to describe a traded asset that is held solely for investment purposes by a large number of individuals. Stocks, bonds, foreign currencies and gold are all examples of traded securities, while most commodities, including ships, that are either consumed or used in production processes, are not. The distinction between underlying variables that are prices of traded securities and those that are not is important in valuation of derivatives. As explained in Section 2.5, the risk-neutral valuation method does not consider an investor's attitude towards risk. The value of a derivative of a traded security does not depend on risk preference, as it is possible to construct and maintain an equivalent portfolio that provides a return equal to the risk-free interest rate with probability 1.

For non-traded securities, the concept of a risk-neutral dynamic portfolio is meaningless due to the fact the commodity can not be purchased or sold in an efficient market. An extension of the risk-neutral valuation argument has to be made. A parameter known as **market price of risk**, λ, enters into the pricing of derivatives of such assets. This parameter measures the extent to which investors require a higher return as compensation for bearing the risk associated with the asset. Including market price of risk in the analysis, it is still possible to price the derivative using a risk-neutral approach. The expected growth rate in the underlying variable must be reduced by the product of the market price of risk, λ, and the volatility, σ[1]. The **risk-adjusted growth rate, μ^*,** is expressed symbolically as:

$$\mu^* = \mu - \lambda\sigma \tag{5.1}$$

The concept of risk-adjusted growth rates and risk-neutral valuation is so far only interesting from a theoretical point of view. The question of how to estimate μ and λ remains unanswered. Since ships are not traded in an efficient market, the expected growth rate and the market price of risk can not be extracted directly from a time series of ship newbuilding prices. The reason for this is that a shipowner can not carry risk, and obtain a return from doing so, by entering into a position in a newbuilding. If there existed quoted futures prices for newbuildings, it would be possible to compare spot newbuilding prices with futures prices, and implicitly find the market price of risk by recognizing the fact that futures prices follow a zero-drift stochastic process in a risk-neutral world[2]. However, there is no futures trading for ship newbuildings, and thus, this method can not calculate λ for newbuilding prices.

Andersen (1992) and Stray (1992) calculate the implied market price of risk associated with freight contracts. They assume that the freight markets are mean reverting, and derive an analytic expression for λ from the relationship between the spot freight rate and a time-charter rate in a mean-reverting universe[3]. Stray shows that the λ-value fluctuates significantly through time, while Andersen demonstrates that the market price of risk is

[1] Hull (1997), pp. 288 - 292
[2] Hull (1997), pp. 296 -297

negatively correlated with the prevailing spot freight rate. Both conclude that the average value is negative, approximately equal to $\lambda = -0.15$. This result leads them to conclude that owners give charterers a discount for fixing the vessels on long time-charters.

The concept of market price of risk and the definition given above resemble closely the capital asset pricing model (CAPM) used in the financial markets. This model argues that an investor requires excessive returns to compensate for any risk that is correlated to the risk in the return from the stock market, but requires no excess return for other risk. The CAPM model defines the parameter β as a measure of risk - it is the covariance between a particular stock and the market index divided by the variance of the market index[4]. In Appendix B, there is a compilation of beta values for major shipbuilding companies. The trend is that these companies have a beta slightly above 1, which means that investors require a somewhat higher return from these stocks compared to the market portfolio. The beta values can indicate a similar trend for ship newbuildings. In absence of other meaningful data, this fact does not support the conclusion that newbuilding prices in a similar fashion as freight contracts have a negative price of market risk. Therefore, in the subsequent calculations in this chapter, the value of λ is set equal to zero. This means that investors in ship newbuilding contracts are neither rewarded nor penalized for taking a position in a newbuilding contract.

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[3] Andersen (1992), p. 56 and Stray (1991), p. 19 and pp. 64 - 68
[4] Brealey and Myers (1996), pp. 160 - 164

5.2 Options on Assets Governed by Geometric Brownian Motion

As explained in Section 2.6, Black and Scholes used Ito's lemma to extend the binomial method for pricing of derivatives to a continuous differential equation, to which the Black-Scholes formula is the closed-form solution. The fundamental assumption in their work is that the price of the underlying traded security follows a geometric Brownian stochastic process. For call options on non-traded commodities that also follow a geometric Brownian motion, the Black-Scholes formula still applies if the input parameters are adjusted for the market price of risk, as explained above. Hull (1997) uses Ito's lemma to show that for non-traded assets, substituting the risk-adjusted expected growth rate, $\mu^* = \mu - \lambda\sigma$, for the risk-free interest rate r_f in the original Black-Scholes equation yields a differential equation that is structurally identical[5]. Thus, it is possible to calculate the value of a call option written on a non-traded commodity using an adjusted Black-Scholes formula in which the expected growth rate adjusted for the market price of risk is substituted for the risk-free interest rate.

The adjusted pricing formula for a call option is transformed to:

$$c = N(d_1)S - N(d_2)Ke^{-(\mu-\lambda\sigma)t} \tag{5.2}$$

where:

- c is the value of the call option
- S is the current commodity price, or in the context of shipbuilding, the prevailing newbuilding price

- K is the exercise price
- μ is the expected growth rate of the underlying commodity price
- λ is the market price of risk
- σ is the standard deviation per period of the continuously compounded rate of return of the commodity price
- t is the time until expiration of the option, or the number of time periods until expiration
- $N(\bullet)$ is the cumulative normal probability distribution function
- $$d_1 = \frac{\ln(S/K) + (\mu - \lambda\sigma + \frac{\sigma^2}{2})t}{\sigma\sqrt{t}} \qquad (5.3)$$
- $$d_2 = d_1 - \sigma\sqrt{t} \qquad (5.4)$$

Section 2.6 also discusses the required assumptions that are necessary for the derivation of the Black-Scholes formula. These assumptions must be revisited in order to understand their implication on the adjusted formula for call options on non-traded commodities:

- The original version of Black-Scholes requires a frictionless market for the underlying security. As explained above, this requirement is not satisfied for non-traded commodities. However, the adjustment of the expected growth rate allows valuation of the derivative as if the underlying asset were traded in a perfect market. The same methodology of risk-neutral valuation can be applied.
- The option is of the European type. Whether or not specified in the contract, in practice ship newbuilding options are always of this type, as early exercise does not

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[5] Hull (1997), pp. 290 - 291

allow the shipowner to cash in or to speed up the delivery of the declared option vessel. Thus, for shipbuilding options, the exercise decision is always made on the expiration date.

- The original Black-Scholes formula requires the risk-free short-term interest rate to be constant over the life of the option. As the adjusted formula instead uses the risk-adjusted expected growth rate, it is necessary to assume that this rate, which depends on the expected growth rate, the market price of risk and the volatility, does not change over the lifetime of the option.
- The volatility of the underlying asset, in terms of the standard deviation, is constant over the life of the option.
- The underlying asset pays no dividends over the life of the option. For owners of commodities, it is customary to consider so-called **convenience yield** rather than dividends. Convenience yield is the benefit that the owner of the underlying asset receives during the lifetime of the option, and that the owner of the option concurrently foregoes. As a new ship does not earn a return to its owner while it is being constructed, the convenience yield for newbuilding options is zero. However, if using this framework to value options on second-hand vessels, the convenience yield is the income from operating the ship that the owner of the vessel, and not the holder of the option, receives. In this case, the Black-Scholes formula for options on dividend paying stocks (Equations 2.6 – 2.8) needs to be used, and the same substitution for the risk-free interest rate is required to adjust for the market price of risk.

- The price of the underlying asset follows a stochastic diffusion Wiener process of the form $dS = \mu S dt + \sigma S dz$. As established in Chapter 4, this is not a good model for the ship newbuilding market, but it is still useful to value options with the adjusted Black-Scholes formula (5.2) in order compare to the result with alternative valuations.

5.3 Options on Assets Governed by Mean-Reversion

Bjerksund and Ekern (1992 (b)) derive a closed-form formula for the value of a call option written on a non-traded commodity under the assumption that the price of the underlying commodity follows an Ornstein-Uhlenbeck stochastic process. The fundamental problem of constructing a risk-neutral portfolio for a non-traded asset is equivalent in this model as in the case of geometric Brownian motion. However, Bjerksund and Ekern deal with this challenge differently. Instead of adjusting the expected growth rate, which in any case is a more subtle concept for mean-reverting processes, they adjust the long-term equilibrium level, α, and the expected value of the commodity price, m. By adjusting these input parameters for the market price of risk, the risk-free interest rate enters the valuation formula without adjustments[6].

The Bjerksund-Ekern adjustments are:

$$\alpha^* = \alpha - \frac{\sigma\lambda}{k} \tag{5.5}$$

where:

- α^* is the risk-adjusted long-term equilibrium

[6] Bjerksund and Ekern (1992 (b)), pp. 8 - 9

- σ is the standard deviation per period of the deviation of the actual value from the expected value
- λ is the market price of risk
- k is the speed of adjustment factor

and

$$m^* = e^{-kt}S + \left(1 - e^{-kt}\right)\alpha^* \qquad (5.6)$$

where:

- m^* is the risk-adjusted expected value of the asset price at the expiration date of the option
- S is the current commodity price, or in the context of shipbuilding, the prevailing newbuilding price
- t is the time until expiration of the option, or the number of time periods until expiration

Bjersund and Ekern proceed along the now familiar route - starting from the instantaneous differential for the Ornstein-Uhlenbeck process and using Ito's lemma to derive a partial equation that satisfies the boundary conditions for the call option. The end result is the following formula for the value of a call option[7]:

$$c = e^{-r_f t}\left\{\left(m^* - K\right)N(d) + \sigma_S n(d)\right\} \qquad (5.7)$$

[7] Bjerksund and Ekern (1992 (b)), p. 15

where:

- c is the value of the call option
- K is the exercise price
- r_f is the risk-free interest rate
- $N(\bullet)$ is the normal cumulative probability distribution function
- $n(\bullet)$ is the normal probability density function
- $d = \dfrac{m^* - K}{\sigma_S}$ (5.8)
- $\sigma_S = \sqrt{\dfrac{\sigma^2}{2k}\left(1 - e^{-2kt}\right)}$ (5.9)

The assumptions underlying this formula are similar to those underlying the adjusted Black-Scholes formula described in Section 5.2:

- Although the stochastic price process is different, the requirement of an efficient, frictionless asset market is not met for exactly the same reasons explained in the previous section in the case of non-traded commodities following geometric Brownian motion. Again, adjusting for the market price of risk transforms the contingent claims analysis such that the risk-neutral valuation framework still applies.
- The ship newbuilding option must be of the European type for this formula to apply, just as for the adjusted Black-Scholes formula.
- The risk-free interest rate is constant over the lifetime of the option.
- The long-term equilibrium level, the volatility of the underlying asset and the market price of risk do not change over the lifetime of the option.

- The underlying asset provides no convenience yield or pays no dividends. As explained above, this is satisfied in the case of ship newbuildings, but not for options on secondhand vessels.
- The price of the underlying asset follows the Ornstein-Uhlenbeck stochastic process of the form $dS = k(\alpha - S)dt + \sigma dz$. In Chapter 4, it was established that this model is not a good description of the cyclicality and path-dependency of newbuilding prices, but it offers an opportunity to model the reverting tendency of vessel prices in a mathematically simple expression.

5.4 Estimation of Formula Input Parameters

The two alternative formulas for calculating the value of ship newbuilding options require the following input parameters:

Parameter	Symbol	Adjusted Black-Scholes Formula	Mean-Reversion Option Formula
Current newbuilding price	S	√	√
Exercise price	K	√	√
Time to expiration	t	√	√
Volatility of newbuilding price	σ	√	√
Risk-free interest rate	r_f		√
Expected growth rate of S	μ	√	
Market price of risk	λ	√	√
Long-term equilibrium level	α		√
Speed of adjustment factor	k		√

Table 5.2: Input Parameters in Option Formulas

The exercise price and the time to expiration of the option are specified in the option contract. Quotes of current newbuilding prices are easily obtained from brokers and shipyards, or as options are typically received in conjunction with firm contracts on identical vessels, the current price is implicitly specified in these contracts. The exercise price of ship newbuilding options is typically equal to the current price of the same vessel type. These parameters, along with the risk-free interest rate, for which the three-month government bond rate for the currency of the contract is most often used, require no effort to obtain.

All the other input parameters need to be estimated carefully from observations of past prices in view of future expectations. The fundamental problem is how well past data predict future development. Thus, choosing the appropriate time period for the estimates is of crucial importance. More data generally lead to more accurate results. However, the value of each parameter changes over time, and data that are too old may not be relevant for predicting the future. A common rule of thumb that is often used for financial derivatives is to set the time period over which a parameter is calculated equal to the time period over which it is to be applied[8]. In the context of shipbuilding options, the low frequency of price data presents a problem if this rule is to be followed. Most newbuilding options have a duration of less than a year, while price data are recorded not more often than on a monthly basis. Thus, parameter estimates should not cover less than one year of data, and estimates for longer time periods should be calculated and compared to the one-year estimates.

The volatility of newbuilding prices, the expected growth rate and the long-term equilibrium level were calculated from the index based on the Clarkson newbuilding price data. Three time horizons, covering data going one year, five years and twenty years back in time, respectively, were chosen for comparison. The results are tabulated below:

Variable	1 year	5 years	20 years	Comment
μ	-1.26%	-2.26%	3.47%	
σ	5.54%	5.70%	8.38%	Adjusted Black-Scholes; Annualized standard deviation of percentage return
σ	2.44%	4.24%	21.42%	Mean-Reversion; Standard deviation of residuals, as a percentage of α
α	177.67	184.34	157.18	
$S(0)$	172.00	189.43	92.24	

Table 5.3: Calculated Parameter Values

An attempt to calculate the speed of adjustment-factor k was deliberately not made. The regression tests described in Chapter 4 conclude that the calculated values of k correspond to a half time on the order of several decades, and the reason for this is that the Ornstein-Uhlenbeck model does not describe very well the cyclicality in the newbuilding market. However, the option values based on the Ornstein-Uhlenbeck process give a good indication of true value if an appropriate speed of adjustment-factor is chosen. Figure 4.1 clearly shows explicit peaks and troughs in the newbuilding price data. The graph peaks in the early to mid seventies, in the early eighties and the early nineties. Similarly, there are two major troughs within this period between the peaks. Thus, over a period of 20 years, the newbuilding price returns five times from an extreme value to an average value. Subsequently, a conservative estimate of the half time of the process is:

$$T = \frac{20\text{ years}}{5\text{ extremes}} = 4\text{ years}$$

[8] Hull (1997), p. 233

The corresponding speed of adjustment factor is found by rearranging Equation 3.14:

$$k = \frac{\ln 2}{T} = 0.1733$$

In the calculations of option value following in the next section, a base case value of $k = 0.17$ is used.

5.5 Calculation of Option Value and Sensitivity Analysis

Having analyzed and estimated the various input parameters needed in the option formulas, it is now possible to proceed with valuation of a set of base case options, as well as performing a sensitivity analysis. For the sake of simplicity, the base case options all share that the exercise price is set equal to the current newbuilding price, the duration is set equal to one year and the current newbuilding price is set equal to, or scaled to 100.

There are four base case options:

- Option A is based on the assumption of geometric Brownian motion.
- Option B is based on the assumption of mean-reversion, with the long-term equilibrium level equal to the current newbuilding price.
- Option C is based on the assumption of mean-reversion, with the long-term equilibrium level one standard deviation above the current newbuilding price.
- Option D is based on the assumption of mean-reversion, with the long-term equilibrium level one standard deviation below the current newbuilding price.

The input parameters used for the various base case options are given below. They are chosen as round-number approximations extrapolated from the calculated numbers in Table 5.3:

Symbol	Option A	Option B	Option C	Option D
S	100	100	100	100
K	100	100	100	100
t	1	1	1	1
σ	5%	5 (=5%)	5 (≈5%)	5 (≈5%)
r_f		5.5%	5.5%	5.5%
μ	-1.0%			
λ	0	0	0	0
α		100	105	95
k		0.17	0.17	0.17

Table 5.4: Base Case Options Input Parameters

It is a trivial task to enter Equations 5.2 and 5.7 into a commercial spreadsheet application such as Microsoft Excel™ or Lotus 1-2-3™, or to write a computer program in C or Fortran that calculates the call option value. Spreadsheets are ideal for analysis of relatively complex equations such as these, because it is easy to change the value of any of the input parameters, and because the applications have built-in features for plotting graphs and performing sensitivity analysis.

Using Microsoft Excel™, the values of the base case options were calculated to be equal to:

	Option A	Option B	Option C	Option D
c	1.54	1.74	2.13	1.39

Table 5.5: Value of Base Case Options

These results show that the right to decide a year later whether to build a new ship with a present price of $100 million has a value on the order of $1 million to $2 million today. This fact should justify the importance of options as an issue in newbuilding negotiations between shipowners and shipyards.

Subjecting the base case options to a sensitivity analysis produces a clear understanding of the drivers of option value. In order to find the sensitivities, one input parameter at a time is changed by 1 percent in each direction[9]. This is repeated for all four options. The resulting bar graphs show how sensitive each option is to changes in the input parameters:

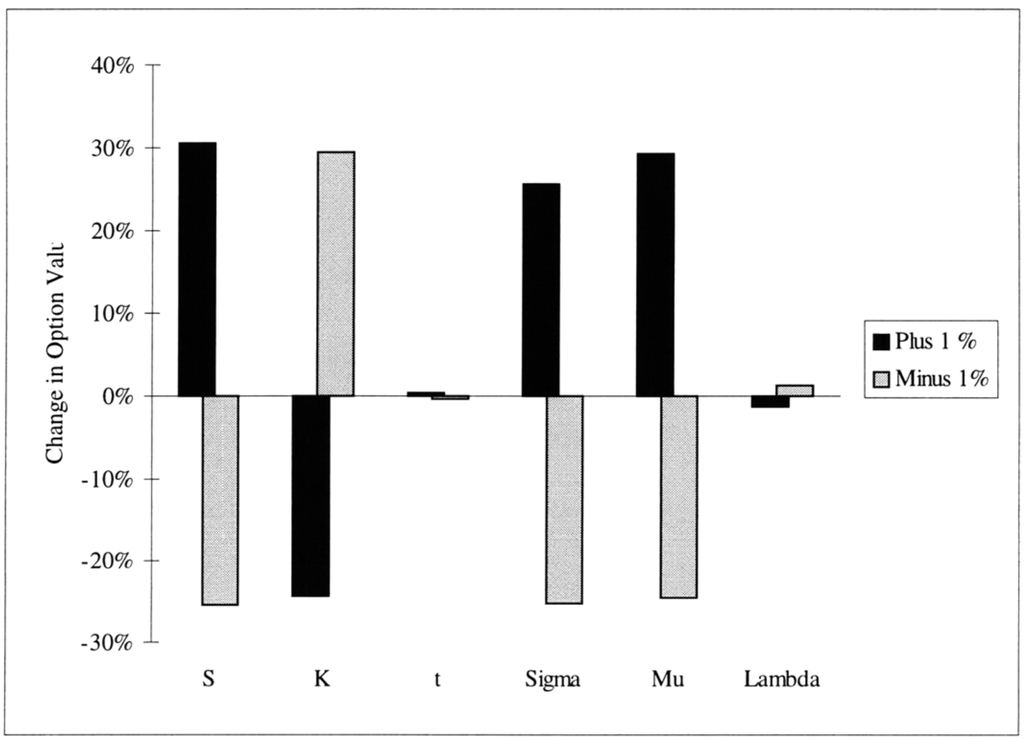

Figure 5.1: Sensitivity Analysis of Option A

Figure 5.1 shows that the adjusted Black-Scholes formula is very sensitive to changes in the current newbuilding price and the option exercise price. These parameters are determined in the option contract, and should not present any confusion when given the task of calculating the option value. More importantly, the formula is also very sensitive to the expected growth rate and to the volatility of the underlying asset price. The value of these variables must be estimated from the history of previous prices and compared to the expectations for the future. It is crucial to understand the implications of the assumptions made at this stage for the resulting option value calculated with the formula.

For the three options defined for a mean-reverting price process, the sensitivities are as follows:

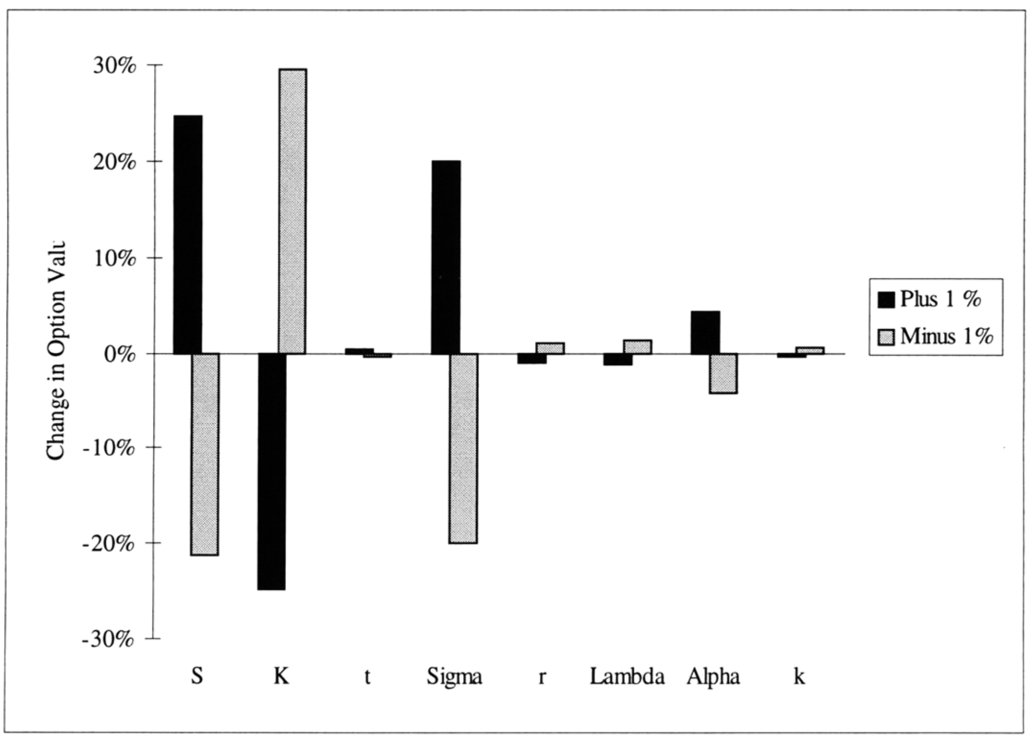

Figure 5.2: Sensitivity Analysis of Option B

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[9] The prices and the time to expiration are changed by one percent in each direction, and the percentage

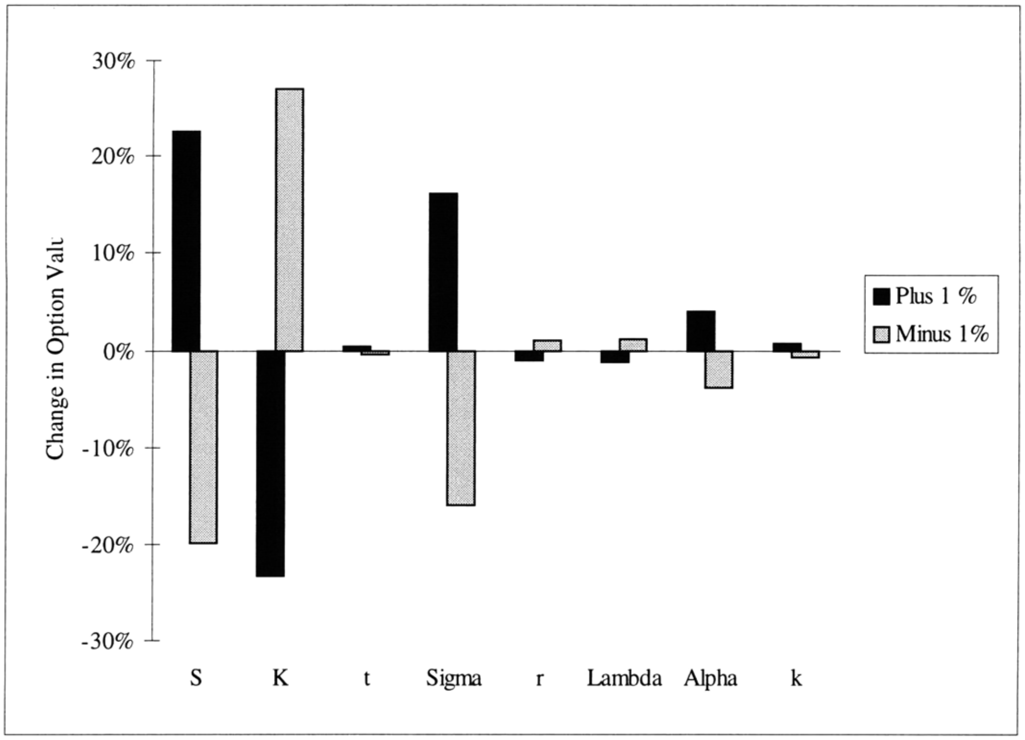

Figure 5.3: Sensitivity Analysis of Option C

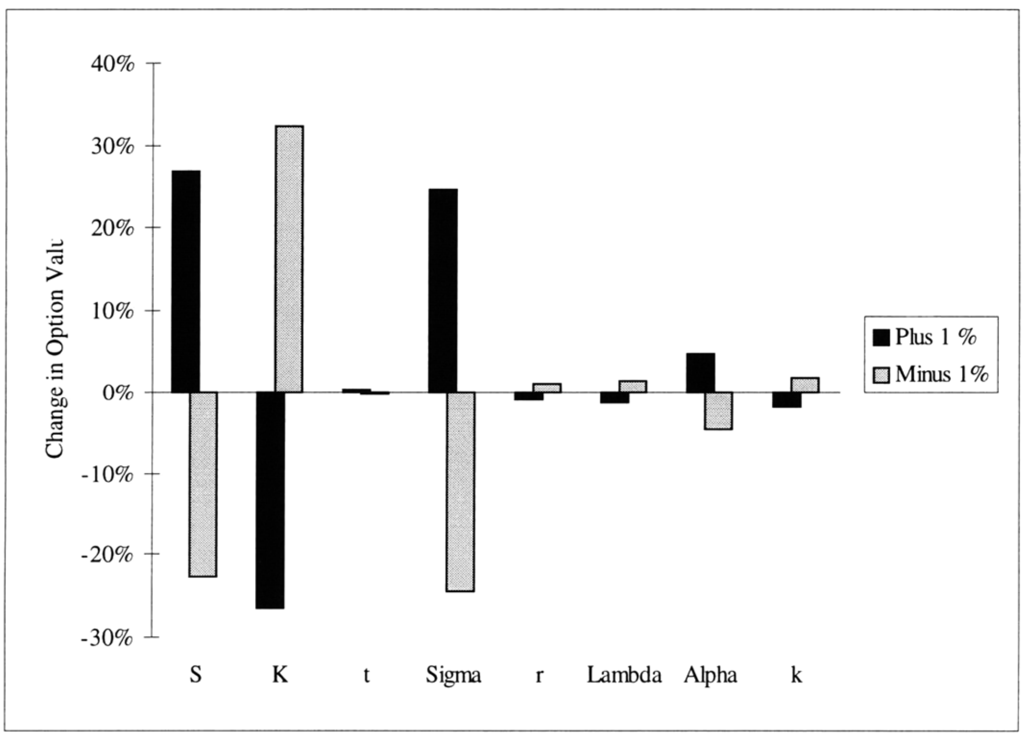

Figure 5.4: Sensitivity Analysis of Option D

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numbers are changed by one percentage point in each direction.

Figures 5.2, 5.3 and 5.4 show very similar results. The value of these options is highly sensitive to changes in the current price, the exercise price and the volatility. Changes in the long-term equilibrium level have a smaller impact on the option value because the value of the speed of adjustment-factor is low, corresponding to a weak mean-reversion tendency. It is also interesting to note that the risk-free interest rate does not have a large impact on the option value, as compared with the expected growth rate for option A. The reason for this is that in the case of A, it is the growth rate μ^* that determines the expected value of the asset price at expiration, while in the mean-reverting cases, it is the long-term mean and the speed of adjustment-factor that determine this quantity. The risk-free interest rate only enters the mean-reversion formula for discounting purposes.

An even better understanding of the mechanics of these options is facilitated by plotting the value of the various option cases as a function of each individual input parameter. Again, only one input parameter is changed at a time, while the values of all the other parameters are kept at the base case values in Table 5.4. The following graphs show the results of these analyses:

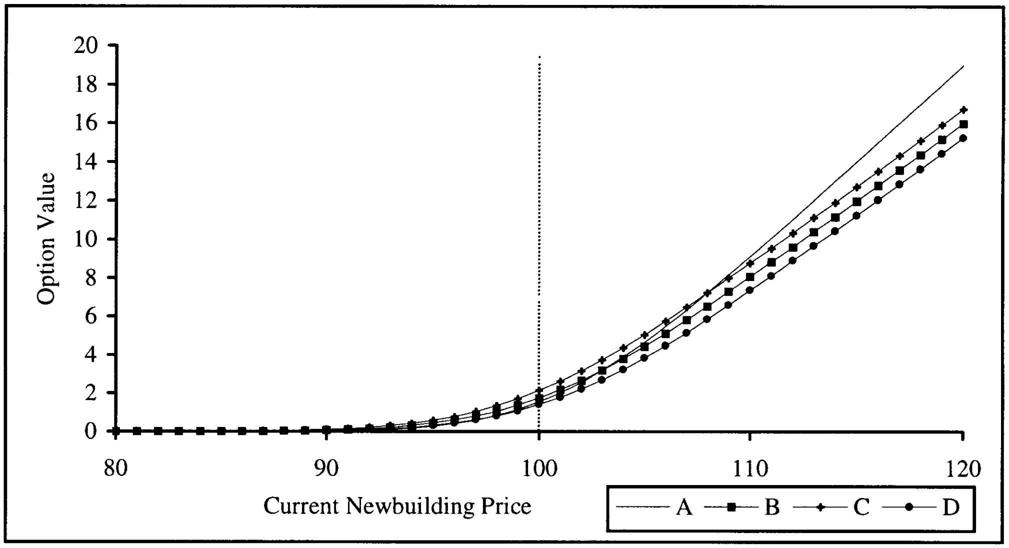

Figure 5.5: Option Value as a Function of Current Newbuilding Price

This figure shows the strong influence of the current newbuilding price on the value of the options. As the newbuilding price grows large, the option value approaches asymptotically the value of the newbuilding price, less the discounted exercise price. The reason why option A seems to grow at a faster rate than the other options is that the growth rates used in the base cases differ between the adjusted Black-Scholes formula (option A) and the mean-reverting formula (options B, C and D). This originates in the different adjustments for the market price of risk in the derivation of each formula.

It is also interesting to note that the option value rapidly approaches zero as the newbuilding price decreases below the base case value of 100. In the example options, the low volatility, and thus relatively high predictability of future prices, makes the probability of a newbuilding price above 100 fall rapidly as the current price decreases. The options are likely to expire worthless.

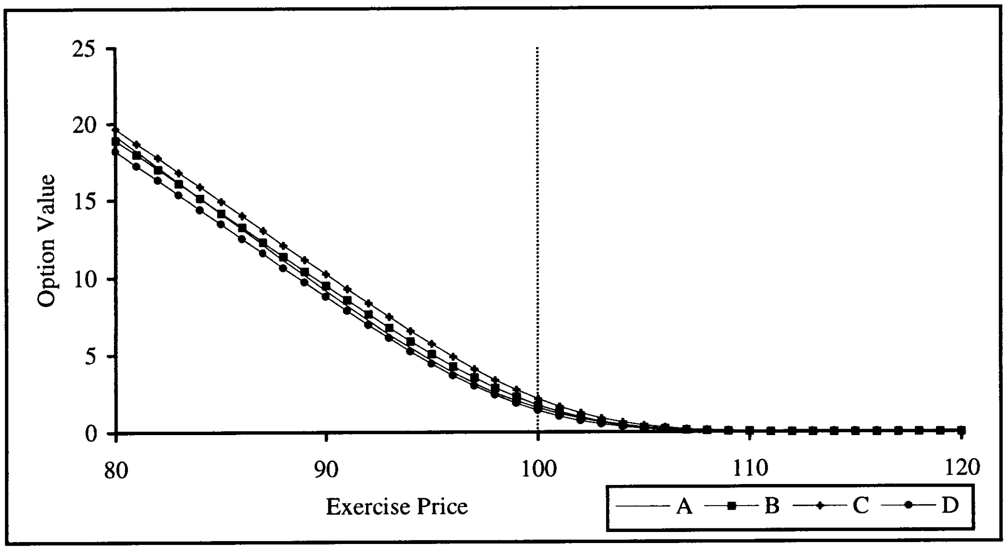

Figure 5.6: Option Value as a Function of Exercise Price

This graph looks like a mirror image of the graph of option value versus current newbuilding price. Although the picture is reversed, both the asymptotic behavior as the exercise price decreases and the rapid decrease towards zero for high values of the exercise price appear for the same reasons as explained for the previous figure.

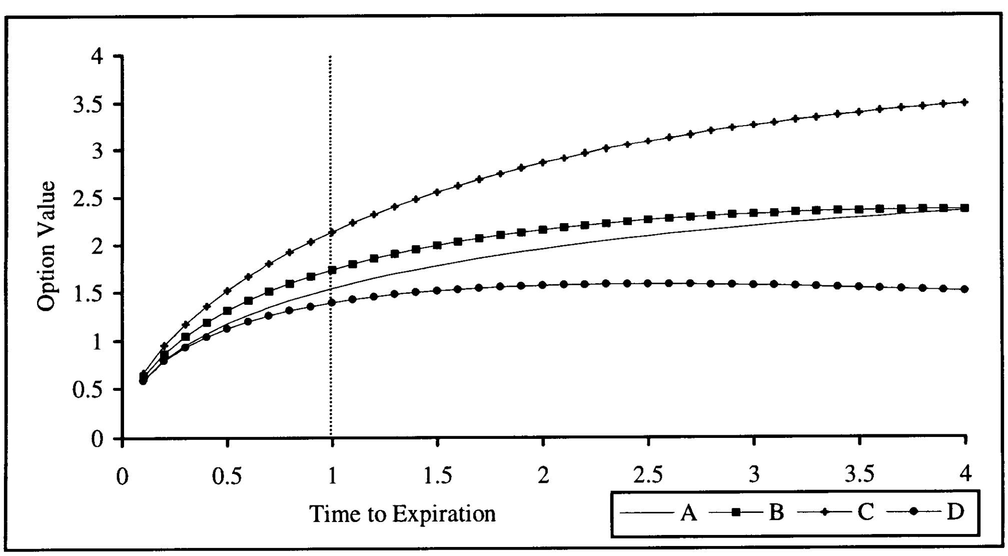

Figure 5.7: Option Value as a Function of Time to Expiration

This figure shows how option value depends on time. For short time to expiration, it is evident that the option value grows with the square root of time, which is also expected from the nature of Equations 5.2 and 5.7. For option A, this trend continues indefinitely, although the option value will be adjusted for the time value of money, as the time becomes large. For options B, C and D, the discounting element will appear as well, but more important is the influence of the mean-reverting tendency. This is evident in the fact that the value of option D decreases as time becomes large. A long time to expiration will pull the expected value at expiration closer to the long-term equilibrium level, and in the case of D, this level is below the current price. Thus, the payoff at expiration is likely to be lower.

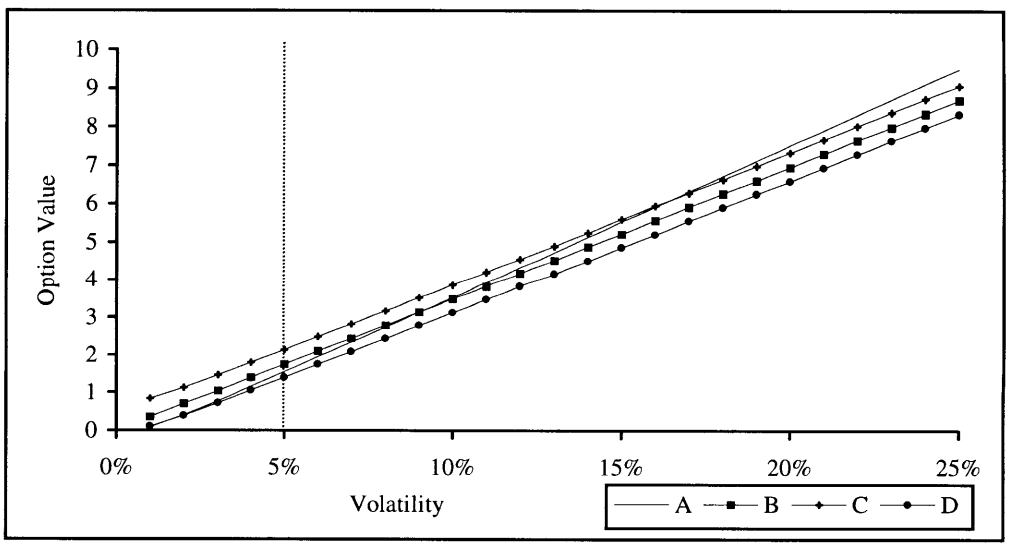

Figure 5.8: Option Value as a Function of Volatility

Figure 5.8 shows the relationship between volatility and option value. There seems to be an approximately linear dependency, and changes in volatility have a large impact on the option value. This figure shows why options on more volatile assets are more valuable than options on assets with a more predictable price.

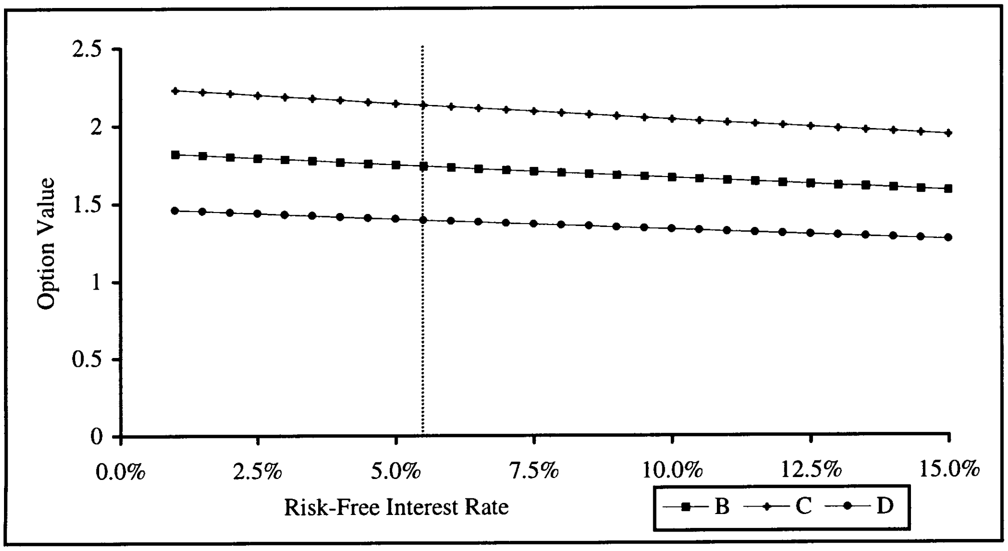

Figure 5.9: Option Value as a Function of the Risk-Free Interest Rate

The risk-free interest rate only enters the mean-reversion option formula, and not the adjusted Black-Scholes formula. Figure 5.9 shows that option value is a decreasing function of the interest rate. The present value of the probability-weighted payoff at expiration of the option decreases as the interest rate increases. The figure also shows that the option value is not very sensitive to the risk-free interest rate.

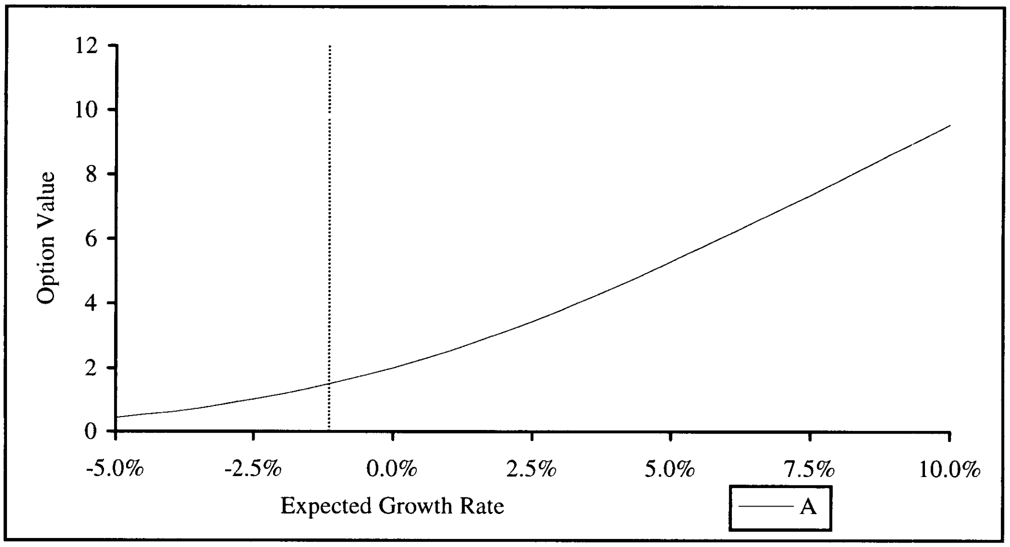

Figure 5.10: Option Value as a Function of Expected Growth Rate

The expected growth rate is only an input parameter in the risk-adjusted Black-Scholes formula. This variable, together with price volatility, is the main driver of option value in this model. The growth rate determines the expected value of the underlying variable at expiration, and a higher growth rate leads to a higher expected value. The value of a call option written on the asset will increase with the growth rate. It is important to note that the growth rate has a large impact on option value.

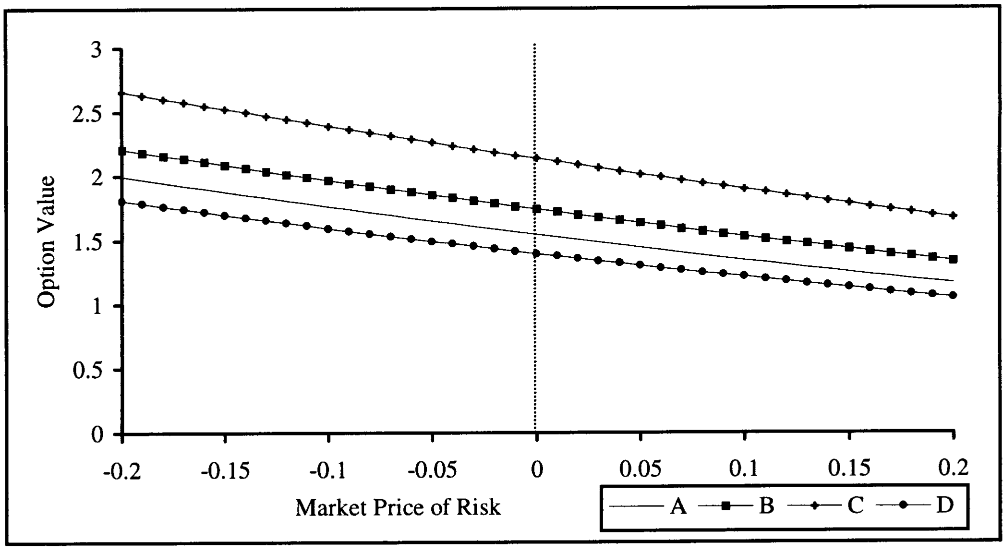

Figure 5.11: Option Value as a Function of Market Price of Risk

This figure shows that option value is decreasing with market price of risk. This is also an expected result in view of the discussion of market price of risk and risk-neutral valuation in Section 5.1. Given a positive market price of risk, investors want to be compensated for the risk associated with a position in newbuildings. Thus, the price of an option on a newbuilding needs to reflect this by offering a discount in terms of lower value.

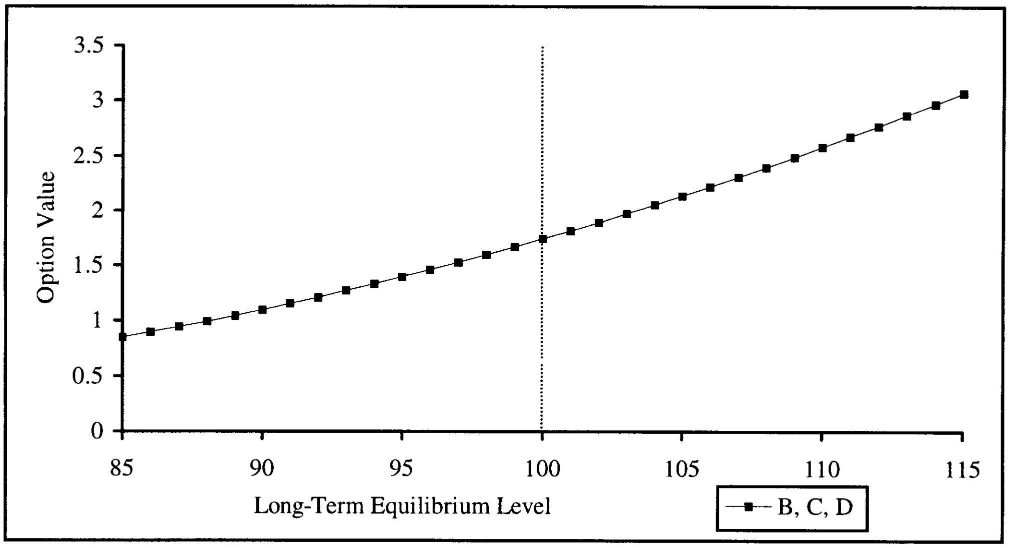

Figure 5.12: Option Value as a Function of Long-Term Equilibrium Level

The main driver of value in the mean-reversion option formula, in addition to price volatility, is the long-term equilibrium level. The only difference between options B, C and D is the value of the long-term equilibrium level used for the base case calculations. Therefore, the relationship between option value and the long-term equilibrium level is identical for the three options, as shown in Figure 5.12. Option value increases with the long-term equilibrium level, because a higher value of this variable leads to a higher expected value of the underlying price at expiration. However, the curve is relatively flat. This is a result of the small value of the speed of adjustment-constant used in the base case calculations.

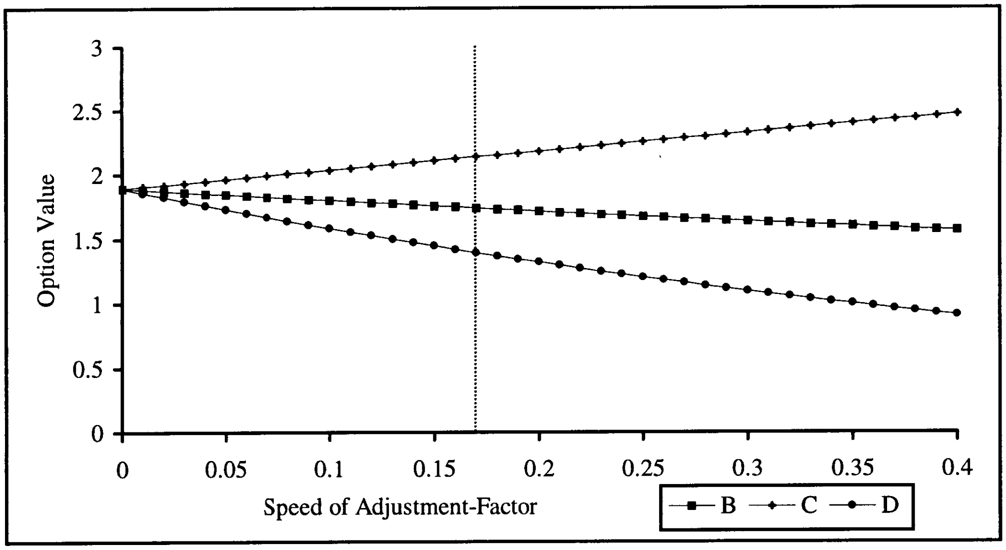

Figure 5.13: Option Value as a Function of Speed of Adjustment-Factor

This figure shows how options B, C and D depend on the speed of adjustment-factor, which is the other fundamental variable describing the mean-reversion features of the Ornstein-Uhlenbeck process. It is interesting to note that the value of option C increases with the speed of adjustment-factor, while the value of options B and D decreases. In the case of option C, the long-term equilibrium level lies above the current newbuilding price. As the speed of adjustment-factor increases, the newbuilding price is pulled more rapidly towards the long-term equilibrium level. The expected price at expiration will increase with the value of the speed of adjustment factor, and accordingly, the value of the option increases. A similar argument explains why the value of option D decreases with the speed of adjustment-factor, given that the long-term equilibrium level is below the current newbuilding price. The case of option B is somewhat more subtle. Here, the long-term equilibrium level is equal to the current price, and as determined by Equation 3.16, the expected value of the newbuilding price is equal to the current price regardless of the time to expiration or the the speed of adjustment-factor. Due to the volatility in the pricing process, the actual price at expiration can be above the expected value, which is also the exercise price, or below the expected value. If the actual price is above the exercise price, the option will give a positive payoff, and if the price is below, the option will expire worthless. This asymmetry explains why the option has a positive value at the initial date. However, as the speed of adjustment-factor increases, the probability of having an actual price far above the exercise price at expiration diminishes, and the probability of being close to the long-term equilibrium increases. Thus, a larger speed of adjustment-factor concentrates the probability distribution of the underlying asset price at expiration around the long-term mean, such that the option value on the intitial date decreases.

5.6 Summary of Option Valuation

The analysis of option value in the previous section clearly demonstrates how option value moves with changes in the input parameters, and how sensitive option value is to each individual variable. An important conclusion is that particular care must be shown when estimating the value of the variables that have the highest impact on option value. The following tables summarize the findings of the previous section:

Adjusted Black-Scholes Formula			
Parameter	Symbol	Sensitivity	Direction
Current newbuilding price	S	High	Positive
Exercise price	K	High	Negative
Time to expiration	t	Low	Positive
Volatility of newbuilding price	σ	High	Positive
Expected growth rate of S	μ	High	Positive
Market price of risk	λ	Low	Negative

Table 5.6: Summary of Sensitivity Analysis of Adjusted Black-Scholes Formula

Mean-Reversion Option Formula			
Parameter	Symbol	Sensitivity	Direction
Current newbuilding price	S	High	Positive
Exercise price	K	High	Negative
Time to expiration	t	Low	Positive
Volatility of newbuilding price	σ	High	Positive
Risk-free interest rate	r_f	Low	Negative
Market price of risk	λ	Low	Negative
Long-term equilibrium level	α	Medium	Positive
Speed of adjustment factor	k	Low	Depends

Table 5.7: Summary of Sensitivity Analysis of Mean-Reversion Option Formula

Chapter 6 Application of Ship Newbuilding Options

Shipowners buy and operate their ships in order to make a return on the invested capital. The prices of ships determine to a large extent the potential for shipowners to make a satisfactory return. If ship prices are low, even a low freight rate can bring profit to the owner. To analyze potential investments, shipowners develop discounted cash flow models in which they make educated guesses of future freight rates and of ship operating costs. The DCF model calculates the newbuilding price level at which ordering a new ship is justifiable, given the available financing. This idea is illustrated in the figure below:

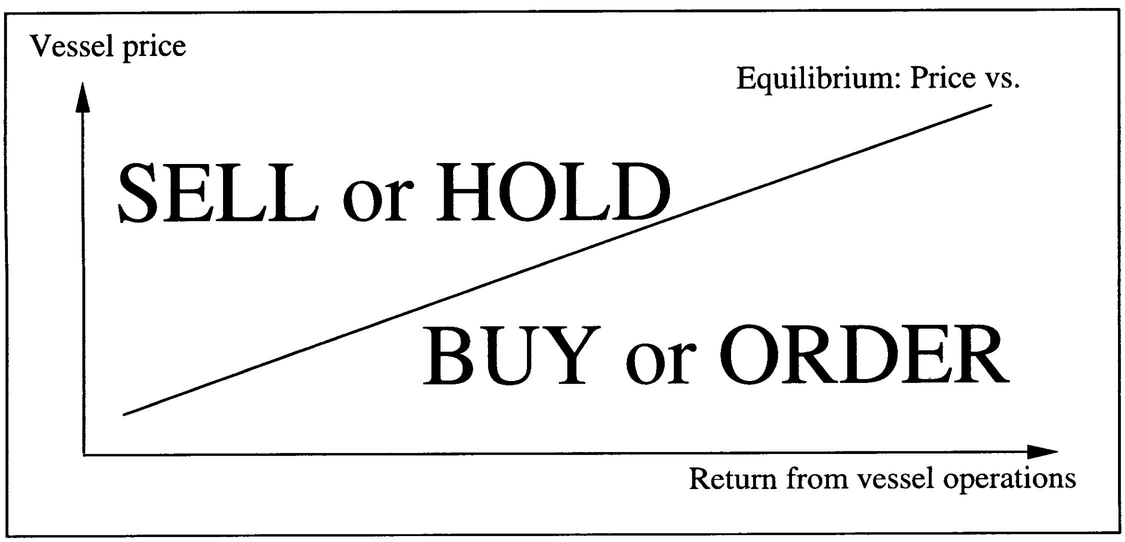

Figure 6.1: Relationship Between Return From Vessel Operations and Vessel Price.

6.1 Fundamentals of Shipbuilding Prices

Newbuilding prices of ships are not necessarily linked to the actual costs incurred by shipyards, but rather, the forces of supply and demand in the market determine the price level[1]. Whatever the costs a shipbuilder may be required to carry, the ultimate return depends mainly on the price that an owner is willing to pay for a new vessel. In the final analysis, this is inherently dependent on the buoyancy of the freight market and on freight revenues[2]. The demand side of the newbuilding market equation depends largely on current and expected future rates in the freight market for the particular vessel type under consideration. In addition, under the overall aegis of the world economic cycle, demand is influenced by structural and regional changes in world commerce and the industry relevant to the sector of the shipping industry served. The cycles in the world economy are being reflected and often amplified in the demand for seaborne trade.

Current total shipyard capacity, utilization rates and cost structure govern the supply side of the shipbuilding market. Shipbuilding cost is a function of the costs of raw materials, labor and equipment, quality of management and level of automation in the shipyard, savings in series building, extra cost for specialized and customized work, inflation, exchange rates, interest rates, government subsidies and available financing. Two of the literature sources give examples of the breakdown of shipbuilding costs, tabulated below:

Input Factor	Shipping[3]	Nomura Securities[4]
Steel	25%	17%
Engines	9%	11%
Other Material	31%	34%
Labor	25%	30%
Other Costs	10%	8%

Table 6.1: Breakdown of Shipbuilding Costs[5]

[1] Wijnolst and Wergeland (1996), p. 281
[2] Drewry (1995), p. 48
[3] Wijnolst and Wergeland (1996), p. 172

The problem that the newbuilding market has always faced is that the investment decisions - that is whether or not to order tonnage - are often based on the prevailing freight market supply and demand balance. In a situation in which the balance is tight, the viewpoint of shipowners tends to suggest that the shortage is in the supply, and this typically leads to ordering of new tonnage. However, as there may well be a lead-time of two years or more before these newbuildings reach the market, the demand side of the equation is liable to have changed. Thus, the reaction of shipowners tends to lag behind market signals, and this has historically led to a series of sharp fluctuations between hectic newbuilding activity and periods of slack demand for new ships[6]. Still, it is important to point out that the most critical component in the tonnage supply and demand equation, and for determining both freight rates and vessel prices, is scrapping of old ships[7].

It has been established that the number of active shipyards is directly proportional to the volumes produced, and that almost any yard with inactive capacity can start producing ships rapidly if demand is high. Although supply is inelastic in the short term, given a scope of a few years, shipyard capacity is very flexible. From this, it can be inferred that the underlying freight markets influence also the supply side of the newbuilding market. Furthermore, technological diffusion is fast in shipbuilding, making it difficult to protect new innovation or designs from strong competition. In addition, prices of newbuildings of

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[4] Nomura Securities (1997), p. 19
[5] These breakdowns of shipyard cost structure are based on Japanese shipyards. The cost structure of shipyards in other countries is the same within a margin of only a few percentage points.
[6] Drewry (1995), p. 38
[7] Drewry (1995), p. 124

different vessel types are highly correlated, on average by a factor of 0.70 or higher[8], and shipyard prices adjust quickly to either regional or ship type differences. These factors all lead to the conclusion that there exists one, global shipbuilding market, and that this market shares many characteristics with traditional commodity markets[9].

Shipping freight markets have been analyzed carefully, and most studies[10] have established that the rate process prevailing in these markets is best described by mean-reversion, which is also typical for many other commodity markets, such as the copper and oil markets[11]. The ship newbuilding market also displays features commonly associated with commodity markets, but in addition it is influenced by the actual production costs of the shipyards. Therefore, it is not possible to extend directly the conclusions derived for seaborne freight rates to ship prices. The regressions of actual newbuilding price data in Chapter 4 also confirm that the mean-reversion model does not describe accurately the price process of newbuildings.

There is a strong element of cyclicality in the newbuilding market. Part of this originates in the commodity nature of the market, and the continuous, lagged adjustment process of shipbuilding supply to demand. The fact that steel represents a significant percentage of total shipbuilding costs and that it is traded as a typical commodity also adds to the commodity nature of the shipbuilding market. Furthermore, the cycles of the freight

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[8] Wijnolst and Wergeland (1996), p. 184
[9] Wijnolst and Wergeland (1996), pp. 185 - 186
[10] This is confirmed in the research project undertaken by the Norwegian Centre for Research in Economics and Business Administration. See Bjerksund and Ekern (1992 (a)), Andersen (1992) and Stray (1991) for details.

markets also have a strong influence on shipbuilding demand, and add additional cyclicality to the price process. Isolated, these features would predict that the newbuilding market is well described by a mean-reversion model, as analysis of other cyclical commodity markets has shown.

However, non-steel costs represent roughly 80% of total shipbuilding costs, and the price of these input factors does not fit into a mean-reversion model. Rather, these costs can be assumed to grow at a fixed rate. A model based on geometric Brownian motion provides a good description of these prices. In addition, the capital employed in shipbuilding requires an expected return each year, similar to all financial assets. As shipbuilding is a capital-intensive industry, this factor must be included.

This discussion justifies why ship newbuildings must be treated as a combination of mean-reverting and continuously growing assets, and why the stochastic process of newbuilding prices can be modeled neither as perfect geometric Brownian motion nor as a perfect Ornstein-Uhlenbeck process. The value of options on newbuildings must therefore be calculated using both formulas developed and analyzed in Chapter 5, and the results should be compared and adjusted given the assumptions for the particular market situation in which the option applies.

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[11] Dixit and Pindyck (1994), p. 74

6.2 Understanding of Options in the Industry

Extensive interviews and discussions with representatives of shipowners, shipyards and shipbrokers in various locations around the world revealed that although most industry players have significant experience with use of options in shipbuilding contracts, there is inadequate understanding of the inherent value and of the mechanics of options. The level of sophistication in the industry has never been regarded as particularly high, and the notion of options is perceived by many as both complicated and only of theoretical importance. Limited use of standardized traded instruments for freight services and vessels means that options are encountered only on an ad-hoc basis, and the absence of derivatives certainly does not enhance the understanding of the principles of option instruments.

Two major misconceptions regarding the asymmetric nature of options were encountered in the interviews. Although most industry players will agree that what was said is wrong, the implications are so important that it is worth while reiterating and correcting the wrongfulness of these statements.

One shipyard representative claimed that it is the shipyard, and not the shipowner that benefits from extending a newbuilding option to an owner. The rationale behind this statement is that when an option is declared, the owner and the yard will renegotiate all the terms of the contract. In this situation, the shipyard makes money off the altered specifications required by the owner. This viewpoint misses a major part of the definition of an option introduced in Chapter 2. The holder of an option has "a right, but not an obligation to take some action". However, the writer of the option, in this situation the shipyard, does not have a right to choose what action to undertake. There is an obligation imposed on the writer to deliver the promise of the option if the holder chooses to exercise. Relating this asymmetry of rights and obligations back to the situation described above, the shipyard is forced to live by the terms of the option, and can not choose to renegotiate upon exercise unless it is specifically agreed.

A second, more common misunderstanding is related to the notion of current option value. Many people find it hard to accept that an option has a certain value, dependent on the assumptions for the future development of the price of the underlying asset, and regardless of whether or not the option actually expires in the money and produces a positive payoff at the expiration date. This is partly explained by the fact that given the typical terms of a newbuilding option, there is a significant probability that the option will expire worthless. On the other hand, there is also a non-zero probability that the option will expire in the money, leading to a positive payoff. Conceptually, it is difficult to understand that option value is driven by uncertainty, and that it is necessary to apply probabilistic, and not deterministic, evaluation methods to calculate option value. Again, it should be explained that the commonly known option valuation formulas essentially are based on a probability-weighted average of the present value of future payoff. This payoff is either positive or equal to zero given the asymmetric structure of options.

6.3 Shipyards' View of Options

Although shipyards admit to using options as a marketing tool to attract customers and win newbuilding contracts, and recognize that options can be very valuable to shipowners, they see several benefits in terms of operational synergies. Options are mainly regarded as a tool for filling shipyard capacity, and the value of an option is perceived to be equivalent to the value of a position in the line for shipyard berth space. A shipyard will not give an option if it is possible to fill the same slot with a firm contract on a new vessel. The duration of an option is always matched such that if it expires undeclared, there is sufficient time to find alternative customers for that particular slot of berth space and to start work on time. Some shipyards will create variations of the typical newbuilding option to maximize the benefit of the option as a scheduling tool. For instance, after a certain amount of time, the holder of an option will not longer have an exclusive option, but rather a limited first right to enter a contract for the slot. If the shipyard is able to find other customers who want to enter into a newbuilding contract, the original owner of the option is given a short period of time to declare the option, and if not exercised immediately, the option is lost. Another variation is to agree that the shipowner compensates the shipyard if the option is not declared on the expiration date.

Shipyards also try to use options to increase the number of ships in a particular series of vessels. In addition to filling capacity, the benefits from this strategy is that large series reduce the allocation of overhead costs per vessel, and allow the shipyard to exploit the so-called "learning-curve" effects for the latter ships in the series. The cost per vessel of the last ship in a large series can be as much as 25% lower than the first ship. Thus, value derived by the shipyard from a large series of vessels can significantly exceed the value of the options given to the shipowner.

Shipyards also recognize that they are exposed to potentially large downside by being on the short side of an option contract. They try to minimize this risk by passing on some of the risk to the suppliers of raw materials and equipment. The cost of labor and to some degree the cost of equipment are viewed as more predictable than the cost of steel. Shipyards commonly enter into options for the required quantities of steel, engines and other equipment to protect against the risk associated with the vessel production costs. As much as 60 to 70% of the total shipyard risk can be passed on to suppliers. This effectively creates a hedge against fluctuations in the price of input factors, which is correlated with the prevailing newbuilding prices. In addition, it guarantees the shipyard that the required steel and equipment is available on time when needed.

6.4 Shipowners' View of Options

Shipowners, in a similar way as shipyards, recognize that options represent strategic and operational value beyond the strictly financial value. An option guarantees the owner a slot position in the shipyard and allows the owner to obtain additional tonnage capacity at an earlier date. In an overall market context, extensive usage of options can reduce the lag time between developments in the freight market and the newbuilding market, and reduce the cyclicality and extreme deviations from the market equilibrium. For the individual owner, holding an option is strategically important as market conditions and internal corporate conditions can change during the lifetime of the option. As a result, while constructing a vessel at the time the option is received might not be justifiable, the internal and external conditions can change such that the threshold for investment is exceeded by the time the option reaches its expiration date. The owner can then enter into a contract for the vessel without having incurred any risk of price changes, and will be able to receive the new ship at an earlier date than otherwise possible.

Still, shipowners are more concerned with obtaining options that are favorable from a financial and pricing point of view, rather than from a strategic and operational point of view. Since there is no monetary exchange when entering into an option agreement, shipowners aggressively try to include as favorable terms as possible, without compromising the price of the contract on the original vessels. As determined in the previous chapter, even minor changes in the strike price, and to a lesser degree changes in the duration of the option, have a large impact on the value of the option. In these negotiations, shipowners clearly have an advantage, as they do not put anything at stake. The yards on the other hand end up with all the downside of the option at the same time as they risk losing the entire shipbuilding contract if the demands are not fully met.

Owners try to use the fact that shipyards would like to secure newbuilding contracts for as many vessels as possible to their advantage as well. For instance, if a shipowner is interested in constructing two new vessels, he might indicate to a yard that he is interested in two vessels plus an option on two additional vessels. The yard will then calculate a unit ship price based on a series of four vessels, and the owner believes that this unit price will be somewhat lower than for a series of only two vessels. If this strategy works, the shipowner will benefit not only from having the option, but will also get a better deal on the vessels ordered firm.

Shipowners gain more from newbuilding options than shipyards do. This is evident in the fact that owners always ask for options, and that yards are typically hesitant in offering options. There is also significant evidence that one, if not both parties to a newbuilding contract realize how valuable the options are. In many cases, adding an option element to a contract, or changing the terms of the option, has led to a successful outcome of difficult negotiations.

6.5 Intermediaries' View of Options

Shipbrokers and market consultants follow developments in the market and give advice to both shipowners and shipyards. They have observed that 90% of all newbuilding contracts contain options of some sort. The typical duration is on the order of 6 months. When the newbuilding market is tight and the shipyards have employment for a long period into the future, options are typically shorter than when the market is slack. Option duration varies from as little as 2 months up to 1 year, and in rare cases the time to expiration is even longer. Options on specialized vessels typically last longer than options on standardized vessels used in commodity shipping.

The intermediaries in the newbuilding market have also observed that the current newbuilding price, expectations for future freight rates and available financing are the main factors influencing the exercise decision. Contrary to standardized options in financial markets, newbuilding options are rarely declared only in order to profit from any possible arbitrage available at the time of exercise. Shipyards do not want and seldom allow resale of newbuildings before delivery, and the market for newly delivered ships is illiquid. A sophisticated owner has unique specifications for a ship's design, performance, equipment, shipyard to use, and quality of work. Shipyards are commonly involved in arranging financing of newbuilding series, and these complex arrangements are difficult to transfer freely from owner to owner. In addition, new ships fall rapidly in value during the first few years of operation. Thus, if additional vessels are to be declared under an option, an operational commitment of the owner is required. For the same reasons, it is typically not possible to sell or transfer a newbuilding option before it expires and needs to be declared.

6.6 Foreign Exchange and Competition Issues

The U.S. dollar is the universal currency in the shipping industry. Accordingly, most shipbuilding contracts are denominated in dollars. At the same time, only an insignificant fraction of the world's shipyard capacity is located in the United States, while East Asia has emerged as the global leader in shipbuilding since World War II. The combined shipbuilding output of Japan, South Korea, China and Taiwan today represents 74% of the total world ship production.

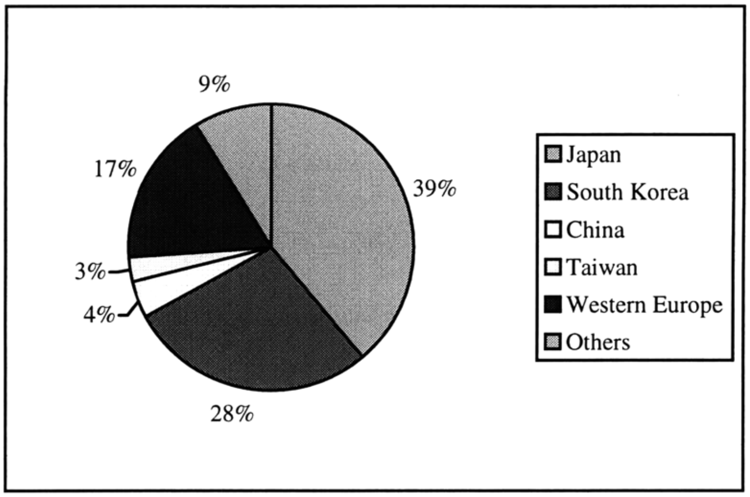

Figure 6.2: World Shipbuilding Activity by Geography as of 1996[12]

Non-U.S. shipyards receive their revenues in dollars, but carry all of the costs of labor and most of the costs of raw materials and equipment in the local currency. Because of extreme fluctuations in the exchange rate of the dollar against the currencies of major shipbuilding nations in the early 1990s, leading to large amounts of lost revenues, a significant number of shipyards has tried to adopt a policy of denominating export prices in domestic currencies, thereby securing revenues in the local currencies. Furthermore, fluctuations in foreign exchange rates alter the competitive position among shipbuilding nations. In the short run, shipyard competitiveness depends solely on exchange rates, while in the long run currency fluctuations have forced innovation and productivity enhancements to occur in the industry. For instance, as the Japanese yen appreciated in value more than two times during the 1980s and into the early 90s, Japanese yards were able to compensate for the adverse consequences by reducing costs and increasing productivity through reductions in workforce level, increased automation, improved logistics and adoption of more intensive series building techniques. The intiative which had the most direct effect on reducing the exposure to currency fluctuations was to shift procurement of steel and ship equipment from domestic suppliers to foreign suppliers, which not only are neutral to currency effects, but also offer the same or similar products at a lower price. During this period, it also became more common to employ sophisticated currency risk management techniques[13].

Currency fluctuations and their implications on the shipbuilding industry have naturally influenced the interaction between yards as sellers and shipowners as purchasers of ships, and the environment in which newbuilding options exist, has changed. The increased competition has led to globalization in the shipbuilding market. It has become more common to give global tender offers for newbuildings, in which the following factors are typically considered: basic cost, quality of work, financing, including newbuilding options, and individual preferences for hull, machinery and equipment specifications. Marketing has also been observed to become more aggressive. Given these trends, creative and tailor-made option elements now appear more frequently in newbuilding contracts.

As long as the price is denominated in dollars, the currency risk associated with newbuilding options is carried by the shipyard. However, the direct impact of this risk has been reduced by the increased use of currency management techniques, and by reducing the fraction of the total costs denominated in local currencies. Still, uncertain future

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[12] Nomura Securities (1997), p. 10. Source: Lloyd's Register of Shipping, London

exchange rates mean that the value of an option to the two contracting parties might be different. The shipowner is neutral to currency fluctuations in a dollar world, while a shipyard on the other side of the option will assign a different value if the exchange rates are expected to change. In this case, options are no longer a zero-sum game, and it is possible to understand why shipowners believe that they receive valuable options, while shipyards do not assess the same value of the same option.

Hull (1997) explains how to calculate the value of **quantos**, which are derivative instruments for which there are two different currencies involved[14]. From the standpoint of a non-U.S. shipyard, an option in a dollar-denominated newbuilding contract is a quanto. The effective payoff at exercise is determined by the newbuilding price in dollars, while the exercise price is the local currency equivalent of a pre-determined dollar amount. It is possible to develop a model for newbuilding options that includes currency issues. However, since other factors in option valuation are more important and at the same time more uncertain, deriving such a formula is not done here.

6.7 Practical Guidelines for Option Valuation

Up to this point, the practical aspects of newbuilding option analysis have not been discussed and analyzed. Shipping and shipbuilding professionals need a set of guidelines in order to understand and value option elements of newbuilding contracts. This section gives a set of general guidelines.

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[13] Drewry (1995), p. 49
[14] Hull (1997), pp. 298 - 301

As established in Chapter 4, option formulas based on both a geometric Brownian price process and on a mean-reversion process do not provide accurate valuations of newbuilding options, as these stochastic processes do not conform well with actual observations of the newbuilding price process. Still, as these represent opposite sides of the spectrum in terms of correlation and path-dependency, it is meaningful to apply the formulas that were derived in Chapter 5, as the true process for newbuilding prices is somewhere between these two models. Thus, the valuation of an option based on the true newbuilding price process is likely to produce a number that is located between the values calculated by Equations 5.2 and 5.7. This is supported by the fact that the two formulas converge when the growth rates and the speed of adjustment-factor simultaneously approach zero.

The task that is most affected by judgement and has the largest implications on the calculation of option value is estimation of the input parameters. Current newbuilding price, exercise price and time to expiration are all determined in the newbuilding contract as a result of negotiations, and they do not need not be estimated or judged by the analyst. However, for volatility and market price of risk, for expected growth rate in the case of the adjusted Black-Scholes formula, and for the risk-free interest rate, long-term equilibrium level and speed of adjustment factor in the case of the mean-reversion formula, the situation is different. The analyst should obtain a series of past price data that is at least as long as the duration of the option under consideration, and estimate the required input parameters from these data. The resulting numbers should be used as a base case. In addition, for each parameter, both a high case value and a low case value should be defined. In doing this, the analyst should use an educated opinion to predict the future development of the newbuilding prices. For instance, increasing the expected growth rate of newbuilding prices can be justified if the current market is perceived as slack, and if the prices are expected to increase substantially. When adjusting the long-term equilibrium level, it should be changed up and down by at least one unit of standard deviation in the high and low cases respectively. Changing the speed of adjustment-factor corresponds to a change in the cyclical trend for newbuilding prices. It is not necessary to change the value of the market price of risk. As explained in Section 5.1, it is impossible to calculate meaningfully a value of this parameter based on available data for newbuildings. Rather, changing all the other parameters will lead to a range of option values that includes the values resulting from any changes in the market price of risk.

Having defined input parameters for three sets of cases, all the various combinations of input values should be entered into the two option formulas, giving a set of option values for each respective model. The actual calculations using the option formulas are easily done in standard commercial spreadsheet applications. After calculating the value of all the scenarios, the analyst is again required to use judgement. From the calculations, the analyst should calculate an average high case, base case and low case value for each formula, respectively, or pick the median value for each scenario. Then, the probability of the each case occurring should be assessed, and subsequently the analyst should calculate the probability-weighted average for the adjusted Black-Scholes formula and for the mean-reversion formula. Finally, the results of the two models should be compared, and most likely, the values will not differ significantly.

The result of this approach, however, does not represent the exact option value, but rather the upper bound to the value. The reason for this is that the option is not transferable or traded, and that the market for the underlying newbuildings is highly illiquid. The option is only valuable if the shipowner sees strategic value in owning and operating the underlying vessel. Therefore, it will be necessary to include a discount to get from the analytical option value to the true value it represents to an owner. Assessing the magnitude of this discount again requires judgement. If the newbuildings covered by the option are certain to be constructed, the discount can be negligible. However, if the shipowner does not believe that the additional option vessels will ever be needed, and if the possibilities to resell the newly constructed ships are slim, the option value falls to zero. 50% is deemed to be a conservative, average estimate of the illiquidity discount.

A summary of newbuilding option analysis is given below:

- Determine the terms of the option: S, K, t
- Estimate from past price data the base case values of the other input parameters required in the two option formulas: σ, μ ; σ, α, k
- Let λ be equal to zero, and find a quote of r_f
- Define the low and high case values of: σ, μ ; σ, α, k
- Calculate the value of the option using all the low case, base case and high case values with both the adjusted Black-Scholes formula and the mean-reversion formula
- Estimate the average option value for each case: low, base, high
- Define the probability of each case occurring, and find the probability-weighted average of the value across the three cases

- Compare the results derived from the adjusted Black-Scholes formula and from the mean-reversion formula
- Include the illiquidity discount to assess the true value that the option represents to its holder

Chapter 7 Concluding Remarks

A major factor that contributed to the idea of doing this thesis was the presumption that few players in the shipping and shipbuilding industries are familiar with option theory and recognize the importance of options both as a financial tool and as a strategic tool. This was confirmed in many of the conducted interviews, although significant interest in the subject matter was also displayed. As option theory only recently entered basic finance courses in business education, few professionals are familiar with options. Without a formal introduction, it is difficult to capture a general understanding of concepts such as volatility-driven value, risk-neutral valuation and probability-weighted asymmetric payoff. Therefore, this study includes a general and basic introduction to option theory, and hopefully it will contribute to broaden the knowledge of options within the shipping and shipbuilding communities.

As the focus of this project is almost exclusively on ship newbuilding options, it is crucial to understand and analyze the newbuilding price process. Actual data are tested to establish whether newbuilding prices follow a model based on constant exponential growth or follow a mean-reversion model. Although the conclusions might be influenced by the limited availability of data, it is evident that neither the geometric Brownian motion nor the Ornstein-Uhlenbeck model fit the data well. However, as the intuition behind each of these models is simple, and as it is possible to explain that factors characteristic of each model influence newbuilding prices, option valuation formulas developed for each model are used to calculate the value of examples of newbuilding options.

The estimates of formula input parameters based on analysis of actual price data also show that the volatility of newbuilding prices is relatively low, and lower than many industry players perceive it to be. Accordingly, projections of future newbuilding prices can be done with a higher degree of confidence than what is possible for prices of many other commodities and assets. The low volatility directly reduces the value of newbuilding options, and in addition increases the sensitivity of option value to changes in current newbuilding price, exercise price, expected growth rate and long-term equilibrium level. Similarly, newbuilding options are less sensitive to changes in duration.

The fact that options in shipbuilding contracts are not traded and not transferable, and that the market for recently delivered ships is illiquid, further reduces the value of these options. The values calculated with the two formulas developed here, or with any other models, should be discounted significantly to include this illiquidity. Thus, there are situations in which newbuilding options can prove to be very valuable, and in such cases shipyards transfer value to their customers without reasonable compensation. However, contrary to popular belief in the industry, in most cases the value of a newbuilding option is limited and should be of secondary importance in negotiations between shipowners and shipyards.

7.1 Recommendations for Future Research

The models for newbuilding prices underlying the option formulas in this thesis can be refined further to reflect the true price process in the newbuilding markets. More complex models of auto-correlation can describe the observed cyclical trends, such that the mathematical models will reflect better the observed data for newbuilding prices. The challenge associated with doing this is that not only are the models likely to be rather complex expressions of stochastic calculus, but also that it will be difficult to apply Ito's lemma and derive an expression for a contingent claim dependent on the variable described by the new mathematical model. It will most probably be impossible to express the value of a newbuilding option in a closed form solution, and instead this needs to be calculated by numerically evaluating stochastic integrals.

Another possible continuation of this project is to analyze how the shipping industry can apply option frameworks for strategic analysis and decision-making. Decisions regarding newbuilding, sale and purchase, scrapping and chartering can all be analyzed using option-based decision theory. Strategic issues such as entering or leaving a particular freight service, corporate acquisitions and divestitures as well as financial decisions are also suitable for option analysis. There exists literature describing specific contexts in shipping where options are present, and there are studies describing how option analysis is used strategically in other industries. However, an all-encompassing study, combining both applications of options, has not been done specifically for shipping companies.

Furthermore, it would be interesting to undertake a study to understand how to increase the value of newbuilding options, if at all possible. This requires increased standardization of not only option contracts and shipbuilding contracts, but also of the actual vessels being built. A major advance that could result from this would be to start trading of newbuilding futures and options associated with these futures. Trading of such instruments would lead to a more transparent and efficient newbuilding market, and all participating parties would benefit.

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Appendix A.1

Testing the newbuilding price data for geometric Brownian motion yielded these results[1]:

	Clarkson			
Vessel Category	*a*	*t*-ratio	*b*	*t*-ratio
Handysize 25 - 30	0.00173	0.87206	0.14601	2.39619
Handysize 32 - 35	0.00188	0.97103	0.14670	2.41774
Handymax 40 - 42	0.00361	1.82634	0.19124	2.31094
Panamax 70	0.00151	0.76767	0.18818	3.11497
Capesize 120	0.00033	0.16120	0.12327	1.85205
Capesize 150 - 165	0.00237	0.89893	0.23438	2.83400
Product 37 - 45	0.00150	0.71266	0.22564	3.74907
Panamax Tanker 68	-0.00207	-0.79757	0.53251	2.52629
Aframax 95	0.00221	1.06616	0.10505	1.70764
Suezmax 140	-0.00010	-0.04617	0.13474	1.93056
VLCC 280 SH	0.00411	1.72424	0.04579	0.65263
VLCC 280 DH	-0.00261	-1.21882	0.17232	1.48249
Average	0.00121	0.57814	0.18715	2.24788

	Platou			
Vessel Category	*a*	*t*-ratio	*b*	*t*-ratio
Handysize 25 - 30	-0.00429	-0.68120	0.18971	0.98307
Handymax 40 - 42	0.00623	1.13238	0.31875	3.46659
Panamax 70	0.00455	0.85144	0.37341	4.12354
Capesize 150 - 165	0.00307	0.74315	0.55991	7.00819
Product 37 - 45	0.00266	0.56767	0.58825	7.17112
Aframax 85 - 105 SH	0.00272	0.71025	0.66861	9.33422
Aframax 95 - 105 DH	0.00685	1.17440	0.41501	3.15092
Suezmax 150 SH	0.00060	0.18323	0.68245	9.86527
Suezmax 150 DH	0.00506	1.00110	0.53766	4.41787
VLCC 280 SH	0.00069	0.22612	0.71016	10.37222
VLCC 280 DH	-0.00690	-1.43624	0.19734	1.37163
Average	0.00193	0.40657	0.47648	5.56951

[1] The numbers following each vessel type indicate the deadweight tonnage ('000) of the vessels in the category. The abbreviations SH and DH refer to single hull and double hull, respectively.

	Marsoft			
Vessel Category	*a*	*t*-ratio	*b*	*t*-ratio
Handysize 25 - 30	0.00277	0.42419	0.39063	3.60523
Handymax 40 - 42	0.00075	0.18230	0.60275	6.45844
Panamax 70	0.00099	0.19604	0.45418	4.19813
Capesize 150 - 165	0.00001	0.00143	0.69383	8.06535
Product 37 - 45	0.00073	0.16590	0.62158	6.58314
Aframax 95	0.00083	0.18707	0.57265	6.00614
Suezmax 140	0.00173	0.44299	0.61894	6.47889
VLCC 280	0.00140	0.34276	0.64679	6.99474
Average	0.00115	0.24283	0.57517	6.04876

Appendix A.2

Performing a regression analysis to determine the mean-reversion parameters yielded these results:

	Clarkson			
Vessel Category	αk	*t*-ratio	-*k*	*t*-ratio
Handysize 25 - 30	0.16515	1.48707	-0.00893	-1.31062
Handysize 32 - 35	0.19149	1.49434	-0.00902	-1.30053
Handymax 40 - 42	0.86509	3.97184	-0.03532	-3.69221
Panamax 70	0.24156	1.35284	-0.00906	-1.19802
Capesize 120	0.39438	1.17965	-0.01130	-1.17028
Capesize 150 - 165	1.41818	2.30843	-0.03054	-2.18648
Product 37 - 45	0.13618	0.97876	-0.00385	-0.68650
Panamax Tanker 68	-2.29741	-0.38464	0.05747	0.36377
Aframax 95	0.28067	1.41514	-0.00642	-1.12140
Suezmax 140	0.22261	0.66960	-0.00487	-0.71016
VLCC 280 SH	0.56179	1.24404	-0.00533	-0.74136
VLCC 280 DH	3.55133	1.70397	-0.04386	-1.86955
Average	0.47759	1.45175	-0.00925	-1.30194

	Platou			
Vessel Category	αk	*t*-ratio	-*k*	*t*-ratio
Handysize 25 - 30	2.50541	1.02339	-0.12666	-1.06209
Handymax 40 - 42	0.49877	1.77707	-0.02164	-1.39829
Panamax 70	0.75920	1.84946	-0.02964	-1.61003
Capesize 150 - 165	0.81369	1.54180	-0.01901	-1.21158
Product 37 - 45	0.68686	1.69258	-0.02166	-1.30607
Aframax 85 - 105 SH	0.75286	1.74840	-0.02032	-1.38480
Aframax 95 - 105 DH	2.36635	2.42285	-0.05036	-2.11442
Suezmax 150 SH	1.14813	1.69406	-0.02460	-1.44718
Suezmax 150 DH	2.76454	2.36856	-0.04524	-2.06397
VLCC 280 SH	1.59616	1.59092	-0.02110	-1.31590
VLCC 280 DH	-0.00690	-1.43624	0.19734	1.37163
Average	1.26228	1.47935	-0.01663	-1.23115

	Marsoft			
Vessel Category	αk	t-ratio	$-k$	t-ratio
Handysize 25 - 30	0.40685	1.07248	-0.01871	-0.80818
Handymax 40 - 42	0.39384	0.90593	-0.01467	-0.71640
Panamax 70	0.35443	0.65110	-0.01292	-0.58820
Capesize 150 - 165	0.80619	0.84017	-0.01914	-0.79256
Product 37 - 45	0.34186	0.63622	-0.00933	-0.49102
Aframax 95	0.64935	0.89045	-0.01346	-0.68549
Suezmax 140	0.52739	0.70032	-0.00769	-0.48023
VLCC 280	0.90034	0.71965	-0.00823	-0.48589
Average	0.54753	0.80204	-0.01302	-0.63100

Appendix A.3

Calculating the percentage difference between the average rate and the value of the calculated long-term equilibrium level α yielded these results:

	Clarkson		
Vessel Category	Average	α	Difference
Handysize 25 - 30	15.75263	18.49483	17.41%
Handysize 32 - 35	17.88891	21.22743	18.66%
Handymax 40 - 42	22.43664	24.48959	9.15%
Panamax 70	22.92613	26.66325	16.30%
Capesize 120	33.86041	34.91159	3.10%
Capesize 150 - 165	43.17483	46.43217	7.54%
Product 37 - 45	23.62312	35.35614	49.67%
Panamax Tanker 68	37.69048	39.97500	6.06%
Aframax 95	32.87444	43.73019	33.02%
Suezmax 140	46.69417	45.68191	-2.17%
VLCC 280 SH	60.20476	105.42908	75.12%
VLCC 280 DH	88.37162	80.97616	-8.37%
Average	37.12484	43.61394	18.79%

	Platou		
Vessel Category	Average	α	Difference
Handysize 25 - 30	20.42448	19.78107	-3.15%
Handymax 40 - 42	17.17946	23.04737	34.16%
Panamax 70	21.42143	25.61406	19.57%
Capesize 150 - 165	32.31339	42.80333	32.46%
Product 37 - 45	22.97558	31.71014	38.02%
Aframax 85 - 105 SH	27.87902	37.05385	32.91%
Aframax 95 - 105 DH	39.93552	46.99033	17.67%
Suezmax 150 SH	38.06201	46.67022	22.62%
Suezmax 150 DH	51.77942	61.10383	18.01%
VLCC 280 SH	60.56069	75.64294	24.90%
VLCC 280 DH	92.70606	0.03497	-99.96%
Average	38.65792	37.31383	12.47%

	Marsoft		
Vessel Category	Average	α	Difference
Handysize 25 - 30	15.91411	21.74164	36.62%
Handymax 40 - 42	20.73217	26.84785	29.50%
Panamax 70	24.27844	27.43651	13.01%
Capesize 150 - 165	38.98088	42.11459	8.04%
Product 37 - 45	27.41222	36.63208	33.63%
Aframax 95	35.94896	48.23864	34.19%
Suezmax 140	45.27629	68.61179	51.54%
VLCC 280	70.90414	109.37716	54.26%
Average	34.93090	47.62503	32.60%

Appendix B

The one-year beta values of major publicly-traded shipbuilding companies are:

Shipbuilding Company	Location	Adjusted β[1]	Raw β
Sumitomo Heavy Industries	Japan	1.29	1.43
Mitsui Engineering and Shipbuilding	Japan	1.54	1.82
Hitachi Zosen	Japan	1.17	1.25
Sasebo Heavy Industries	Japan	1.45	1.68
Mitsubishi Heavy Industries	Japan	0.94	0.92
Kawasaki	Japan	1.26	1.39
Ishikawajima-Harima	Japan	1.37	1.55
Namura Shipbuilding	Japan	1.13	1.19
Sanoyas Hishimo Meisho	Japan	1.36	1.54
Daewoo Heavy Industries	S. Korea	1.22	1.33
Hanjin Heavy Industries	S. Korea	1.15	1.23
Samsung Heavy Industries	S. Korea	1.17	1.26
Hyundai Mipo	S. Korea	1.03	1.05
Keppel Corporation	Singapore	1.16	1.24
Jurong Shipyard	Singapore	0.65	0.48
Sembawang Corporation	Singapore	1.39	1.59
Hitachi Zosen Singapore	Singapore	0.63	0.45
Kvaerner	Norway/UK	1.24	1.36

Average	1.18	1.26

Source: Bloomberg L. P., April 7, 1998

[1] The adjusted beta values are calculated as:

$$\text{Adjusted}\,\beta = 0.67 \cdot \text{Raw}\,\beta + 0.33 \cdot 1.00$$

The concept of adjusted beta values has been proven to give better predictions than raw beta values. This is described in Brealey and Myers (1996), p. 208.