

ERASMUS UNIVERSITY ROTTERDAM
ERASMUS SCHOOL OF ECONOMICS
MSc Economics & Business
Master Specialisation Financial Economics

Short term forecasting of crude oil prices
An agent based perspective

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Finish date: January 2011

PREFACE AND ACKNOWLEDGEMENTS

The topic of my thesis is agent based models and forecasting. I decided to investigate this area for two reasons. First, because I feel that behavioral based models reflect better the reality. I was always impressed by the beauty contest view of the markets that has been expressed by Keynes and the philosophical debates with Hayek. I feel that agent based models capture those philosophical considerations and give particularly good explanations for the arguments of both sides. The second reason that I chose this topic is the forecasting investigation. I believe that it is of valuable importance to know the practical applications (and limitations) of every model.

Concerning the research procedure, I can say that this thesis was an experience. Strictly speaking, it was a unique experience. Well, the obvious question is why. I have the feeling that I have been engaged into a research area that I had very limited previous knowledge. This fact made the whole thesis more challenging. However, as a popular quotes says “no pain-no gain”. My belief is that I learned something new. Given the fact that one of the topics that I touched is forecasting, I feel that I gained insights which can be of value added for the future.

Of course, this investigation at hand would not have been completed without the help of many people who assisted me. First and foremost I am thankful to my parents. Their support through my University endeavors was more than enough. Next, I would like to thank my supervisor for her patience, understanding and support through the writing process. Additionally, I would like to say that I am heavily indebted to Saskia ter Ellen. Her help was significant and the insights that she provided me on the topic were highly valuable. Last but not least, I would like to thank Prof. Dr. Dick van Dijk for his recommendations regarding the literature in financial econometrics and programming. Finally, I would like to thank all the people who provided me with feedback concerning this thesis. Their comments were valuable.

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ABSTRACT

This thesis forecasts short term crude oil price changes, based on behavioral models. The crude oil prices which are used are month ahead forward prices. Concerning the models, an explicit distinction is made between chartist investors and fundamentalists. The estimates of the model show that chartists are more noticeable in the market. Additionally, there is a distinction between symmetric and asymmetric models and between models with alternative assumptions. The reason for the distinction between symmetric and asymmetric models is to capture precisely the bandwagon and contrarian investment behavior respectively. The purpose for the distinction between the main and the alternative model is to show how the different assumptions may impact the model results. The research results show that symmetric models have lower forecasting errors than the asymmetric models. However, in hypothesis test of equal prediction accuracy it is shown that both symmetric and asymmetric models perform equally well. Finally, a comparison of the HAMs with the random walk model is made. It is shown that static HAMs do not outperform random walk models, on short term investment horizons.

Keywords:

Behavioral Finance; Asset Pricing; Financial Forecasting; Energy Forecasting.

TABLE OF CONTENTS

PREFACE AND ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	v
LIST OF FIGURES	v
CHAPTER 1 Introduction	1
CHAPTER 2 Literature review	3
2.1 Mean variance theory, risk and return.....	3
2.2 Asset pricing anomalies and traditional explanations	4
2.3 The momentum and reversal anomalies and traditional explanations	5
2.4 Behavioral finance, underreaction, conservatism and representativeness	6
2.5 Agent based finance	7
2.6 Heterogeneous Agent Models in practice	9
2.7 Behavioral finance, concluding remarks.....	10
CHAPTER 3 Overview of oil prices	12
3.1 Oil prices, an introduction.....	12
3.1 Structural models for oil prices	13
3.2 OPEC production behavior and oil reserve models	13
3.3 Oil price forecasting.....	14
CHAPTER 4 HAM models. Data and methodology.....	16
4.1 Data, range, frequency and transformations	16
4.2 Main Model. Fundamentalists and chartists.....	17
4.3 Alternative model for fundamentalists and chartists.....	19
CHAPTER 5 HAM results and interpretation.....	21
5.1 Main model. Chartists and fundamentalists, results and interpretation	21
5.2 Alternative model. Chartists and fundamentalists, results and interpretation	23
5.3 Final remarks about the models	27
CHAPTER 6 Forecasting	23
6.1 Performance measures, the MAE and the MSE.....	28
6.2 Symmetric and asymmetric HAMs. The Diebold-Mariano test.....	34
6.3 HAM comparion with the random walk model	35
6.4 Forecasting conclusions	37
CHAPTER 7 Conclusion.....	38
7.1 Concluding remarks	38
7.2 Research limitations and suggestions for the future.....	38

REFERENCES.....	40
APPENDIX A Unit Root tests	44
APPENDIX B Program codes for one step ahead forecasts.....	45

LIST OF TABLES

Table 5.1	Coefficient estimates of symmetric and asymmetric HAMs	21
Table 5.2	Coefficient estimates of symmetric and asymmetric HAMs. Alternative model	24
Table 5.3	Summary Statistic of the dependent variables ($P_{t+k}-P_t$)	25
Table 5.4	Summary Statistic of the independent variables ($P_{t+k}-F_t$); ($P_{t+k}-C_t$)	26
Table 5.5	Summary Statistic of the fundamental variables ($P_{t+k}-F_t$)	26
Table 6.1	MAE and MSE of the main and alternative HAM	29
Table 6.2	Diebold-Mariano coefficients and t-tests. Symmetric versus asymmetric models	35
Table 6.3	Diebold-Mariano coefficient and t-tests. HAM versus random walk models	36

LIST OF FIGURES

Figure 3.1	Month ahead crude oil prices per barrel. West Texas Intermediate, Dubai, Brent	12
Figure 6.1	Forecasts of the main model. Asymmetric versions	30
Figure 6.2	Forecasts of the main model. Symmetric versions	31
Figure 6.3	Forecasts of the alternative model. Asymmetric versions	32
Figure 6.4	Forecasts of the alternative model. Symmetric versions	33

CHAPTER 1 Introduction

The volatile nature of oil prices tends to attract the attention of many analysts. Oil price fluctuations are of particular importance since they directly influence decisions regarding production costs, investment opportunities, future economic growth and planning. However, oil can also be viewed as a financial asset rather than just a consumption commodity. Since the deregulation of the oil markets during the decade of 1970, oil is traded on exchange markets and investors can buy and sell it, having pure financial objectives. Some of the motives underlying the investments in oil contracts are usually the potential profits from future price changes and the hedging of exposures that are directly linked with oil prices. Consequently, the need for a sound model that can capture the changes of oil prices is important for investment decisions.

This thesis is going to investigate the drivers of oil price changes from a financial viewpoint and has a twofold purpose. The first one is to develop theoretically sound, yet practically applicable models. The second aim is to scrutinize the forecasting accuracy of the models. The paradigm that is going to be followed is derived from the branch of Heterogeneous Agents Models (HAMs) and takes into consideration the heterogeneous beliefs that investors have regarding the actual and expected prices of a particular asset. In brief, according to the Heterogeneous Agents framework, investors due to their different beliefs and trading strategies are distinguished between fundamentalists and chartists. For this reason, for the investigation at hand, there is going to be a deviation from the traditional asset pricing approaches and the HAMs framework seems to be a viable alternative.

The application of HAMs on empirical level is not new. According to the research of Brock and Hommes (1997) and Frankel and Froot (1986), it is shown that HAMs can describe the way that financial markets function. Boswijk et al. (2007) apply HAMs to stock indices and De Grauwe and Grimaldi (2005) try to test the applicability of HAMs on exchange rates. Additionally, ter Ellen and Zwinkels (2010) and Huisman, Mailliepard and Zwinkels (2010) apply HAM to oil prices and electricity prices respectively. The research results suggest that HAMs can have a strong descriptive characteristic, produce significant estimators and in cases of forecasting accuracy, HAMs outperform standard models like the random walk.

Under the framework of this thesis, the Heterogeneous Agents Models which are going to be estimated, they will have a daily investment horizon. Additionally, a distinction is going to be made between investors with contrarian and bandwagon expectations. In that sense, there are going to be two versions of HAMs, a symmetric and an asymmetric. Additionally, the forecasting accuracy of the models is going to be investigated and a comparison with the random walk model is going to be made. For this purpose, using each model, one step ahead forecasts are going to be generated. The intention of the forecasting investigation is to examine whether the distinction between the symmetric and

asymmetric version of HAMs is of added value on daily investment horizons. The same applies to the comparison of HAMs with the random walk model. Consequently, the second investigation will examine whether HAMs can outperform random walk models in terms of forecasting accuracy.

For the cases of model comparisons, hypothesis tests are going to be formulated. The first hypothesis test has to do with the intragroup distinction of HAMs (symmetric vs asymmetric) and the second hypothesis test has to do with the comparison of both symmetric and asymmetric version of HAMs with the random walk model. The performance of the hypothesis tests is going to be derived from the framework developed by Diebold and Mariano (1995) where the researchers develop a testing procedure which can be used for the comparison of the forecasting accuracy of econometric models.

The structure of this thesis is the following: In Chapter 2, the research which covers the development of the HAMs is going to be discussed extensively and failures of traditional asset pricing approaches are going to be illustrated. In chapter 3, an overview of the crude oil prices is going to be given and empirical evidence that covers important aspects of the modeling of oil prices is going to be presented. In chapter 4 the methodological issues of HAMs are going to be discussed. The derivation of the HAMs is going to be presented and the associated assumptions that accompany the models are going to be stipulated. Consequently, using different assumptions, two different versions of HAMs are going to be derived. In Chapter 5, the estimated parameters of the models are going to be presented together with summary statistics of the results. In Chapter 6, the forecasting accuracy of the models is going to be investigated using standard forecasting statistics and the main hypothesis of this thesis are going to be tested. Finally, in Chapter 7 a conclusion of the research results is going to be given. Any particular findings, inconsistencies and future suggestions are going to be presented.

CHAPTER 2 Literature Review

The most profound theoretical approach in modern asset pricing is summarized under the mean variance framework. The main theoretical implications of this framework show that the risk of an asset -measured by its variance- and the mean of the returns of the asset are linearly related. Additionally, it is implied that high returns generated by a particular asset class (or a portfolio of assets) are explained only by higher risk. Finally, under the same framework it is claimed that there is no other factor that can explain returns despite risk and that markets reflect all the available information. These are the main implications of the mean variance theory. However, as it will be proved, there are certain anomalies-phenomena that violate the above mentioned fundamental axioms. Traditional asset pricing models fail to provide sound explanations for the peculiar phenomena and novel theories are needed. New approaches, rooted on behavioral sciences show that people base their decisions in less sophisticated methods, rules of thumb, heuristics and biases. Additionally, it is shown that there is strong case against the efficient market hypothesis and investors seem to be prone to base their decisions on different set of signals and strategies.

2.1 Mean variance theory, risk and return.

It has been already indicated that the mean variance framework is one of the most profound paradigms in asset pricing theory. The main implications of this theory, directly determine the type and significance of the relationship between the risk of an asset and the return of it. Therefore, this paradigm -as any of them- is based on certain assumptions. According to Sharpe (1964), Treynor (1961), Lintner (1965) Fama (1968) and Cochrane (2005) the main assumptions of the mean variance framework in relation to the market, state that all the investors have the same expectations and that asset markets are perfect and efficient. Therefore, if the underlying assumptions are satisfied then two main conclusions can be derived. First, it could be argued that the returns and risk are linearly related. Second, it can be proved that the total risk is the only factor that can explain returns (and by implication prices). Additionally, given this framework, the Efficient Market Hypothesis (EMH) is implied. That means that market prices reflect all the necessary information and every new signal will be immediately incorporated.

A pioneering empirical investigation of the implications of the mean variance framework has been made by Fama and Macbeth (1973), where the researchers tried to investigate whether the relation between risk and return is linear and if there is any other factor that can explain risk. In doing so, the researchers added quadratic terms to the linear capital asset pricing model in order to capture non-linearity. The research results show that there is a positive relation between risk and return and also that the higher-order quadratic terms which were added, were insignificant. Therefore, Fama and Macbeth (1973) argue that their results support the propositions of the mean variance theory. However,

it should be noted that particular attention should be given to the research results since there is a potential bias as a result of the methodological issues. This bias and certain assumptions of the model were challenged by Roll (1977) who claimed that there can be misspecifications.

Another research paper of Black, Jensen and Scholes (1972) also investigates the form of the mean variance framework. The researchers add another risk term in their analysis which they call the “beta factor” and they show that it has substantial influence on the returns. Thus, after testing for the significance of this additional risk factor, they conclude that the relation between risk and return may not be exclusive. Additionally, Roll and Ross (1980) in support to the research of Black, Jensen and Scholes (1972) are expanding the horizon of additional factors, based on Arbitrage Pricing Theory. They show that risk is not the only factor that explains returns even in multi-period models. Their results indicate that additional macroeconomics factors, can explain high returns. Consequently, it could be claimed that there is a strong case to question some of the underlying assumptions of the mean variance theory. The first one has to do with the exclusive relationship between risk and variance and the second deals mainly with the one-period maximization problem.

As it has been illustrated, traditional asset pricing theories impose strong assumptions and restrictions in the relationship between risk and return. For this reason, there are numerous instances where this framework, cannot explain sufficiently the peculiar characteristics of asset markets. Empirical evidence shows strong cases of deviation from the implied theory. These cases are called anomalies.

2.2 Asset pricing anomalies and traditional explanations.

Returns are directly associated with risk. If returns are high, that implies that the assets are highly risky. However, there are certain observations in asset prices which do not conform to the previously mentioned statement. As it has already been indicated, returns are also influenced by other factors. The firm size and accounting information ratios can be factors of particular importance.

A typical observation in equity prices is that small firms, and companies with low market value, tend to earn higher returns than large firms with larger size or higher market to book values. These are the so-called “size effect” and “value” anomalies according to Banz (1981) and Basu (1983) respectively. According to the researchers, the two factors can indeed explain high returns but as it seems they are not directly linked with the risk as it is measured by the variance. A possible explanation for this phenomenon is that firm size and book to market value of companies can have an indirect influence on risk. For the first case, it could be stated that small firms can be perceived as risky due to the fact that they are more vulnerable to adverse economic conditions (Fama E., French K., 1996). For the second case, the explanation could be that low book to market value may reflect absence of investment capital

and low expansion possibilities for the firm at stake. Thus, a firm with low market to book value can be perceived highly risky from investors and should compensate them with excess returns.

The evidence presented in the case of the “size” and “book to market value” effects, shows that mean variance framework can be modified and the prime restrictions concerning the exclusive risk and return relation can be relaxed, as in the case of APT. Additional factors can indeed explain the variation in returns and theoretical explanations even within the modified mean variance framework can be obtained. However, there are specific anomalies which the traditional theory asset pricing theory cannot sufficiently explain. The most prominent types of these anomalies are the “momentum” and “reversal”.

2.3 Momentum and reversal anomalies and traditional explanations.

According to Jigadeesh and Titman (1993), the momentum anomaly indicates that stocks which were performing well in the past three to twelve months continue to perform well during the same subsequent period (i.e. one year). The same applies to “poor performers”. Stocks which were performing poorly in the past continue to perform poorly in the nearby future. The investment implication of the momentum anomaly is straightforward. Investors, who go long on good performing stocks and go short on poor performers, earn high returns relatively to the risk that they bear. A possible explanation of this phenomenon provided by the researchers is that transaction costs, lack of liquidity or statistical issues can be reasons that amplify the momentum. The cornerstone idea behind these results is that market frictions, namely transaction costs and liquidity, can indeed be the driving forces of this phenomenon. An alternative explanation is also provided by Fama (1997). In the research of Fama. (1997), it is provided supportive evidence of the view that anomalies are random and arise due to methodological issues. According to this evidence, it is shown that anomalies have equal chances to appear and are strongly persistent just in the short run and they disappear in the long run. Consequently, it could be claimed that the evidence presented by Fama (1997) comes in support to the view of the EFM and the mean variance theory.

The reversal anomaly, according to Cochrane (2005) implies that investors, who buy long term poor performing stocks and sell long term “winners”, earn high returns relatively for the risk that they bear. This result has two main implications. First, it shows that stocks which were performing well in the short run are prone to perform poorly in the long run and vice versa. Second, it provides evidence that asset prices which diverge too much from their intrinsic values are brought, in the long run, back to an equilibrium level. Expensive stocks (past good performers) are prone to be sold and cheap stocks are more likely to be bought aggressively. Thus, an economic rationale for this anomaly exists and Cochrane (2005) argues that reversals are actually expected to occur.

As it becomes evident, the puzzle still remains. Is the traditional asset pricing theory sufficient to give a holistic explanation of the anomalies? After all, it is shown that there can be traditional explanations for the perverse phenomena that occur. For the case of the momentum anomaly, in a complementary study, Jigadeesh and Titman (1999) show that behavioral models stipulate better the persistence and significance of the effect. Possible explanations based on behavioral models indicate that markets underreact according to new information causing the anomaly to be persistent. Hong and Stein (1999) investigate the momentum and the reversal effects and the associated trading strategies. The researchers state that markets initially underreact to new information and gradually, in longer horizons, this underreaction leads to large price divergence from the equilibrium levels (overreaction). This price divergence in turn calls for the reversal effect. Markets realize the disequilibrium and sell (buy) overpriced (underpriced) assets. These observed facts have certain implications. First, it can be explicitly recognized that financial markets are not perfectly competitive as the mean variance framework suggests. Second, it can be shown that individuals do not have the same expectations and interpret differently the information that they receive (Jigadeesh and Titman, 1999). Finally, it is illustrated that there are investors groups which can dominate the market.

2.4 Behavioral Finance. Underreaction, conservatism and representativeness.

Literature in behavioral finance tries to explain the momentum anomaly, stating that the underreaction of investors is a possible reason that justifies this phenomenon (Barberis, Shleifer and Vishny , 1998). Underreaction takes place when investors incorporate only gradually new information concerning asset prices. Thus, investors do not update their views frequently and they continue to believe that asset prices represent the same characteristics which they had initially. For this reason, good performing assets continue to show the same performance in the future and analogous but reverse results hold for the “bad performing” assets (Barberis, Shleifer and Vishny , 1998). The rationale behind this peculiar updating process is derived from psychology. Edwards (1968) frames this behavioral pattern under the term “conservatism”. According to Edwards (1968) conservatism refers to the observation that people cannot interpret correctly the diagnostic meaning of an observation when it is combined with other observations. That implies that people do not update their views correctly, given new information available.

Another behavioral aspect which can have extensions to asset markets is the representativeness heuristic. According to Kahnemman, Slovic and Tverksy (1982) the representativeness heuristic shows that people tend to make judgments concerning new events or information, being influenced by the similarity of the event/information with general parent population characteristics. In short, representativeness can be described as a classification mechanism which people use to classify things which depict similar traits. An illustration of this bias with an example that is found in Kahneman and

Tversky (1971) can give better insights. We assume that there are two hospitals, one large and one small. On a particular day 60% of those borne at the hospital are boys. Which hospital is likely to be? People, misguided by the representativeness heuristic and the belief in the law of small numbers are most likely to choose the larger hospital. They would think that a rare event (relatively large number of boys) is most likely to be observed in a large hospital. However, this reasoning underestimates the fact that large samples tend to be more stable around the average (50% of boys and girls in that case) than smaller samples (Taleb, 2010). This is the way that representativeness appears in decision making. In financial markets, one can say that asset managers and traders tend to believe that returns of the past can be representative of the results in the future. Thus the representativeness bias tends to appear in the form of extrapolation of past trends.

2.5 Agent Based Finance.

So far it has been mentioned that investors can take decisions based on rules of thumb, heuristics and behavioral biases. This fact obviously comes in contrast with the mainstream idea that investors take optimal decisions based on all the available information which is reflected in the price of the asset. Keynes (1936) was one of the first economists who observed the fact that markets can be indeed be driven by irrational investors and that prices may not reflect the true-fundamental value. This perspective found a strong opposition mainly by Hayek (1945) who claimed that prices are the communication device of the market and they reflect all the available information concerning the asset. If prices change, then probably a characteristic of the asset changed. The Hayekian view was also supported by Friedman (1953) who argued that any deviation of the asset price below or above the fundamental-intrinsic value will be alleviated in the long run by arbitrageurs. Thus, according to the views of Hayek and Friedman prices -on average- reflect all the information available in the market and the underlying economic fundamentals.

Cespa and Vives (2009) inspired by the philosophical underpinnings of Friedrich Hayek and John Maynard Keynes, studied dynamic trading and the determination of asset prices under multiple equilibria. The researchers argue that traders who have short-run investment horizons tend to depict a bias in relation to public information, meaning that they are extrapolating trends. In that sense a “Keynesian region” is obtained. That implies that for short-run price difference trading, the behavior of traders is related to the average market expectations, confirming the Keynesian beauty contest view of the markets. On the other hand, the researchers show that traders with long-run investment motives tend to be less biased in the estimation of the fundamental value and thus, a “Hayekian region” is attained. Under the Hayekian region, it is argued that asset prices reflect the economic fundamentals.

It is obvious that the research of Cespa and Vives (2009) is motivated by philosophical considerations and it can be considered just as contribution to the field of agent based finance. The beginning of the modeling of investment heterogeneity has been done by De Long et al. (1989). In their research paper, the authors argue that asset prices can indeed deviate from the underlying fundamentals even for long horizons. De Long et al. (1989) developed a theoretical model and they distinguished between two types of agents, the sophisticated investors and the noise traders. Sophisticated investors are valuing assets based on fundamental analysis, whereas irrational investors are extrapolating trends.

After specifying the demand function for the asset and the utility function of the agents, the researchers came to the price solution of the model. In the price solution it is shown that irrational traders can survive and influence asset prices even in the long run. The main reasons for the existence of this phenomenon are the so-called “hold more effect” and the “create space effect”. In brief, according to this effects, it is shown that noise traders can earn higher returns relatively to the risk that they bear (and thus they are profitable) and also that rational investors are not able to lessen price discrepancies through arbitrage. The explanation that is given for this phenomenon is that rational traders think that price deviations can continue in the future due to the trend extrapolation tactic of noise traders.

Additional theoretical papers which illustrate that investors may have heterogeneous beliefs are those by Frankel and Froot (1986) and Brock and Hommes (1998). In the paper of Frankel and Froot (1986), the main theoretical framework is built around the United States Dollar and the associated currency bubble that was observed during the 1980's. The researchers, instead of distinguishing between rational and irrational investors, they assign specific characteristics to the investor groups, which are fundamentalists, chartists and portfolio managers. Fundamentalists (rational investors) base their expectations on fundamental analysis and economic reasoning. Chartists (irrational-noise investors) are extrapolating past trends to the future and finally, portfolio managers use inputs from fundamentalists and chartists to form and update their decisions. The benchmark for performance evaluation that is used by portfolio managers is the forecasting accuracy of chartists and fundamentalists. The main finding of the researchers, is that the way that portfolio managers update their decisions largely impacts the price formulation in the market. Thus, any deviation of the currency price from its intrinsic value can be justified if this deviation is associated with a strategy that can have better predictive accuracy.

In a complementary research, Brock and Hommes (1997) find similar results to those of Frankel and Froot (1986) but they extend their model by adding more investor groups and dynamics. Brock and Hommes (1997) argue that different investors have different beliefs and they distinguish between five broad groups. Fundamental analysts, trend chasers (chartists), rational investors, contrarians and

biased investors. The important point to realize is that the irrational traders are not identical to biased investors (or trend chasers) as in previous research papers. The same applies for fundamentalists and rational investors. They are not the same. Rational investors have a perfect foresight of the market, whereas fundamentalists form expectations on the basis of fundamental analysis. Additionally, it is worth mentioning that contrarians are called the investors who buy assets when prices decline and sell when prices rise.

Brock and Hommes (1997) show initially that if all the investors are rational and have identical expectations, as the traditional asset pricing theory would suggest, then the equilibrium price would be identical to the intrinsic price of the asset. Proceeding with the results, Brock and Hommes (1997) prove that investors have heterogeneous beliefs and they change their strategies according to the past profitability that was generated by each investor group. This creates the so-called intensity of choice parameter in the model. This intensity of choice parameter is the main element which creates asset price dynamics that drive the actual price away from the implied equilibrium value.

2.6 Heterogeneous Agent Models in practice.

So far, it has been shown that HAMs have sound theoretical and intuitive appealing. However, another aspect for consideration is their applicability to different asset classes. Boswijk et al (2007) apply HAMs to the stock prices of the Standard and Poors 500 (S&P 500) Index using yearly data from 1871 to 2003. The authors make the classical distinction between fundamental analysts and trend followers, and they argue that those groups switch strategies according to past performance in terms of forecasting errors. Their research results show that fundamentals are driving the stock prices in the long run, whereas trend extrapolation can be considered as an investment strategy with short-run focus. Additionally, it is shown that any price deviations that are observed usually have different interpretations between investors. If the stock prices deviate from the fundamentals gradually, then this type of price discrepancy is not expected to persist. However, if the price deviation is rapid, then the trend extrapolating strategy will be more immense and by implication any deviations from the fundamentals will be amplified. (Boswijk et al. 2007)

A similar research is done by De Grauwe and Grimaldi (2005), where a HAM is applied to exchange rates. The researchers, argue that there are stylized facts and puzzles in the exchange rates. Facts like excess skewness, volatility, kurtosis and the disconnect puzzle, constitute the modeling of exchange rates based on macroeconomic models difficult. For this reason they argue that a HAM can be a better choice for that case. The research results show that the chartists strategies are more pronounced and followed most of the time by investors. This fact may also give an explanation for the exchange rate disconnect puzzle. Additionally, De Grauwe and Grimaldi (2005) argue that in countries with high

volatility in fundamentals (like high inflation) the link between exchange rate changes and fundamentals is high. The contrary applies for countries with relatively stable fundamentals. In that case, exchange rate changes and the underlying economic indicators are loosely linked.

A complementary research that investigates the validity of HAMs in case of exchange rates is done by De Zwart et al. (2009). The researchers apply a HAM to emerging and developed currency markets and they investigate the value of fundamental and technical (trend-following) analysis. The concluding remarks show that fundamental analysis can be profitable in both emerging and developed markets and that technical analysis can be profitable only in emerging markets. Additionally, it is shown that when fundamental and technical analyses are combined, then the two strategies can be profitable both in developed and developing markets.

Application of HAMs on commodity and energy markets has been done by Ellen and Zwinkels (2010) and by Huisman, Malliepard and Zwinkels (2010), where the researchers apply HAMs on crude oil and electricity contracts respectively. In the paper of Ellen and Zwinkels (2010) the researchers apply a HAM to West Texas Intermediate (WTI) and crude oil Index respectively. They find strong evidence that investors have heterogeneous beliefs since both the fundamentalist and trend-following strategies show significant results. Additionally, they perform out-of-sample forecasts where they find that HAMs outperform in forecasting accuracy both the random walk and vector autoregressive models.

The research of Huisman, Malliepard and Zwinkels (2010) focuses on three electricity forward contract indices. The indices included are the Dutch APX, the German EEX and the nordic Noordpool Index, which are used as benchmarks. The results show that both fundamentalists and chartists are present in the market and that the switching behavior of investors between the strategies is quite intensive. Additionally, it is argued that the presence of investors who follow a chartist strategy is more apparent on average. However, this phenomenon is reversed when the electricity contracts are coming closer to maturity. Then, at this point, the presence of fundamentalists dominates the market (Huisman, Malliepard and Zwinkels, 2010).

2.7 Behavioral finance, concluding remarks.

It has been indicated that the mean variance framework and the associated theory do not sufficiently explain certain market phenomena like the momentum and reversal anomalies. Traditional explanations, try to attribute this phenomenon to market imperfections, measurement issues or they provide evidence that such phenomena are expected to occur. However, it has been shown that the anomalies are likely to be the results of the behavioral biases that investors may have. More specifically, investors may extrapolate past trends to the future and they can also be conservative in

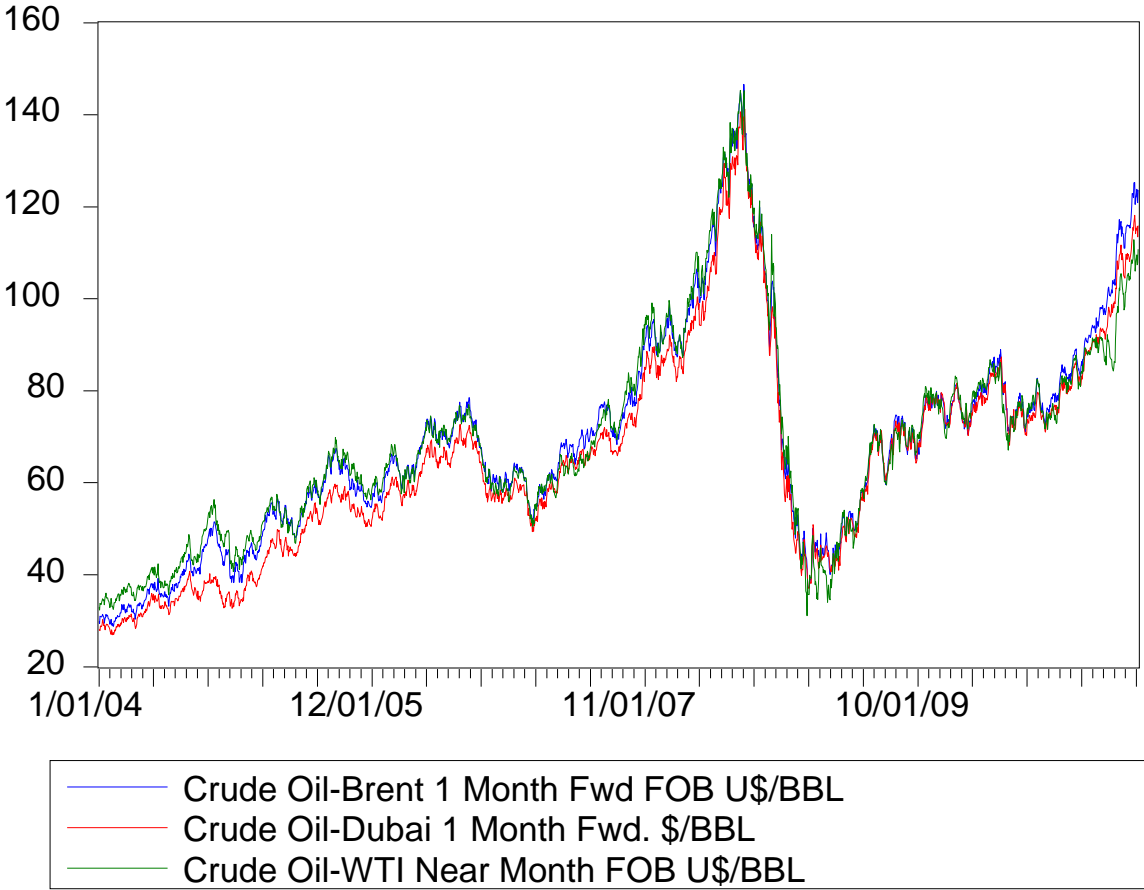
updating their views concerning the price of a certain asset. This type of strategy is incorporated under the Agent Based paradigm and the associated HAMs of behavioral finance. According to this framework, it is shown that investors may be either rational (fundamentalists) or irrational (trend-following) and the interaction between the two groups generates asset price dynamics which can explain some perverse asset pricing phenomena. Additionally, it has been shown that HAMs can produce testable results, have strong descriptive power and under certain conditions outperform standard models in terms of out of sample predictive accuracy.

CHAPTER 3 Overview of oil prices

3.1 Oil prices, an introduction.

Oil prices depict seasonality, spikes and are highly volatile (Huisman, 2009). Consequently, in order to give a better understanding of the oil prices, it could be good to depict a graph with the oil prices of the three indices used for the analysis. The period range begins from 2004 and ends to 2011. All the prices in the graph are shown in US dollars and are referring to forward contracts closing one month ahead. For all the indices included, prices are settled daily. Also the corresponding commodities are traded on daily basis.

Figure 3.1 Month ahead crude oil prices per barrel. West Texas Intermediate, Dubai, Brent.



As it can be seen, the oil prices are highly volatile. A peak at the middle of 2008 is observed and then a significant decline causes the prices to reach a level of almost 30 US dollars per barrel. However, from this period and up to now, oil prices show an increasing trend. For the purpose of descriptive analysis of the graph, the periods are going to be divided. The first period will be from 2004 up to 2006. The second period will be from 2006 up to 2008 and the final period from 2008 up to April 2011.

During 2004 up to 2006, an increasing trend of the oil prices is observed. According to Dees et al (2008) the main reasons that can explain the increase of oil prices have to do mainly with the availability of crude oil and demand-supply considerations. More specifically, it is argued that in the United States, the supply of oil during the underlying period faced significant shortcomings due to the steady number of oil refineries which date back to 1981. Additionally, it is also claimed that a large number of oil refineries in the United States was under maintenance. As a consequence, the market of crude oil faced supply shortages which in turn influenced the global oil prices during the period 2004 up to 2006 (Dees et al., 2008).

For the second period, from 2006 up to 2008 it is observed that oil prices increased at higher rates and decreased sharply after the financial crisis of 2008. Although, the sharp price decrease can be attributed to the financial crisis, the significant price increase remains questionable. Dees et al. (2008) argue that the non-linear relationship between oil prices and supply caused the prices to peak. Other factors such as insufficient production capacities (like in the previous period), extreme events and expectations concerning the market conditions of the future (like contango or backwardation) may sufficiently explain the increasing peak of the prices. However, there are also assertions that the oil price increase in 2008 was the result of speculative investments. Talley and Meyer (2008) declare that there was strong evidence of speculation in oil markets, which caused the prices to increase. The journalists, given evidence from Congressional committees in the United States, state that 70 per cent of the trades in futures of the New York Merchantile Exchange (NYMEX) and the Intercontinental Exchange (ICE) have speculative nature. As a consequence, they argue that the main reason for the oil price increases was speculation in the futures market.

As it can be seen, there are no clear answers as to which are the main reasons which led the oil prices to increase rapidly. Given the evidence presented, it could be argued that for the period 2006 up to 2008, shifts in the demand-supply conditions and speculation caused the prices to increase dramatically. The aftermath of this increase was a sharp decline of the prices during the financial crisis. For the period from 2008 up to 2011, the general tendency that is observed is that oil prices tend to increase but in smaller rates compared to the past. This increase of the oil prices can be attributed to the expansionary growth of developing economies, to geopolitical uncertainties in the Middle East and to the current production quotas of the Organization of Petroleum Producing Countries (OPEC) (ExxonMobil, 2010)

3.2 Structural models for oil prices

After the deregulation of oil prices during the 1970's in the United States, the determinants of oil prices have triggered the interest of many researchers. Bacon (1991) gives thorough explanations

concerning the factors that influence oil prices. Bacon (1991) argues that the price of oil is largely dependent on its market availability which is in turn a function of demand and supply. Global supply of oil is determined by the world producing countries and the Organization of Petroleum Exporting Countries (OPEC). Global demand is associated with consumption. The factors that affect final oil consumption are likely to be associated with the global Gross Domestic Product growth, country specific taxation issues, exchange rate effects, transaction costs and potential price distortions that are linked with the production process (e.g. refining costs and capacities). The supply of oil can be distinguished between two components, the non-OPEC supply and the OPEC supply. The non-OPEC countries supply is usually linked with the costs of the exploration, development and production. These costs together with the availability of future oil reserves and taxation issues are the most significant factors. Concerning OPEC-supply of oil, the factors that affect supply decisions are the production quotas that are set by OPEC and the local demand by the country members of the cartel (Bacon, 1991).

A model that tries to assess quantitatively the relation between macroeconomic factors and the price of oil is developed by Dees et al (2005). Dees et al (2005) investigate the quarterly changes of oil prices and make a distinction in the potential behavior of the OPEC cartel which they assume to be either cooperative or non-cooperative. Again, in this research paper, it is assumed that oil prices are characterized by global supply and demand. The researchers show that the most important factors that affect demand are the GDP, the real oil prices, exchange rate effects and potential technical trends (like spikes or shocks) that may temporarily affect the prices. For the supply determination, Dees et al (2005) find that it is largely dependent on production quotas from OPEC, production costs of both OPEC and non-OPEC countries, oil reserves of countries that belong to the Organization of Cooperation and Development (OECD) and production and refinery capacities.

Moreover, for the oil supply determination, the researchers also account for geopolitical factors that may play a crucial role in terms of production decisions. The results of the research show that the variables in their equilibrium model are significant and they can produce testable predictions. Dees et al., (2005) used a “backcast” method to test the predictive accuracy of the model. More specifically, they tried to test whether the model could “follow” past pricing behavior given exogenous shocks. Their simulation outcomes declared that indeed, their model is able to account for the divergent behavior of the oil prices given exogenous shocks.

3.3 OPEC production behavior and oil reserve models.

After observing the most important determinants of oil prices and the crucial role that the OPEC cartel has on prices and quantities produced, it is worth to have a closer look on the factors that affect the

OPEC production. Kaufmann et al. (2007) are investigating models that try to capture the degree by which economic and institutional factors affect the crude oil production of OPEC member countries. In their analysis they utilize models that frame OPEC both as cartel and non-cartel organization. Their research outcomes are quite impressive. They find that OPEC does not fit particularly well to any of the models used. The explanation that they provide is that certain geological, institutional and economic factors are adding to the complexity of the OPEC production behavior. The researchers claim that this is an expected result given the real-life complexities that are involved in the oil production process and OPEC (Kaufman et al., 2007).

Ye, Zyren and Shore (2002) try to forecast the WTI oil price changes based on a simple model that accounts for oil inventory levels. The rationale behind this research is that oil reserves can serve as a good proxy for the demand and supply imbalances that occur. Therefore, these imbalances in turn can provide a good insight concerning future price fluctuations. The data for the research are based on actual oil reserves for the OECD countries, future forecasts and inputs that are estimated by the researchers themselves. For the assessment of the predictive accuracy of their model, Ye, Zyren and Shore (2002) develop an in-sample dynamic forecast. The outcome of this forecast, shows that the model has good predictive accuracy and can indeed explain to a large extent oil price fluctuations.

3.4 Oil price forecasting

Alquist, Killian and Vigfusson (2011) try to forecast real and nominal oil prices based on different techniques. The researchers distinguish mainly between two periods, before 1973 and after 1973 when the United States became more dependent from external supply of oil. The research outcomes provide evidence that at horizons up to six months unrestricted Vector Autoregressive models (VARs), estimated recursively, tend to have higher accuracy in terms of out of sample forecasting of real oil prices. Additionally, the researchers compare non-linear models with VARs and their outcomes show that joint non-linear models do not outperform in terms of forecasting accuracy the linear autoregressive models. However, it should be stated that the researchers declare explicitly that the VAR models also fail in terms of out of sample predictive power in a plethora of cases.

Knetsch (2007) develops a forecasting model for oil prices, based on the convenience yield. In the research paper of Knetsch (2007) the main forecasting problem involves the forecast of all future expected payoffs that the investor is receiving (convenience yields). It is argued that it is easier to forecast marginal convenience yields rather than oil prices. The forecasting performance evaluation of this model is done by the means of statistical hypothesis testing. The outcomes show that the marginal convenience yield model outperforms in terms of accuracy the predictive power of the random walk model. However, it is argued that random walk models also have strong forecasting ability.

CHAPTER 4 HAM models. Data and methodology.

For this thesis the main investor groups will be the fundamental analysts (fundamentalists) and trend followers (chartists). There are no other groups like noise traders or fully rational traders as they are presented in the work of Brock and Hommes (1997). Additionally, for the development of the models, the main assumption is that there is no switching between the two investor groups. In that sense, the models that are going to be presented are static. That implies accordingly that fundamentalists and chartists follow their own strategy irrespectively of its past performance. Moreover, a distinction will be made between symmetric and asymmetric models. That means that it will be investigated whether the negative and positive price differences from the relative benchmarks are interpreted in the same way by investors. Finally, an alternative version of the HAMs is going to be presented. The intention behind the inclusion of the alternative version is to investigate whether different assumptions - formulated on ad-hoc basis- can produce better results. All the above mentioned models are going to be estimated using the ordinary least squares regression method.

4.1 Data, range, frequency and transformations.

In most of the cases, HAMs are applied to monthly data of crude oil forward prices (Ellen and Zwinkels, 2010). However, it is also observed that higher frequency daily data can also be used, as it is evident from the application of HAMs on electricity contracts (Huisman, Malliepard and Zwinkels, 2010). Finally, it could be argued that even yearly data may not be excluded as an option. Boswijk et al (1997) applied HAMs on yearly data of stock prices of the S&P 500 Index. As it becomes evident, the data frequency depends on the research objectives, the assumed investment horizon and the trading frequency of investors. For crude oil prices and the associated indices the data frequency that is preferred is typically monthly. However, for this thesis, daily data of forward crude oil contracts are going to be used. The data range is from 01/01/2004 up to 20/04/2011 (dd/mm/yyyy) and they were retrieved from Datastream™.

The data frequency is of high importance. Huisman, 2009 shows that oil prices have high volatility which is also time varying. Additionally, it is claimed that oil prices -in medium term horizons- are mean reverting. These characteristics, set oil assets apart from other asset classes like stocks which are better approximated by random walk models. However, the same characteristics make oil similar to other investment assets like exchange rates. Chortareas et al. (2007) try to forecast exchange rate volatility and they show that daily data can provide better forecasts since they capture the high time varying volatility of exchange rates. Consequently, for this reason, daily data are going to be used for this thesis.

Another aspect of the data analysis has to do with the transformation form. In general, it can be said that it is considered better to model oil prices in logarithmic form since any spikes and high volatility effects may be alleviated (Huisman, 2009). Consequently, for this thesis any price that is used is by definition in logarithmic form, except if it is stated otherwise.

4.2 Main model. Fundamentalist and chartists.

The main challenge for the application of the HAMs to the relative asset class is to find the corresponding proxies that can capture the behavior of both fundamentalists and chartists. It was highlighted that fundamentalists look on the fundamental price of oil and that they focus on the economic variables that affect the asset price. In the case of oil prices the best proxy for the fundamental price it could be given by estimating a structural model based on macroeconomic factors and supply and demand considerations. However, this estimate needs to be based on strong assumptions and the number of factors that have to be included can be relatively large. This fact obviously makes such estimation tough and carries the additional risk of biased input estimators.

A solution to this problem proposed by Schwartz and Smith (2000) and implemented by Ellen and Zwinkels (2010) shows that oil prices after periods of large deviations, return back to a mean-equilibrium level. For oil prices it is argued that half-lives are usually close to seven months, whereas complete mean reversion can take up to two years. This feature has certain implications for the estimation of the fundamental oil price. If there are investors that can bring the price level back to equilibrium level and there is an economic motive for that, then this pricing pattern can be used for modeling the behavior of fundamentalists. As it has been already shown, fundamentalists do not extrapolate past trends and bring prices back to a stable equilibrium level, justified by the asset fundamentals. Therefore, given the time period of seven months up to two years that is needed for the prices to revert back to equilibrium level, it can be said that a moving average of 360 days (one and a half years of trading days) can be used as a proxy for the fundamental price. Therefore, the fundamental price is:

$$F_t = (\sum_{n=1}^{360} P_{t-n} + P_{t-1} + P_{t-2} + P_{t-3} + \dots + P_{t-360})/360$$

After specifying the price that serves as a proxy for the fundamental value, it is important to specify the way that the fundamental price can be used to formulate decisions for the expected price change. Following the framework of Ellen (2010) the fundamental value which can be incorporated to the price change is as follows:

$$P_{t+k} = P_t + a_1(P_t - F_t) + e_t \quad (1)$$

and the associated expected price change at time t+k is:

$$P_{t+k} - P_t = c_0 + a_1(P_t - F_t) + e_t \quad (2)$$

The number of k is two and it was determined by a regression analysis which shows that for every index, prices of the previous two days have significant impact on the current price. Therefore, it has been assumed that the information which is included in the current price, it will also affect the price of the next two days. This assumption, which is based on empirical evidence, shows that there is a delayed reaction to current price changes.

In the asymmetric version of the model, there is going to be a distinction between positive and negative price differences. The model for fundamentalists is therefore:

$$P_{t+k} = P_t + a_2(P_t - F_t)^+ + a_3(P_t - F_t)^- + e_t \quad (3)$$

and the corresponding expected price change is:

$$P_{t+k} - P_t = c_1 + a_2(P_t - F_t)^+ + a_3(P_t - F_t)^- + e_t \quad (4)$$

Where, F_t is the fundamental price and is considered to be the moving average price of oil for the past one and half years. The positive (+) and negative (-) signs above the price differences represent positive and negative price differences respectively, which they count for investment expectations and asymmetry.

A positive sign declares that the actual price is higher than the fundamental price. A negative sign implies the contrary. In the case of asymmetric models, contrarian investment expectations are observed if there are negative coefficients in negative price deviations (thus, positive expected price change) and negative coefficients in positive price deviations. Bandwagon investment expectations are observed when we have positive coefficient estimates in negative price deviations and positive coefficients in positive price deviations. Investors who follow bandwagon strategies, buy assets when the prices start to rise and sell assets when prices decline. Investors, who have contrarian investment strategies, buy assets when the prices start to decline and sell assets when prices start to rise.

For the case of the chartists, their main challenge is to capture their extrapolative expectations and pricing behavior. Chartists usually look on historical data and use technical analysis in order to determine their "idiosyncratic" chartist price. For this reason, the chartist price (C_t) is assumed to be captured better from an Autoregressive Model.

The Autoregressive model has the form:

$$C_t = P_t = \beta_1 P_{t-1} + \beta_2 P_{t-2} + \dots + \beta_n P_{t-n} \quad (5)$$

The empirical estimate of this model shows that the number of lags with the most significant coefficients is two. For this reason, an AR(2) model will be used for the formulation of the chartist price.

After the specification of the chartist price, the corresponding symmetric model of expected price is:

$$P_{t+k} = P_t + \gamma_1(P_t - C_t) + e_t \quad (6)$$

and the associated model for price change is:

$$P_{t+k} - P_t = d_0 + \gamma_1(P_t - C_t) + e_t \quad (7)$$

Again, the number of k is two. Current prices are assumed to affect the prices in the next two days.

The corresponding asymmetric model has the form:

$$P_{t+k} = P_t + \gamma_2(P_t - C_t)^+ + \gamma_3(P_t - C_t)^- + e_t \quad (8)$$

and the corresponding asymmetric model with price changes is:

$$P_{t+k} - P_t = d_1 + \gamma_2(P_t - C_t)^+ + \gamma_3(P_t - C_t)^- + e_t \quad (9)$$

After the specification of the models, the total symmetric model of chartists and fundamentalists is given by equations (2) and (6) therefore, we have:

$$P_{t+k} - P_t = c_0 + a_1(P_t - F_t) + \gamma_1(P_t - C_t) + e_t \quad (10)$$

and the corresponding total asymmetric model is:

$$P_{t+k} - P_t = g_0 + a_2(P_t - F_t)^+ + a_3(P_t - F_t)^- + \gamma_2(P_t - C_t)^+ + \gamma_3(P_t - C_t)^- + e_t \quad (11)$$

Equations (10) and (11) are going to be the main models of the thesis and they are going to be estimated using the ordinary least squares regression method. The intention is to investigate the impact which chartists and fundamentalists have on the price changes of two days ahead.

4.3 Alternative model for Fundamentalists and Chartists.

It has been already indicated that the Heterogeneous Agent Models are built upon certain sets of assumptions concerning the behavior and expectations of both fundamentalists and chartists. In the version of the model that has been derived in the previous section, the main assumption concerning the behavior of fundamentalists is that they formulate their fundamental price on the basis of the moving average of the past 360 trading days (one and half years). This assumption is derived from the theory; however it is formulated on ad-hoc basis. For this reason, for the alternative version of the model, this assumption is going to be relaxed. It is going to be assumed that fundamentalists look on the oil prices of the past six months (180 trading days) and that they formulate their fundamental prices based on the

corresponding moving average. The intention behind this change is to investigate whether fundamentalists have shorter horizons in their price formulation decisions.

Given the modifications to the models, the alternative fundamental price is:

$$F = (\sum_{n=1}^{180} (P_{t-1} + P_{t-2} + P_{t-3} + P_{t-4} + \dots + P_{t-180})) / 180$$

and the new symmetric and asymmetric models will have the form:

$$P_{t+k} = r_0 + \delta_1(P_t - F_t) + \theta_1(P_t - C_{t-1}) + e_t \quad (13)$$

$$P_{t+k} - P_t = r_1 + \delta_2(P_t - F_t)^+ + \delta_3(P_t - F_t)^- + \theta_2(P_t - C_{t-1})^+ + \theta_3(P_t - C_{t-1})^- + e_t \quad (14)$$

CHAPTER 5 HAM results and interpretation

It has been mentioned that the crude oil indices that are going to be used are the WTI, the Brent and Dubai free on board. Again, as it has been already mentioned the equations estimated are (10) and (11) for both the main and the alternative model. For the alternative model, also the AIC for each index and the number of lags is mentioned. Finally, summary statistics of the dependent and independent variables of the models are going to be presented. The results are presented in the sections that follow.

5.1 Main model. Chartists and fundamentalists, results and interpretation.

The main consideration of the model is to investigate whether chartists and fundamentalists have an impact on the changes of crude oil prices. Moreover, each model will be estimated for every index and a comparison of the results will be made. Therefore, for fundamentalists and chartist the combined symmetric and asymmetric models are as follows:

$$\begin{aligned} \text{i)} \quad & P_{t+k} - P_t = c_0 + a_1(P_t - F_t) + \gamma_1(P_t - C_t) + e_t \\ \text{ii)} \quad & P_{t+k} - P_t = g_0 + a_2(P_t - F_t)^+ + a_3(P_t - F_t)^- + \gamma_2(P_t - C_t)^+ + \gamma_3(P_t - C_t)^- + e_t \end{aligned}$$

The results are summarized in the below table:

Table 5.1 Coefficient estimates of symmetric and asymmetric HAMs.

Coefficients	Brent	Dubai	WTI
SYMMETRIC			
c_0	-0.00005 (-0.081461)	-0.0000303(0.000554)	0.000112(0.000670)
a_1	0.002120 (0.003342)	0.0001521 (0.001980)	0.001986 (0.002375)
γ_1	-1.018105 (0.039214)***	-1.025626 (0.25627)***	-1.007326 (0.027341)***
Adj. R-squared	0.500762	0.509667	0.468430
Durbin Watson	2.00261	2.002701	2.064847
ASSYMETRIC			
g_0	0.001789 (0.001382)	0.000537(0.001109)	-0.000538 (0.001281)
a_2	0.002470 (0.00449)	0.002427 (0.004293)	0.001670 (0.005477)
a_3	-0.002191 (0.006054)	-0.000675 (0.003524)	0.004141 (0.004181)
γ_2	-1.167443 (0.051093)***	-1.081994 (0.048504)***	-0.953353 (0.053660)***
γ_3	-0.876181 (0.837776)***	-0.969493 (0.048391)***	-1.055100 (0.049173)***
Adj. R-squared	0.505003	0.509009	0.467521
Durbin Watson	2.00261	2.004504	2.001802

*Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; standard errors (in parenthesis). Corrections for heteroskedasticity have been made.*

The results of the table show some interesting facts. The most remarkable result is the significant impact of the chartists' strategies in every index of the crude oil market. The coefficient estimates are

different than zero and highly significant both in symmetric and asymmetric versions of the models. In the case of symmetric models, the negative coefficient of chartists shows contrarian expectations. To have a more clear view of the contrarian expectations, I take as an example the γ_1 coefficient of the Brent index. Contrarian investment expectations in the case of the Brent index, imply that chartists -in case of positive one percent price difference from their “idiosyncratic” price (i.e. $P_t > C_t$)- expect that in two days ahead the price will decline by -1.018105%. The same reasoning applies in the case of negative price differences. In case of negative one percent price difference today (i.e. $P_t < C_t$), chartists expect in that in two days ahead the price will increase by 1.018105% (since negative price change “multiplied” by a negative coefficient leads to a positive result). In the same way can be interpreted the coefficients of the remaining indices. However, it should be noted that a major drawback of this interpretation is that it assumes that both negative and positive price differences influence the decisions of the chartists in the same way. This is not the case as it is shown by the asymmetric versions of the models.

In the case of the asymmetric models, again, it is shown that chartist investment strategies produce better results. All the coefficients for the chartists for all the indices are different than zero and significant. However, the main difference here is that positive and negative price differences are not interpreted in the same way by investors as it is assumed in the case of symmetric models. Taking as an example the Brent Index and the corresponding chartist coefficients γ_2 (*for* $P_t > C_t$) and γ_3 (*for* $P_t < C_t$) it can be seen that they have different values. The value for γ_2 coefficient is -1.167443 and the value for the γ_3 coefficient is -0.876181. The value of the γ_2 coefficient shows that a one percent positive price difference today will lead the chartists to believe that -in the time horizon of the next two days- the price of crude oil will decline by almost 1.167443%. The value of the γ_3 coefficient shows that a negative one percent price difference today will lead the chartists to believe that in two days ahead, the price will rise by almost 0.876181%. Consequently, given the results, it could be argued that chartists have contrarian investment strategies. This is an indication of mean reverting expectation. Chartists seem to believe that oil prices discrepancies will be alleviated in a very short time period.

Another notable fact concerning the chartist strategies is that positive and negative price differences are not interpreted in the same way. As it can be observed from the results of the table 5.1, positive and negative price differences do not have the same coefficients. The positive price difference (γ_2) coefficients have slightly higher value than the corresponding one of the negative price differences (γ_3). This result shows that chartists may believe that prices are already above from an assumed “equilibrium” level and they expect that price decreases will occur to a larger extend than price increases. This interpretation can be justified from the fact that crude oil prices depict an increasing trend over the last three years (middle 2008-middle 2011). However, it should be noted that the trend of

increasing crude oil prices over the past years, may have only a marginal effect on the chartist expectations concerning short term price changes.

Taking into consideration the case of fundamentalists, it could be argued that their presence is not strongly observed both in symmetric and asymmetric versions of the models. The coefficient estimates a_1 ; a_2 ; a_3 of symmetric and asymmetric models respectively are insignificant. A possible explanation for the insignificant estimates is that the fundamental price -that has been assumed to be the moving average of the past one and half years- may not be representative. This is a strong assumption and it is quite unlikely that such a long term fundamental price can influence the price difference of the next two days, as in the case at hand. For this reason, this assumption is going to be relaxed in the alternative version of the Heterogeneous Agents Model that will be presented in the next section. A moving average of the past 180 trading days could be assumed to be a better proxy for the fundamental price, since fundamentalists may formulate their prices based on shorter past horizons.

Concerning the case of the indices, it could be said that the regression estimates do not differ significantly. In the case of Brent, Dubai and WTI it is common to observe that chartist have significant estimates and fundamentalists do not seem to have an impact on price changes. Moreover, another point for consideration is the intercept coefficient of every model. The intercepts -that is the c_0 in the case of asymmetric models and g_0 the in the case of symmetric model- it could be said that they declare a “residual” price variation of the model. As it seems the results show that the intercept coefficients are insignificant both for symmetric and asymmetric models. For this reason, it can be said that any “residual” price variation that is observed from the model is insignificant. Additionally, concerning the statistical fit of the HAMs, it could be argued that chartist and fundamentalist interactions explain almost 50 per cent of the price variations of crude oil prices. This is measured by the adjusted R-squared. This fit shows that the framework of fundamentalists and chartists may explain to a certain degree the price variations of the crude oil. However, it should be noted that any conclusions concerning the descriptive ability of HAMs should be derived with caution since the nature of the above estimated models is static and it does not take into consideration the dynamics of the models.

5.2 Alternative model. Chartists and fundamentalists, results and interpretation.

The framework of Heterogeneous Agent Models has the inherent challenge to find good corresponding proxies to quantify the strategies-behaviors of different investor groups. The model that has been estimated previously was based on the assumption that fundamentalists look on the moving average of the prices of the past 360 trading days. As it can be seen, this assumption can be disputable even if it

has strong theoretical support. For this reason, an alternative HAM will be estimated. For the alternative HAM, as it has been already mentioned, the fundamental price will be estimated based on the past 180 trading days. Therefore, the models take the following form:

$$i) P_{t+k} = r_0 + \delta_1(P_t - F_t) + \theta_1(P_t - C_t) + e_t$$

$$ii) P_{t+k} - P_t = r_1 + \delta_2(P_t - F_t)^+ + \delta_3(P_t - F_t)^- + \theta_2(P_t - C_t)^+ + \theta_3(P_t - C_t)^- + e_t$$

$$\text{Where, } F_t = (\sum_{n=1}^{180} (P_{t-1} + P_{t-2} + P_{t-3} + P_{t-4} + \dots + P_{t-180})) / 180$$

Table 5.2 Coefficient estimates of symmetric and asymmetric HAMs. Alternative model.

Coefficients	Brent	Dubai	WTI
SYMMETRIC			
r_0	-0.000239 (0.000642)	0.000567 (0.000862)	0.000250 (0.000873)
δ_1	0.004889 (0.004274)	-0.001930 (0.006120)	-0.002133 (0.006347)
θ_1	-1.014077 (0.035610)***	-1.025626 (0.25627)***	-1.006313 (0.041546)***
Adj. R-squared	0.499988	0.445318	0.468244
Durbin Watson	2.002450	1.976435	1.980448
ASSYMETRIC			
r_1	0.002013 (0.001259)	0.001518 (0.001627)	0.000388 (0.001613)
δ_2	-0.000945 (0.005706)	-0.003969 (0.010094)	0.000472 (0.009375)
δ_3	0.004673 (0.007069)	-0.00061216 (0.019980)	-0.008128 (0.018131)
θ_2	-1.122420 (0.050488)***	-0.949074 (0.059816)***	-1.017820 (0.090011)***
θ_3	-0.911439 (0.073632)***	-0.847191 (0.060080)***	-0.996023 (0.058760)***
Adj. R-squared	0.502003	0.443321	0.469574
Durbin Watson	1.99800	1.976980	1.980520

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; standard errors (in parenthesis). Corrections for heteroskedasticity have been made.

The results of the alternative model do not differ significantly from those of the original one. As it can be verified, the coefficient estimates of chartists are different than zero and highly significant both in the cases of symmetric and asymmetric models. For the case of fundamentalists, again, the coefficient estimates seem to be insignificant for all the indices and the symmetric and asymmetric versions of the models. For this reason, it could be argued that the fundamental price, as the moving average of the past 180 days, does not improve significantly the performance of the static HAMs, when dealing with daily data. This result is something that should be expected. It is difficult to assume that a fundamental price which is based on long term horizons can affect significantly the price changes of crude oil for the next two days. However, it should be noted that version of HAMs which are presented in this

this is static. A dynamic specification of HAMs with time varying weights could show that the fundamental price can have an impact on the price changes of the next two days. This can be a topic for further elaboration.

For the case of chartists, it can be observed that the coefficients θ_1 and $\theta_2; \theta_3$ of the symmetric and asymmetric models respectively are negative. These results were also observed in the main model which has been estimated. Therefore, the interpretation of the coefficient estimates remains the same. Taking as an example the Dubai Index and the corresponding chartist coefficients θ_2 (for $P_t > C_t$) and θ_3 (for $P_t < C_t$) of the asymmetric model, it can be seen that the value for θ_2 coefficient is -0.949074 and the value for the θ_3 coefficient is -0.847191. The θ_2 coefficient declares that a one percent positive price difference today will lead the chartists to believe that the price of crude oil will decline by almost 0.949074% in the next two days. The value of the θ_3 coefficient shows that a negative one percent price difference today will lead the chartists to believe that in two days ahead, the crude oil price will increase by almost 0.847191%.

Concerning the statistical fit -as indicated by the adjusted R-squared- of the alternative model it could be said that it is slightly worse compared to the original one. For all the indices and the symmetric and asymmetric versions of the models, the adjusted R-squared decreases or stays almost the same. However, it should be noted that the decrease is only marginal. With respect to index results, it could be said that there are no particular differences. For all the indices, the estimates for the fundamentalists seem to be insignificant and for the chartists significant. Moreover, all the intercepts for all the models are insignificant. Consequently, given the results of both fundamentalists and chartists and the indicators for the statistical fit, it could be claimed that the alternative specification of the fundamentalists does not seem to add value to the estimated HAMs. However, in order to have a better view of the independent variables of the models, summary statistics of the fundamentalists, chartists and price changes are provided in the tables that follow.

Table 5.3 Summary statistics of the dependent variables ($P_{t+k} - P_t$).

Statistics	Brent	Dubai	WTI
Mean	0.001489	0.001482	0.001271
Median	0.003395	0.003684	0.002424
Maximum	0.189798	0.218043	0.212523
Minimum	-0.149544	-0.165317	-0.189422
Std. Dev	0.029732	0.028744	0.034276
Skewness	-0.121847	-0.112915	-0.111226
Kurtosis	5.579825	6.809751	6.770745
Jarque-Bera	532.4343	1154.899	1131.334
Probability	0.000000	0.000000	0.000000
Observations	1903	1903	1903

Table 5.4 Summary statistics of the independent variables ($P_t - F_t$) ; ($P_t - C_t$) (Main model)

Statistics	Brent Fundamentalists	Brent Chartists	Dubai Fundamentalists	Dubai Chartists	WTI fundamentalists	WTI Chartists
Mean	0.083031	-0.001489	0.095433	-0.001482	0.070548	-0.001271
Median	0.144802	-0.001819	0.159502	-0.001710	0.131961	-0.001680
Maximum	0.525242	0.099029	0.551138	0.097795	0.528664	0.129158
Minimum	-0.895874	-0.125951	-0.849730	-0.115110	-1.096316	-0.215954
Std. Dev	0.264249	0.020863	0.262728	0.020268	0.275966	0.023391
Skewness	-1.508923	-0.080277	-1.524330	0.089007	-1.632982	-0.437504
Kurtosis	5.273558	5.495634	5.311172	5.132325	5.985525	10.14131
Jarque-Bera	918.4526	495.8873	941.5726	363.0370	1259.639	4104.452
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	1544	1903	1544	1903	1544	1903

Table 5.5 Summary statistics of the independent fundamental variables ($P_t - F_t$) (Alternative model)

Statistics	Brent Fundamentalists	Dubai Fundamentalists	WTI fundamentalists
Mean	0.083031	0.095433	0.070548
Median	0.144802	0.159502	0.131961
Maximum	0.525242	0.551138	0.528664
Minimum	-0.895874	-0.849730	-1.096316
Std. Dev	0.264249	0.262728	0.275966
Skewness	-1.508923	-1.524330	-1.632982
Kurtosis	5.273558	5.311172	5.985525
Jarque-Bera	918.4526	941.5726	1259.639
Probability	0.000000	0.000000	0.000000
Observations	1544	1544	1544

The summary statistics of the variables show some important results. Concerning the case of dependent and independent variables, the Jarque-Bera statistic shows that they are not normally distributed. According to Brooks (2008) the Jarque-Bera statistic gives an indication of the normality of the distribution of the returns of a variable. This statistic is based on the skewness and kurtosis of the distribution, which are known as third and fourth moments of a distribution respectively. Brooks (2008) argues that skewness measures the degree of asymmetry of a distribution about its mean. Kurtosis gives an indication of the fat tails of the distribution. The Jarque-Bera test has as a null hypothesis that the variable (or returns) are normally distributed with skewness and kurtosis being zero (Brooks, 2008). As it can be verified from the p-values of the Jarque-Bera test, the null hypothesis can be rejected. Therefore, it can be assumed that the dependent variables of the regression are not

normally distributed. However, this result should not be puzzling. According to Kozhan (2010) high frequency data typically show excess kurtosis, meaning that they have fatter tails. As a consequence, the normality hypothesis is rejected but still, any inference is valid asymptotically.

5.3 Final remarks about the models.

The theory of the Heterogeneous Agents Models shows that both fundamentalist and chartist investment strategies have a significant impact on the price changes of particular assets. Additionally, it is argued that fundamentalist strategies bring the prices back to an equilibrium level, implying that fundamentalists have a stabilizing effect on the prices. In the case at hand, it has been found that fundamentalists do not have a significant impact on the price changes. This result has to do either with the static nature of the model and/or with the investment horizon which is daily (i.e. two days ahead). However, it should be noted that in case of application of HAMs on daily data, chartist investment strategies seem to be more significant. Additionally, it has been found that chartists have contrarian investment expectations. This result shows that chartists believe that any price deviations above or below their “idiosyncratic”-chartists prices will be alleviated in short time horizons. This is a puzzling result since it shows that chartists have a stabilizing effect on the prices. Finally, it should be noted that the results should be interpreted with caution. Even in the presence of theoretical support, it could be said that the specification of both chartists and fundamentalist investment strategies are on ad-hoc basis. Different assumptions concerning the behavior of chartists and fundamentalists may lead to different results and conclusions.

CHAPTER 6 Forecasting

The forecasting part will illustrate how accurately the two versions of the HAMs are performing on short-term investment horizons. The forecasts that are going to be generated are one step ahead using the rolling window regression methodology. The window size is 400 observations for the symmetric models and 800 observations for the asymmetric ones. The algorithms and the programs are formulated according to the description of Kozhan (2010). The reason for this short term approach has to do mainly with the frequency of the data. Since the data frequency is daily, it is considered better to have forecasts based on daily horizons. Additionally, the assessment of the forecasting performance is going to take place. The Mean Squared Error (MSE) and the Mean Absolute Error (MAE) are used as tools for the measurement of the forecasting accuracy of the models. Last but not least, the hypothesis tests which were formulated at the beginning of the thesis, are going to take place. First, a comparison of the forecasting accuracy of the symmetric and asymmetric versions of the HAMs is going to take place. Second, a comparison of the forecasting accuracy of the main and alternative HAMs with that of the random walk model is going to be made. The hypothesis testing for the forecasting accuracy follows the framework of the Diebold-Marriano test.

6.1 Performance measures. The MAE and the MSE.

In order to evaluate accurately the performance of the out of sample forecasts of the crude oil prices, the measures that are going to be used are the Mean Absolute Error and the Mean Squared Error. According to Diebold (1998) both MAE and MSE are important measures for the forecasting accuracy of the models. However, it is shown that for models which are estimated using the ordinary least squares method the most important determinant is the MSE since it is related to two other statistic measures, namely the sum of squared residuals and the R-squared (Diebold, 1998).

The Mean Absolute Error is defined as: $MAE = \frac{1}{T} \sum_{t=1}^t |e_{t+h,t}|$ (15)

Where, $e_{t+h,t}$ is the error of the out of sample forecast of h at time point t .

In principle, the MEA sums the absolute value of forecasting errors and divides them by the number of periods used in the sample.

The Mean Squared Error is: $MSE = \frac{1}{T} \sum_{t=1}^t (e_{t+h,t}^2)$ (16)

Where, $e_{t+h,t}^2$ is the squared error of the forecast of h at time point t .

The rationale behind the MSE is that it takes the sum of the squared errors so that there are no negative error values. Then, again the measure is divided by the number of periods that we include in the

sample for the forecasts. The results of the out of the one step ahead forecasts for the symmetric and asymmetric HAMs are summarized in the next table.

Table 6.1 MAE and MSE of the main and alternative HAM.

Indicator	Brent	Dubai	WTI
MAIN MODEL			
Symmetric			
MAE	0.015523872	0.015408374	0.0183218
MSE	0.000456602	0.000430313	0.0006854
Asymmetric			
MAE	0.016161636	0.016112784	0.01951516
MSE	0.000508305	0.000491751	0.00081013
ALTERNATIVE MODEL			
Symmetric			
MAE	0.015428995	0.015350552	0.0181903
MSE	0.000453173	0.000428297	0.0006798
Asymmetric			
MAE	0.016123549	0.016085283	0.0194407
MSE	0.000507146	0.000489334	0.0008039

Two important facts can be observed from the above table. First, it can be seen that symmetric models usually have lower MAE and MSE compared to the asymmetric ones in both versions of the HAMs. That implies that in terms of forecasting accuracy -as measured by MAE and MSE- symmetric models seem to have better results. However, it cannot be concluded whether the symmetric versions of the models outperform the asymmetric ones. For this purpose a Diebold-Mariano test will be performed and presented in the next section. The second fact has to do with the comparison of the main and the alternative models. As it can be seen from the MAE and MSE the alternative model seems to have slightly better results. However, again, it cannot be concluded that the alternative model outperforms the main one. It can only be claimed that in terms of forecasting accuracy, the alternative model, with different specification for the fundamentalists, produces better forecasting results. Finally, before the Diebold-Mariano test it could be valuable to depict the forecast figures of the two models. The forecasts of the main and the alternative model are presented in the next figures.

Figure 6.1 Forecasts of the main model. Asymmetric versions

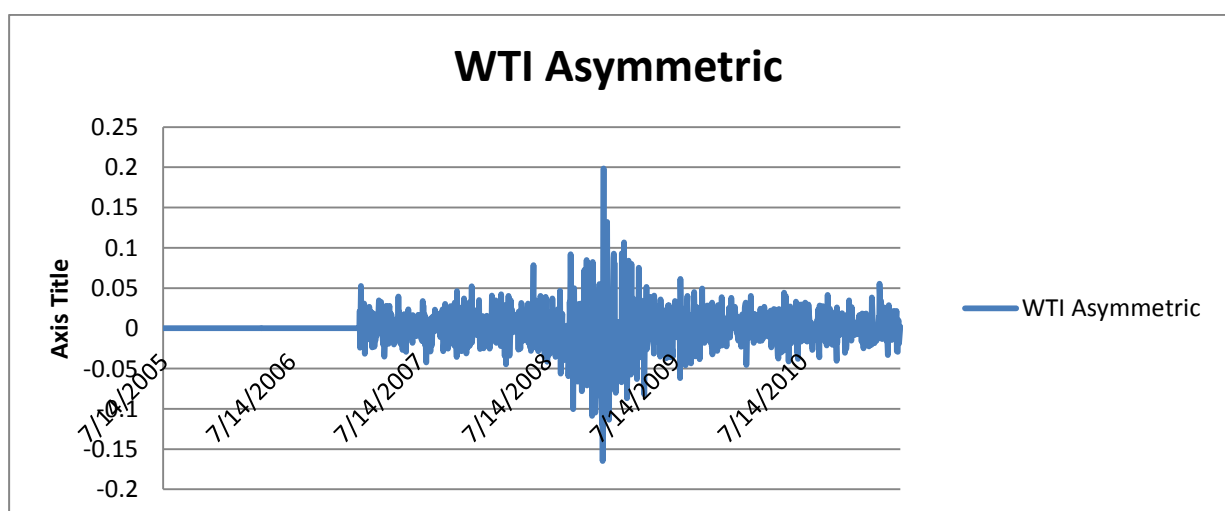
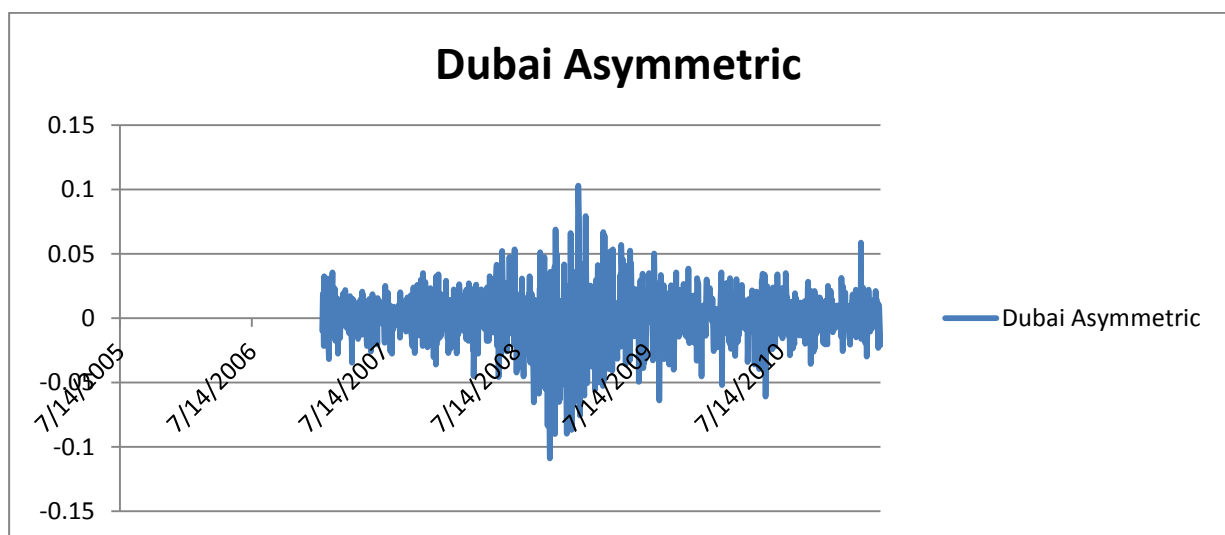
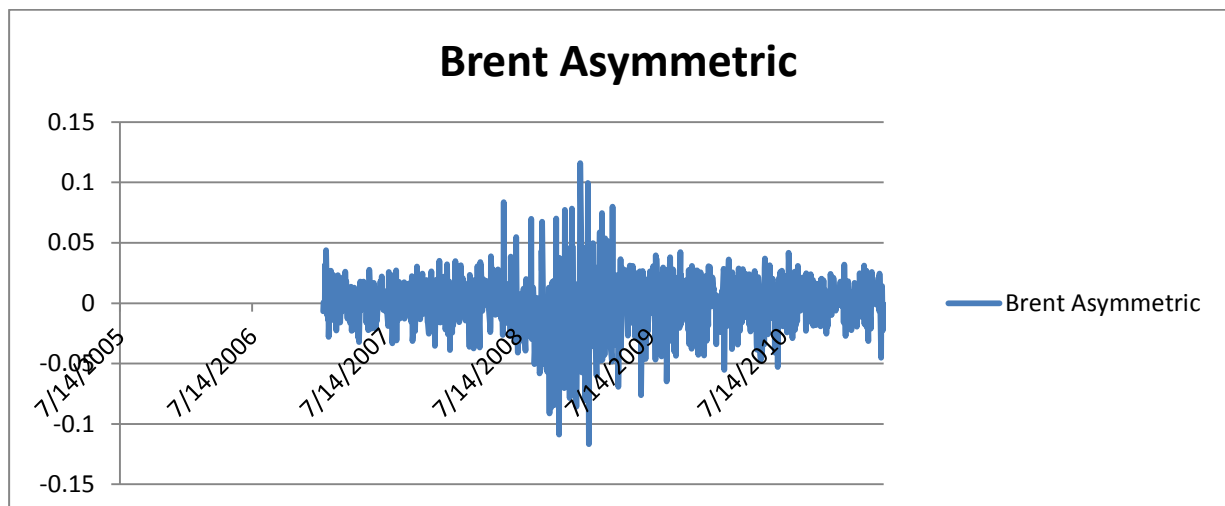


Figure 6.2 Forecasts of the main model. Symmetric versions.

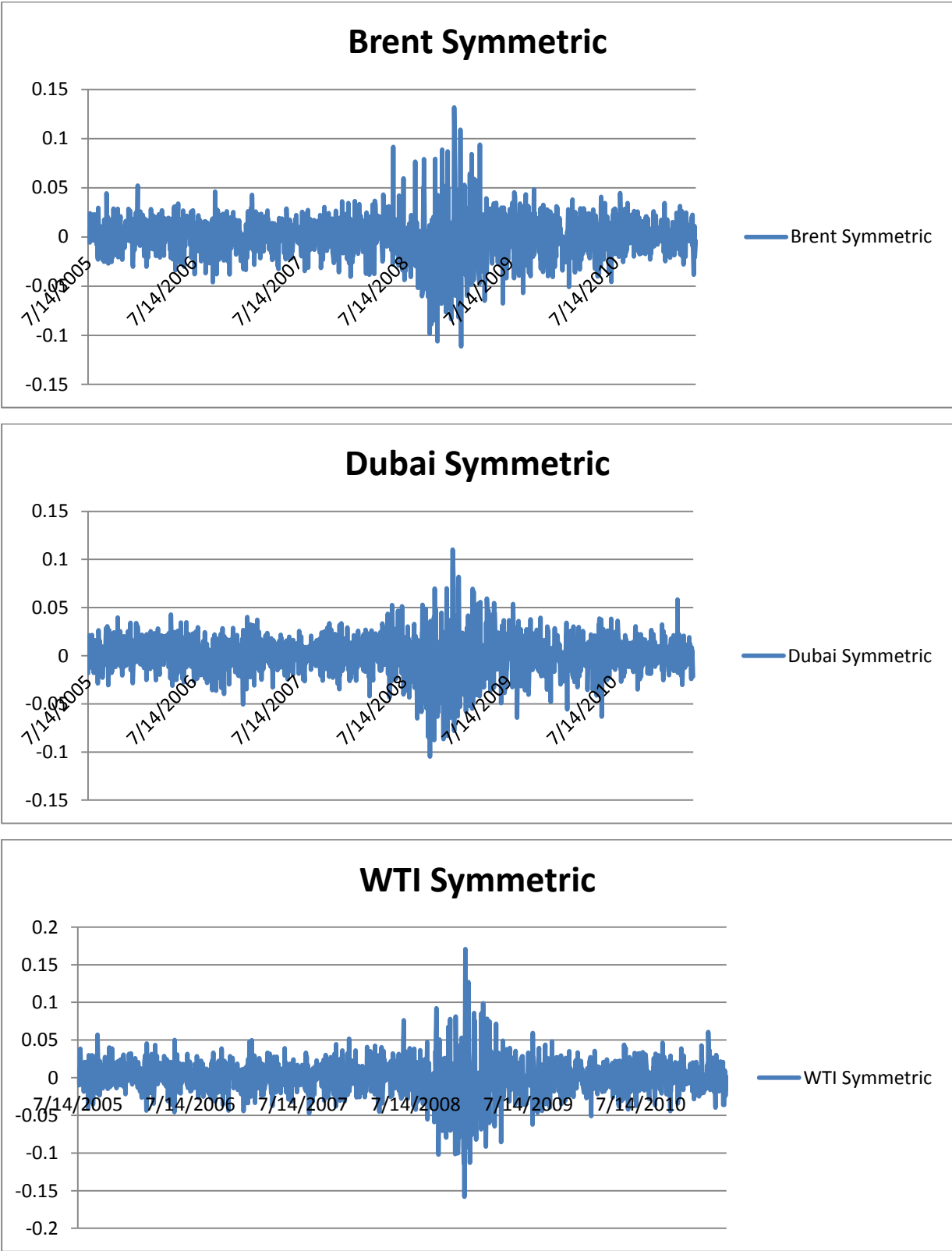


Figure 6.3 Forecasts of the alternative model. Asymmetric versions.

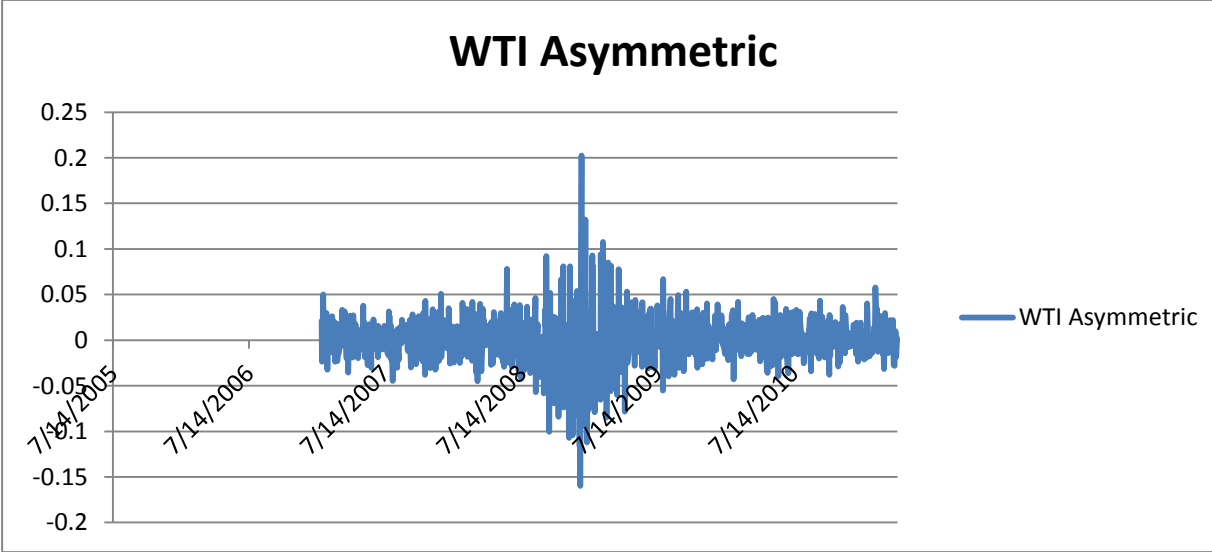
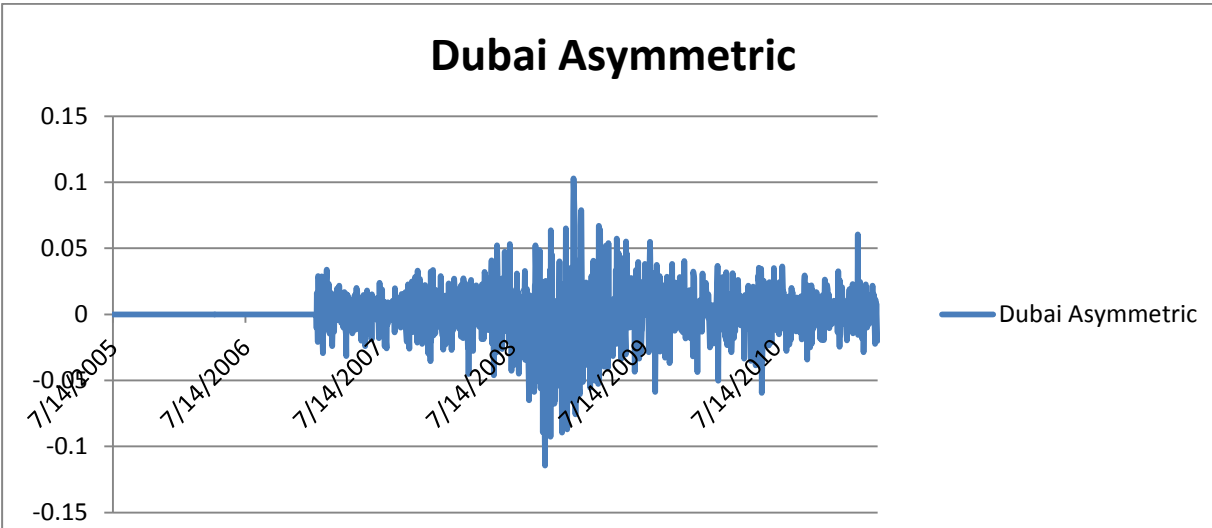
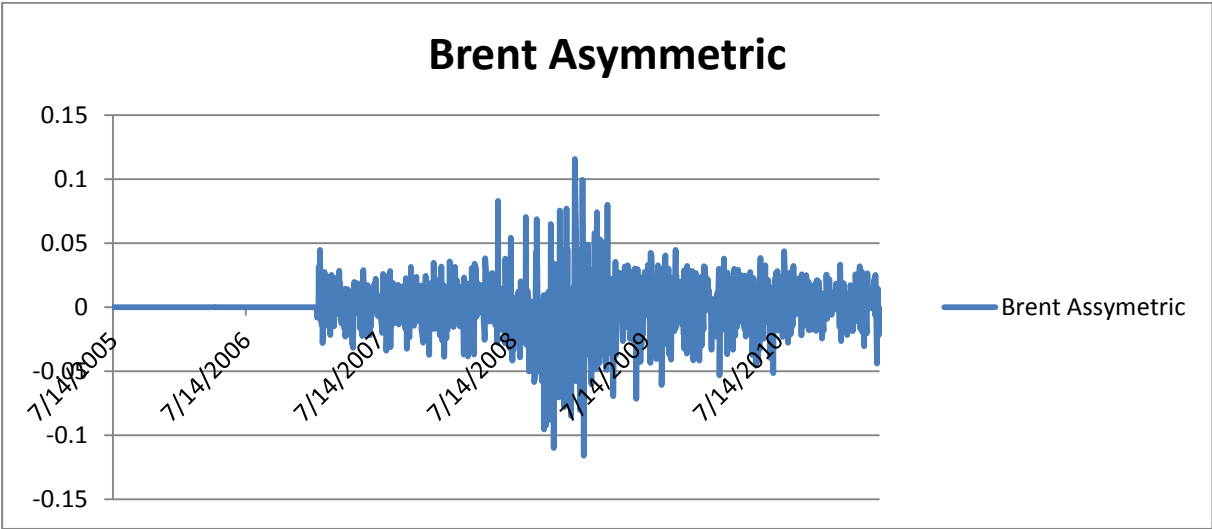
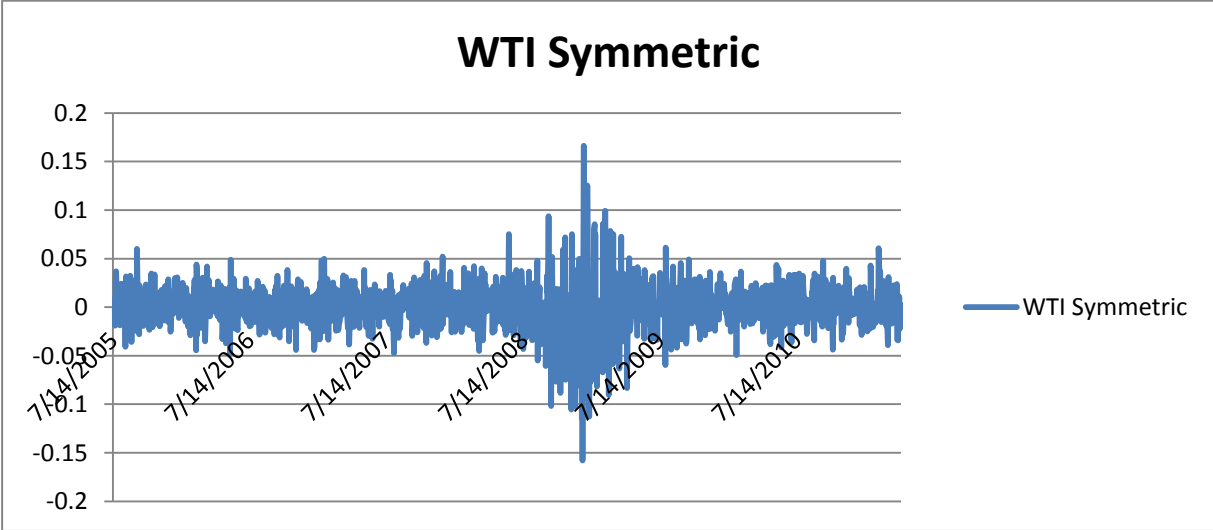
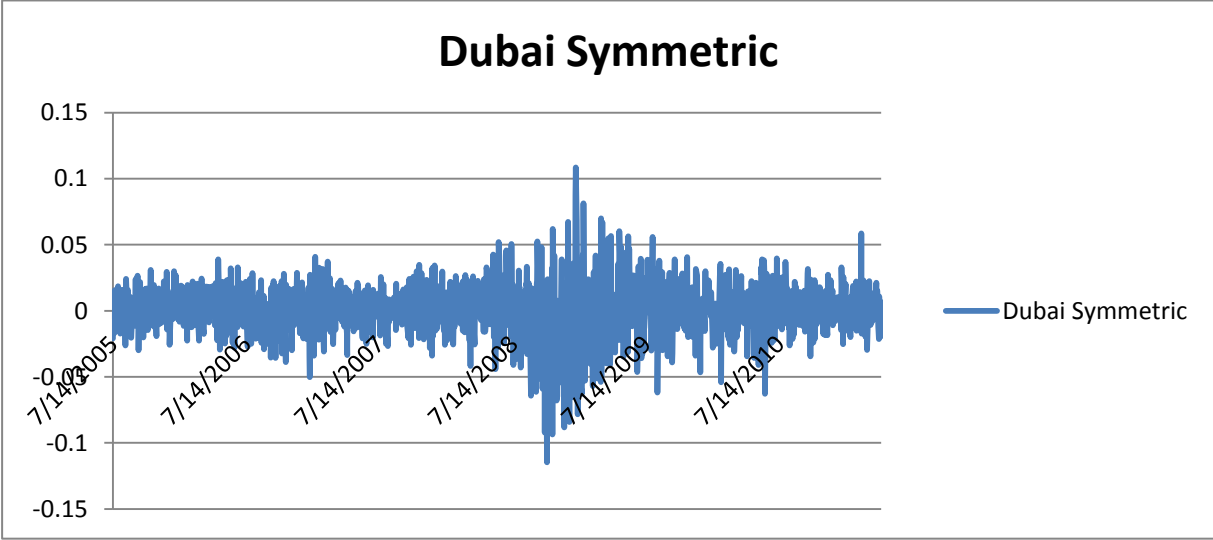
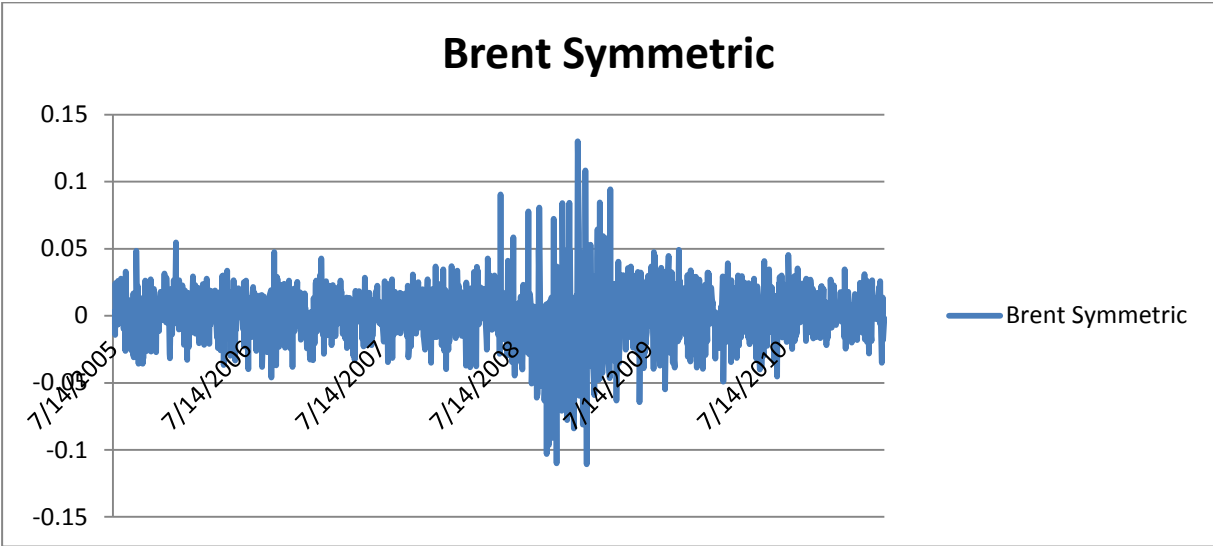


Figure 6.4 Forecasts of the alternative model. Symmetric versions.



6.2 Symmetric and asymmetric HAMs. The Diebold Mariano test.

The consideration up to now had to do with comparison between two different versions of HAMs based on standardized statistics. It has been shown that under certain circumstances, symmetric HAMs can produce better results for both the main and the alternative model. However, another important consideration is to test whether symmetric HAMs can outperform significantly the counterpart asymmetric models. For this purpose, the Diebold Mariano test is going to be used, where an explicit hypothesis test is going to be formulated.

According to Zivot (2006) the Diebold-Mariano test statistic can compare two models in terms of forecasting accuracy. The main advantage of this statistic is that it formulates an explicit hypothesis test. Under the null hypothesis both models forecast equally well. The alternative hypothesis states that one of the models performs better (depending on which one is used as a benchmark). To illustrate better the Diebold-Mariano test, it is vital to address the underlying statistical issues. Zivot (2006) argues that the Diebold-Mariano test depends on the loss differentials that each model generates in forecasting. Loss differentials are the differences between the squared forecasting errors of the two models. For the case at hand the squared loss differentials between the symmetric and asymmetric models are:

$$d_{squared,t} = (\hat{e}_t^{symm.})^2 - (\hat{e}_t^{asymm.})^2 \quad (17)$$

The associated Diebold-Mariano test is: $DM = \frac{\bar{d}}{SE(\bar{d})}$ where $SE(\bar{d})$ represents the standard error of the loss differentials.

Having the loss differentials of the forecasting errors of the models, the next step is to regress them against a constant and to apply the Newey-West for correction of potential heteroskedastic standard errors (Zivot, 2006). The relevant indicators that will be used are the Diebold-Mariano coefficients and the associated t-tests. A negative Diebold-Mariano coefficient shows that the symmetric models have better predictive accuracy compared to the asymmetric counterparts. A positive implies the contrary.

After establishing the Diebold Mariano test, the hypothesis test is going to be formulated. As it has been already mentioned, the intention is to test whether asymmetric HAMs outperform the symmetric counterparts. The intention of this hypothesis test is to investigate whether the distinction between symmetric and asymmetric HAMs adds value in terms of forecasting accuracy or whether this distinction is made mainly to illustrate some stylized facts of the Heterogeneous Agents Models. Therefore, the one sided hypothesis test is:

H_0 : Both symmetric and asymmetric versions of HAMs have the same forecasting accuracy on daily investment horizons.

H_a : Asymmetric versions of HAMs have better forecasting accuracy than the symmetric counterparts on daily investment horizons.

The following table summarizes the Diebold-Mariano coefficients and t-tests.

Table 6.2 Diebold-Mariano coefficients and t-tests. Symmetric versus asymmetric models.

Index	DM coefficients	t-tests
MAIN MODEL		
Brent	1.54E-05	0.202373
Dubai	-3.29E-06	-0.805249
WTI	-5.79E-06	6.61E-06
ALTERNATIVE MODEL		
Brent	3.29E-06	0.746612
Dubai	-2.12E-06	-0.475007
WTI	-2.76E-06	3.08E-06

All the coefficient values have p-values higher than 10 percent. Newey West correction for heteroskedasticity has been made.

The above table shows the values for the Diebold-Mariano test for one step ahead forecasts. The models compared are the symmetric and asymmetric versions of the two HAMs. The loss differentials were calculated as it is indicated by (17). For the one step ahead forecasts it should be noted that given the corresponding t-tests, we cannot reject the null hypothesis that both models have equal predictive accuracy. Therefore it could be argued that for the one step ahead forecasts, based on the Diebold-Mariano hypothesis testing, both symmetric and asymmetric models perform -on average- equally well. That implies that we cannot reject the initial null hypothesis of this thesis, which implies that both models predict equally well. Additionally, it can be claimed that the asymmetric specification of the static HAM model does not add any particular value in terms of forecasting accuracy. As it seems, the distinction between symmetric and asymmetric models has merely a descriptive nature.

6.3 HAM comparison with the random walk model.

The consideration up to now had to do with comparison between two different versions of HAMs based on standardized statistics and the Diebold Mariano test. It has been shown that under certain circumstances, both symmetric and asymmetric HAMs perform equally well. However, another important consideration is to test whether HAMs can outperform standard models like the random walk. According to Brooks (2008) the random walk model, takes the following specification:

$$P_t = y_1 P_{t-1} + e_t \quad , \text{ where } y_1 = 1. \quad (18)$$

In order to compare the random walk model with the HAMs, one step ahead forecasts will be created. Again, the rolling window method will be used where the window size is 400 observations. Additionally, in order to have a meaningful comparison with the HAMs, the difference between the forecasted prices will be taken. That implies that after obtaining the fitted values for P_t , the difference $P_{t+k} - P_t$ will be calculated where $k=2$. After the specification of the random walk and the associated forecasts, the second hypothesis test of this thesis is going to be formulated. It will be tested whether HAMs or random walk models have higher forecasting accuracy.

The hypothesis tests are as follows:

H_0 : Random walk models and HAMs have the same forecasting accuracy on daily investment horizons.

H_a : Either random walk models or HAMs have better forecasting on daily investment horizons.

The hypothesis tests are going to be tested using the Diebold-Mariano framework.

The corresponding loss differential of the random walk model is:

$$d_{squared,t} = (\hat{e}_t^{HAM})^2 - (\hat{e}_t^{RW})^2 \quad \text{and as a consequence} \quad DM = \frac{\bar{d}}{SE(\bar{d})} .$$

Negative values imply that the random walk model generates higher forecasting error and therefore the HAMs outperform the random walk model. Positive values imply that the random walk model outperforms the HAMs on short term investment horizons. The results of the Diebold-Mariano test are shown in the next table.

Table 6.3 Diebold-Mariano coefficients and t-tests. HAM versus Random walk models.

Index	DM coefficients	t-tests
MAIN MODEL		
Symmetric		
Brent	-0.000920	-0.672273
Dubai	-0.000601	-0.560588
WTI	-0.00155	-0.012643
Assymmetric		
Brent	-0.000935	-0.682286
Dubai	-0.000940	-0.698625
WTI	-0.000440	-0.281913

ALTERNATIVE MODEL		
Symmetric		
Brent	-0.000552	-0.502648
Dubai	-0.000603	-0.562788
WTI	-0.000160	-0.134057
Assymmetric		
Brent	-0.0000935	-0.131711
Dubai	-0.000942	-0.700793
WTI	-0.000446	-0.285940

All the coefficient values have p-values higher than 10 percent. Newey West correction for heteroskedasticity has been made.

The above results show that all the coefficients for the Diebold-Mariano test are negative and insignificant. That implies that for all the models at hand, we cannot reject the null hypothesis of the thesis that both random walk models and HAMs perform equally well on short horizons. Consequently, it could be stated that for forecasting purposes, both static HAMs and the random walk model have the same predictive power when dealing with short-term investment horizons. Additionally, as it can be seen, there is no particular difference in the case of the alternative model. In all the cases, it is shown that the random walk model and HAMs have the same predictive accuracy. Concerning the strong predictive accuracy of the random walk model, it could be said that it was also found in the research paper of Knetsch (2007). Knetsch (2007) tries to forecast oil prices based on convenience yields and he makes out of sample forecasts of the models. The research outcome shows that the marginal convenience yield model outperforms in terms of accuracy the predictive power of the random walk model. However, random walk models are typically found to have substantial predictive power.

6.4 Forecasting Conclusions

The forecasting part of this thesis shows that symmetric and asymmetric static HAMs have the same predictive power. The null hypothesis of equal predictive accuracy cannot be rejected. Additionally, a comparison of the HAMs with the random walk gives the same results. It is shown that both models have the same predictive accuracy when dealing with short-term horizons. However, one should be careful when deriving any particular conclusions. The proper specification of HAMs is dynamic, meaning that there are time-varying weights attached to fundamentalists and chartists. Apparently, this is not the case for this model. On top of that, it should be kept in mind that the data which are used are daily. Different data frequencies may lead to different results. Therefore, any conclusions with respect to the general forecasting ability of the HAMs should be avoided.

CHAPTER 7 Conclusion

7.1 Concluding Remarks

This thesis applied HAMs to crude oil price indices and forecasted oil price changes based on these models. The cornerstone idea behind HAMs is that asset markets are not perfect. People who are trading on asset markets can have certain behavioral biases which are not captured by traditional asset pricing models. These behavioral biases lead to phenomena which are called anomalies. Under the framework of this thesis, it is argued that the most prominent anomalies are the momentum and reversal. Accordingly, modern financial literature shows that these anomalies are the result of the interaction between two investor groups, the chartists and the fundamentalists. After the application of HAMs to crude oil prices, it is shown that chartists have higher impact on the market. A distinction between two models with different assumptions has been made. In the model where the fundamentalists have shorter horizon, it has been shown that their significance stays the same. Moreover, a distinction between symmetric and asymmetric HAMs has been made. It is shown that for daily investment horizons, this distinction may not be of particular value.

Finally, one step ahead forecasts were generated. In terms of forecasting errors, it is shown that symmetric models slightly outperform the symmetric counterparts in both the main and the alternative model. However, this outperformance seems to lack of significance since under the Diebold-Mariano hypothesis testing. It is shown that both symmetric and asymmetric models perform equally well. Finally, a comparison of the forecasting accuracy of HAMs with that of the random walk model has been made. It is shown that both symmetric and asymmetric versions of the model have equal predictive accuracy with that of the random walk model.

7.2 Research limitations and suggestions for the future.

After the conclusion of the research results, it is wise to have a look on the assumptions that were made and the limitations that may arise. It has been already indicated that HAMs try to reflect the behavior of two groups, fundamentalists and chartists. However, this behavior can be described in different ways. For this thesis, it has been assumed that chartists try to extrapolate past prices. For this purpose an AR(2) model has been used, which declares that chartists look on prices of the past two days and decide accordingly. This is of course just an assumption. In the reality, there are plenty of factors that can contribute to the decisions that trend extrapolators make. Macroeconomic factors can be the case. The same applies for fundamentalists. It has been assumed that the fundamental price of oil can be approximated by the moving average of the price of the past one and half years or the past nine months. This is a strong assumption but it has sound theoretical support. Oil prices tend to overshoot and then are brought back to equilibrium. This process takes almost two years and the half-

lives last approximately seven months. However, a much better proxy for the fundamental price could be a structural model that incorporates oil demand and supply considerations, production costs, economic growth rates, exchange rates changes, changes in the production quotas of OPEC and geopolitical factors that can have qualitative impact. Such a model would describe better the fundamental value of crude oil.

Concerning the model results, it can be said that they should be viewed much more from a descriptive point of view. That implies that one should expect to be given an idea about the crude oil market functioning rather than precise point estimates. It should also be noted that the adjusted R squared of the model estimates, in most of the cases is close to 50 percent. That implies that only fifty percent of the price movements of crude oil can be explained by the interaction between fundamentalists and chartists, given this model. Additionally, it is worth mentioning that the models which were developed are not dynamic. HAMs are usually inherently non-linear in nature and a dynamic specification is in need. The coefficients of HAMs usually change according to weights being given to chartists and fundamentalists. In turn, the weights depend on the relative forecasting errors generated by fundamentalist and chartist strategies. In short, chartists and fundamentalists are not “fixed” groups and change dynamically. This is the best approximation of how HAMs perform. However, it is also shown in the relevant literature that linear specifications of HAMs may also produce significant results. This is the case with this thesis.

Concerning the forecasting part, it should be noted that the Diebold-Mariano test statistic is based on the assumption of asymptotic normality. This fact may not be so representative of the nature of the data. Financial data, returns and price changes usually depict high kurtosis and skewness causing - usually- the violation of the normality assumption. Adding also the fact that the nature of the data which is used is daily, it can be said that the test statistics may have potential biases, even if corrections for heteroskedasticity and autocorrelation were made. Finally, it could be worth to recommend some potential research ideas concerning HAMs for the future. First, it could be said that it would be of added value if the fundamental price of HAMs is estimated using structural models,. Additionally, it could be interesting to compare the forecasting accuracy of HAMs with that of structural models of oil prices. This would show whether HAMs can outperform the sophisticated models used for economic forecasting. These are the recommendations which I think that can add value in the field of HAMs, forecasting and oil price research.

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Appendix A. Unit root tests

Chartists

1) Brent

ADF Test Statistic	-18.72544	1% Critical Value*	-3.4368
		5% Critical Value	-2.8635
		10% Critical Value	-2.5679

2) Dubai

ADF Test Statistic	-19.44493	1% Critical Value*	-3.4368
		5% Critical Value	-2.8635
		10% Critical Value	-2.5679

3) WTI

ADF Test Statistic	-19.26111	1% Critical Value*	-3.4368
		5% Critical Value	-2.8635
		10% Critical Value	-2.5679

Fundamentalists Main Model

1) Brent

ADF Test Statistic	-1.539657	1% Critical Value*	-3.4375
		5% Critical Value	-2.8639
		10% Critical Value	-2.5680

2) Dubai

ADF Test Statistic	-1.487981	1% Critical Value*	-3.4375
		5% Critical Value	-2.8639
		10% Critical Value	-2.5680

3) WTI

ADF Test Statistic	-1.770012	1% Critical Value*	-3.4375
		5% Critical Value	-2.8639
		10% Critical Value	-2.5680

Fundamentalists Alternative Model

1) Brent

ADF Test Statistic	-2.154722	1% Critical Value*	-3.4371
		5% Critical Value	-2.8637
		10% Critical Value	-2.5679

2) Dubai

ADF Test Statistic	-1.978933	1% Critical Value*	-3.4371
		5% Critical Value	-2.8637
		10% Critical Value	-2.5679

3) WTI

ADF Test Statistic	-2.338070	1% Critical Value*	-3.4371
		5% Critical Value	-2.8637
		10% Critical Value	-2.5679

Appendix B. Program codes for one step ahead forecasts

1) Asymmetric model HAM. Example case: HAM for WTI

Actual Model:

$$P_{t+k} - P_t = r_1 + \delta_2(P_t - F_t)^+ + \delta_3(P_t - F_t)^- + \theta_2(P_t - C_t)^+ + \theta_3(P_t - C_t)^- + e_t$$

Model specification in Eviews:

$$Y_WTI = C(1) + C(2)*(WTI_FUND_180*(WTI_FUND_180>0)) + \\ C(3)*(WTI_FUND_180*(WTI_FUND_180<0)) + C(4)*(WTI_CHART*(WTI_CHART>0)) + \\ C(5)*(WTI_CHART*(WTI_CHART<0))$$

Code for one step ahead forecasting in Eviews according to Kozhan (2010):

```
smpl @all
scalar n=@obs(y_wti)
scalar window=800
series f_wti180_a
equation wti_180a
for !i=0 to n-window-1
smpl @first+!i @first+!i+window-1
wti_180a.ls y_wti c wti_fund_180*(wti_fund_180>0) wti_fund_180*(wti_fund_180<0)
wti_chart*(wti_chart>0) wti_chart*(wti_chart<0)
smpl @first+!i+window @first+!i+window
f_wti180_a=@coefs(1)+@coefs(2)*wti_fund_180*(wti_fund_180>0)+@coefs(3)*wti_fund_1
80*(wti_fund_180<0)+@coefs(4)*wti_chart*(wti_chart>0)+@coefs(5)*wti_chart*(wti_chart
<0)
next
delete window n
```