Chapter 1. Introduction

1.1 Introduction

This dissertation studies implications from non-synchronous trading and non-trading effects in the Norwegian equity market. By intuition these non-trading effects may affect the daily return and volatility characteristics and induce considerable mean and variance changes into individual asset, portfolio and index series. Moreover, implied by mean-variance changes from non-synchronous trading and non-trading, relevant risk measures in capital asset pricing models and abnormal return calculations employing the market model in event studies may be strongly affected.

In contrast to much of the international literature, which has concentrated their analyses on highly liquid markets, this dissertation focuses on illiquid return series. As the available of data series is no longer limited to highly developed markets, investigations can now be conducted for less liquid markets, which constitute the majority of world equity markets. This dissertation therefore aims at applying and extending econometric techniques toward solving some issues of interest in financial model specifications for thinly traded markets. Investigations in these less liquid markets may bring new insight into pricing mechanism and dynamics in several ways. Firstly, in thin markets it is important to investigate conditional mean characteristics for asset series that exhibit non-synchronous trading and non-trading effects. It is well known that every equity market occasionally shows assets that do not trade for long periods of time, owing to i.e. news pending and important event announcements or simply due to large bid and ask spreads that halt trading over a time interval. Hence, we may observe closing prices that are registered at uneven and possibly irregular, intervals. Several important features may be studied in these markets, which is likely valid in more developed markets for individual assets. For example, non-synchronous trading and non-trading effects may alter mean characteristics relative to continuously traded assets. Campbell et al. (1997) show in their model that non-synchronous trading may reveal spurious serial correlation and cross-autocorrelation, due to periods of zero returns. Moreover, thin markets may alter volatility characteristics. For example, it is well known that the volatility is changing over time in the world’s financial markets. Scholes and Williams (1977) and

Lo and MacKinlay (1990) show that non-synchronous and non-trading results in overstated variances.

In seven essays the dissertation measures the effects from non-synchronous trading and non-trading in (1) univariate time series (three papers), (2) one-factor equilibrium models (the Capital Asset Pricing Model) (two papers) and (3) event studies employing the market model for abnormal return calculations (two papers). By applying asset, portfolio and index series containing divergent trading frequency in the Norwegian equity market, we may extract general properties in both mean (serial correlation) and volatility (changing) from observed non-synchronous trading and non-trading.

The three first papers study mean and volatility characteristics from individual, portfolio and index series. The first paper (Solibakke, 2000a) measures average mean and volatility for an asset sample showing continuous vs. one, two and three days of non-trading[1] in an open and closed Norwegian equity market. The starting point is Scholes and Williams (1977) and a price process characterised by a Brownian Motion (Bachelier, 1964). Note especially that the methodology only compares characteristics in individual assets showing a sufficient number of observations for both continuous and one to three days of non-trading. Consequently, the mean and variance calculations are grand averages over all assets in the Norwegian market.

The mean ratio results are not conclusive, driven by large variances relative to mean returns. In contrast, the variance results show higher significance. In an open market the variance seems to be the non-trading multiple plus one of the consecutive day volatility. The results strongly reject constant variance for observed non-trading days. However, in a closed market the results cannot reject constant volatility. A Poisson adjustment to variance calculation does not materially change the results. Consequently, the first paper suggests that the mean-variance equity market pricing processes are insensitive to trading frequency. However, the Brownian motion

[1] Non-trading returns means that we calculate settlement price returns observing one to three days of non-trading. For one non-trading day we calculate Monday to Wednesday, Tuesday to Thursday and Wednesday to Friday settlement price returns.

processes are dependent on an open market. When the market is closed the pricing processes seem to stop and the mean and variance is zero. This price information is important for over the counter (OTC) option traders. Volatility seems not affected by non-trading. Hence, the Black and Scholes formula (1972) can be applied irrespective of trading/non-trading. However, the daily volatility should either be measured within periods of continuous trading or by applying volatility calculations from actual returns that are adjusted by the number of non-trading days between observations.

The second paper in the dissertation studies existence of non-synchronous and non-trading and mean and volatility predictability in Norwegian portfolio and index series. We form four equal-weighted portfolio series each consists of 20 to 25 assets grouped by average trading volume in Norwegian Kroner (NOK). The index series contain an all assets value-weighted and an all assets equal-weighted index. As trading volume and market value are highly correlated series, the equal-weighted index by definition, will contain the highest influence of non-synchronous and non-trading. The investigation emphasizes the modelling approach and measures cross-serial correlation among the four equal-weighted asset series. Elaborate specification tests investigate model misspecifications and spurious parameter results.

The results from the investigation induce both mean and latent volatility predictability. The mean show a consistent negative serial correlation for series containing non-traded elements and shows positive serial correlation for continuously traded series. The strongly significant negative correlation in thinly traded series seems to persist after the crash in October 1987. Hence, the results indicate predictability in mean returns, rejecting the martingale hypothesise. Moreover, the latent volatility seems to show strongest serial correlation for thinly traded series. The index series follow the results from continuously traded series. Hence, the results indicate highest predictability in non-synchronous and non-traded asset series. However, the results must be modified by the fact that series exhibiting strong non-trading effects and therefore predictability, report model misspecification and spurious parameter results. Note especially that model misspecification is also found for the equal-weighted index. Hence, investors and portfolio managers should interpret the results with care. Moreover, for administrators and regulators at the stock exchange these results induce a need for policy regimes that enhance liquidity in equity markets. Consequently, advanced trading strategies and knowledgeable traders applying advanced econometric conditional models may therefore benefit from trades with uninformed and not that knowledgeable traders in thinly traded equity markets.

The third paper studies non-linear dependence in asset, portfolio and index series and extends results from the second paper. The paper investigates non-linearity misspecification and non-linear dependence in series exhibiting varying degree of non-synchronous- and non-trading. The results show consistent and significant non-linear dependence for asset, portfolio and index series containing series exhibiting non-synchronous- and non-trading. Hence non-trading seems to be the main contributor to formal mean and volatility model misspecifications in thin markets, while changing unconditional volatility causes data dependence for continuously traded series and liquid markets.

The next two papers of the dissertation focus on one-factor equilibrium models, that is, Capital Asset Pricing Models (CAPM). In particular, paper four and five investigate the influence from frequent non-trading in asset and index series, employing univariate and bivariate specifications, respectively. The fourth paper studies the one-factor model employing four series; two equal-weighted and two value-weighted indexes. As the relevant risk (beta) is one in these models, the variance represents relevant risk. The results show that the one-factor model cannot be rejected. However, the equal–weighted series report strong influence from non-trading effects showing misspecifications for daily return series. Hence, frequent non-trading seem to affect both mean and volatility processes as a so far not identified factor. The results for these series may therefore be spurious.

The fifth paper studies the one-factor model applying a bivariate specification, where asset and portfolio series are specified together with a proxy for the market portfolio, which is assumed to be the all-market value-weighted index. The specification focuses on the daily dynamics between asset and portfolio series in relation to the dynamics in the market portfolio proxy. The bivariate specification obtains the entire variance-covariance matrix, which means that we also identify the conditional beta and the relevant risk in the CAPM sense. The results show insignificant relevant risk effect (covariance / market variance), together with residual risk (variance) and one-dynamic factor effect (market variance). These results either suggest rejection of the conditional one-factor model or the daily model specification show misspecification. As only frequently non-traded assets report misspecification, the continuously traded assets together with the market portfolio, seems to reject the conditional CAPM. However, the conditional beta frequency distribution suggests a relevant risk consistently increasing by trading frequency/volume.

The last two papers in the dissertation investigate non-synchronous trading and non-trading effects during event and non-event periods. The sixth essay investigates event-induced volatility employing the market model specification. Hence, we hypothesise that changing trading volume and information flow may change volatility, which will disrupt the homoscedasticity assumption in classical event studies. As our results clearly indicate that the event periods show strongly higher volatility relative to non-event periods, the event-study models need to control for non-synchronous trading and volatility clustering in calculating abnormal returns. The paper therefore suggests an alternative specification for the classical market model and abnormal return calculations.

The last paper of the dissertation employ the suggest methodology from paper six and perform a new market model event study relative to a classical event study. Firstly, to obtain model advantages a simultaneous normal return model and abnormal return calculation must be performed. A separate estimation period will not adjust for the increased event period volatility. Secondly, the number of model misspecifications shows a significant reduction. Thirdly, the results suggest new findings from a merger and acquisition sample. For acquirers we find no significant abnormal return for any sub-period. Hence, for buyers around announcement date we find no abnormal returns to shareholders. However, for sellers we find high and maintaining abnormal return with low to no prior anticipation. Hence, the results form the efficient market hypothesis seem to hold for acquirers but selling firm shareholders obtain a significant abnormal return.

the conditional mean and volatility lag structures for return series for an equity market that exhibit thin trading relative to more liquid equity markets in i.e. New York (NYSE) and London (FTSE). The investigation brings evidence to bear on workings of thinly traded financial markets in general and these markets' return generating mechanism in particular. The main focus of the dissertation may therefore be summarized in two problem-domains in international finance; (1) non-synchronous trading and non-trading effects and (2) conditional heteroscedasticity and volatility clustering

The rich accessibility of financial data has stimulated tremendous growth and developments in econometric models and empirical studies in highly liquid capital markets for the past few decades. New models and complicated econometric techniques have been proposed and developed to deal with various kinds of empirical studies in finance. However, there are still many problems left unsolved due to the complicated nature of capital markets and market data. Moreover, much of the international literature has concentrated their analyses on highly liquid markets. This fact is partly due to the available of data series has been limited to highly developed markets as for example New York, London and Tokyo. Hence, many models and studies have solely been conducted for highly liquid assets and markets even though the majority of world equity markets show lower liquidity. In the last two decades these less developed and liquid markets have gained the same availability of long data series as the more developed markets.

This dissertation therefore aims at applying and extending econometric techniques toward solving some issues of interest in financial model specifications for thinly traded markets. Investigations in these less liquid markets may bring new insight into pricing mechanism and dynamics in several ways. Firstly, in thin markets it is important to investigate conditional mean characteristics for asset series that exhibit non-synchronous trading and non-trading effects. It is well known that every equity market occasionally shows assets that do not trade for a period of time, owing to i.e. news pending and important event announcements (i.e. mergers and acquisitions) or simply a large bid and ask spread that halt trading over a time interval. Hence, we may observe closing prices that are registered at uneven and possibly irregular, intervals. Several important features may be studied in these markets, which is likely valid in more developed markets for individual assets. For example, non-synchronous trading and non-trading effects may change conditional mean and volatility characteristics relative to continuously traded assets. Campbell et al. (1997) show in their model that non-synchronous trading may reveal spurious autocorrelation and cross-autocorrelation, due to periods of zero returns. Hence, serial correlation needs to be specified in return series.

Secondly, in thin markets it is important to investigate conditional volatility characteristics for asset series that exhibit volatility clustering. As non-synchronous trading, it is well known that volatility clustering is observable in the world's financial markets. Volatility clustering induces changing volatility over time and causes conditional heteroscedasticity to the return series. Note that ordinary least square regressions (OLS) assume conditional homoscedasticity, which may imply spurious parameter results. The two main ways to model changing volatility is Autoregressive Conditional Heteroscedastic (ARCH) (Engle, 1982) and stochastic volatility models (SV). In this dissertation ARCH models will be applied extensively. However, the author has presented papers applying Efficient Method of Moments estimation (Gallant, Rossi and Tauchen, 1992, 1996), which may be classified under the category stochastic volatility.

Thirdly, an important investigation in thin markets is the ability of lag specification models to produce residuals that report test statistics that induce correctly specified models. Moreover if rejected, what is the major feature of the market that induces the rejection result of the model specification.

The dissertation therefore performs thorough investigations for three areas of interest in international finance, which may be present in the thinly traded Norwegian equity market. The first category is univariate studies applying individual asset series, portfolio series and index series. The main hypotheses are non-synchronous trading and non-trading effects, volatility clustering and importantly ARMA-GARCH model misspecification. Any misspecification may show need for more elaborate models for univariate asset return dynamics. Moreover, the source of misspecification may be identified. The second category is factor models and the conditional Capital Asset Pricing Model (CAPM). The main hypotheses are non-synchronous trading and non-trading effects, volatility clustering, cross mean and volatility effects and ARMA-GARCH model misspecification of the CAPM propositions. The third and last category is classical event studies employing the market model. The main hypotheses are non-synchronous trading, volatility clustering and ARMA-GARCH model misspecification in classical event studies.

The first three essays investigate properties in univariate time series. The first essay performs a direct non-trading investigation for individual stocks and study continuous trading mean and volatility versus 1, 2 and 3 days of non-trading mean and volatility in both open and closed markets. The second essay studies conditional mean and volatility lag structures in linear ARMA-GARCH specifications to measure non-synchronous trading and non-trading in the conditional mean as well as conditional heteroscedasticity measures in the conditional volatility. The study employs trading volume as a proxy for non-synchronous trading and non-trading effects. Hence, the investigation may characterise trading frequency properties for both mean and volatility processes for continuous versus thinly traded assets. Moreover, elaborate specification tests is performed to measure wrongly specified lag structures and mean and volatility dynamics; that is, a wrongly specified model. The third essay investigates whether trading frequency causes non-linearity in asset pricing dynamics after applying ARMA-GARCH filters for the conditional mean and volatility processes. Intuitive, analytical and linear reasoning becomes very difficult if non-linearity and data dependence is found in any of these asset series, after controlling for non-synchronous trading and volatility clustering.

The next two essays investigate the interesting and important issue whether less liquid equity markets alters known facts and dynamics in factor models as for example the capital asset pricing model. For market equilibrium models, non-synchronous trading and volatility clustering may cause bias and spurious relationships in the moments and the co-moments of returns that make intuitive, analytical and linear reasoning difficult. Hence, this dissertation performs two different empirical studies of the one factor model (CAPM). The fourth essay in the dissertation performs a univariate investigation of the conditional CAPM. The investigation employs two value-weighted and two equal-weighted market indices in the relatively thinly traded Norwegian market. Applying equal-weighted and value-weighted indices may show effects from non-synchronous trading and conditional heteroscedasticity as non-trading may have stronger bearings in equal-weighted indices than in value-weighted indices.[2] The fifth essay performs a bivariate investigation of the one factor model (CAPM) in the Norwegian market. We employ return series and the value weighted market index to investigate non-synchronous trading and non-trading effects as well as conditional heteroscedasticity. For both essays risk measures and test statistics for model misspecification are important factors that will be discussed thoroughly.

Classical event studies in financial markets apply important assumptions about synchronous trading and unchanged volatility in event periods. An investigation that compares non-synchronous trading and non-trading effects and conditional heteroscedasticity in event and non-event periods is therefore of great interest. Note that any differences in event and non-event periods suggest OLS assumption

[2] Due to the fact that trading volume and market value has high positive correlation (Campbell et al, 1997).

rejections. Moreover, many authors have warned about failures in classical event studies. If an investigation rejects a hypothesis of synchronous trading and unchanged conditional volatility from non-event to event periods, our investigation suggest a need for a change in methodology for classical event studies. The sixth essay set out to show that trading frequency and volatility change mean and volatility characteristics from non-event to event periods and may have important effects on abnormal return calculations. Both investigations apply a sample of merges and acquisitions in the relatively thinly traded Norwegian market. Grouping assets for sellers, acquirers and both, we set out to show effects from non-synchronous trading and volatility clustering. If the changes seem significantly different, we may propose a new methodology for event studies in the future.

The seventh essay applies the new proposed methodology from the sixth essay (chapter VII) and perform a classical event study for mergers and acquisitions in Norway and compares results from the classical Ordinary Least Square (OLS) methodology and the new proposed ARMA-GARCH methodology, defined in the sixth essay. The investigation focus mainly of the differences between the methodologies as the OLS results is already published in Eckbo and Solibakke (1992). The new methodology applies BIC preferred ARMA-GARCH lag structured for all assets and therefore account for both non-synchronous trading and non-trading effects as well as conditional heteroscedasticity. We employ classical abnormal return and significance calculations.

We employ return series from the Norwegian Equity Market and perform the above-defined empirical research on the issues non-synchronous trading and non-trading effects, changing and asymmetric volatility and model misspecification of the asset series dynamics. Hence, we build elaborate econometric models for mean and volatility estimation in a market that contains assets that exhibit non-synchronous trading and non-trading effects, conditional heteroscedasticity and potential data-dependence and model misspecification. Our objective is to control for non-synchronous trading and non-trading effects, conditional heteroscedasticity and all data-dependence in thinly traded markets. As will be shown below in Section 1.2, the Norwegian market show characteristics that makes it a perfect choice for these empirical investigations.

The rest of the introduction is therefore organised as follows. For the Norwegian equity market Section 1.2 defines and proves thin relative trading as well as thin relative asset trading applying autocorrelation methodologies and results from Campbell et al. (1997). Section 1.3 describes the main interrelated topics and therefore the bearing of the dissertation. Section 1.4 describes the main hypothesis in the seven essays constituting this dissertation. Section 1.5 addresses the main target groups. Section 1.6 overviews the main findings from our investigations and finally Section 1.7 describes the layout and presentation of the essays that contribute the dissertation.

1.2 Thinly Traded markets and assets

This dissertation performs several empirical investigations on the Norwegian equity market, which in this dissertation is hypnotized to be a thinly traded market relative to more developed markets. Hence, the dissertation hypnotizes that the market exhibit non-synchronous trading and non-trading effects. Applying the definition employed in Campbell et al. (1997), these non-synchronous trading and non-trading effects arise when time series from asset prices are recorded for our database series at time intervals of one length when they in fact are recorded at time intervals of other, possibly irregular, lengths. For example, the daily closing prices of the Norwegian firm Farstad Shipping (Ålesund) are quoted on the Oslo Stock Exchange and reported daily in Dagens Næringsliv. Note that the closing price reported in Dagens Næringsliv is the price at which the last transaction in Farstad Shipping occurred on the previous day. In a thinly traded equity market the closing price will generally not occur at the same time each day. Hence, Farstad Shipping may on one particular Monday quote its last reported trade at $14^{\underline{05}}$, which will become the closing price reported in Dagens Næringsliv that particular Monday even though the Oslo Stock Exchange closes at $16^{\underline{00}}$. Moreover, the following day Tuesday, the last quoted trade was reported at $15^{\underline{15}}$. This example shows that referring to them as "daily" prices, we have implicitly and incorrectly assumed that they are equally spaced in 24-hour intervals. Hence, non-trading may induce potentially biases in the moments and co-moments of assets returns. In particular, in this dissertation we focus on coefficients for means, variances, co-variances, betas, autocorrelation and cross-autocorrelation in asset return series.

To show that the Norwegian market is a thinly traded market relative to more liquid markets in for example New York and London, we employ the autocorrelation results shown by Campbell et al (1997) and Lo and MacKinlay (1990). In their work, non-synchronous trading and non-trading effects is measured using daily, weekly and monthly stock returns. Non-symmetric co-variances suggest lead and lag structures over markets. Moreover, applying the same methodology, we will show that the Norwegian equity market exhibit characteristics that report a market containing both frequently as well as thinly traded assets. Both analyses are performed below

1.2.1 Relatively thinly traded markets.

The first investigation applies daily value weighted indices from USA (US), United Kingdom (UK) and Norway (N) for the time period from 1984 to 1998. Highest trading volume is found for the S&P500 (US) index, followed by FTSE350 (UK) and TOTX (N). We report the first-order autocorrelation matrices $\hat{\Gamma}_1$ for the vector of three indices using daily (Panel A), weekly (Panel B) and monthly (Panel C) data in Table 1. Table 1 shows clearly that these matrices are not symmetric. Hence the second column of Table 1 reports the autocorrelation matrices minus their transposes, and it is evident that elements below the diagonal dominate those above the diagonal. The result is valid for daily, weekly and monthly returns. Moreover, the results confirm the lead-lag pattern reported in the ARMA-GARCH investigation of Solibakke (1999). Our results therefore show that the relative thinness is greatest for Totx (N), followed by Ftse350 (UK) and finally S&P500. Hence, the Norwegian market is a relatively thinly traded market.

{Insert Table 1 about here}

1.2.2 Relatively thinly traded assets.

The second autocorrelation analysis employs fifteen randomly picked assets from the Norwegian equity market. In this section we aim to show that the trading volume span in the quoted assets at the Oslo Stock Exchange is large. Table 2 reports characteristics of some of these assets. The first asset (*F1*) is a continuously and frequently traded asset while asset six (*F6*) is characterized by a high non-trading probability[3]. Table 2 implies a strong divergence in trading frequency. For example asset F6 is only traded in approximately 30% of the listed days on the exchange, while asset F1 is continuously traded at the exchange. Average trading volume is a decreasing function of non-trading and the standard deviation seem to increase the higher the non-trading probability. We find no clear pattern in the mean return.

{Insert Table 2 about here}

Table 3 reports first order autocorrelation matrices Γ_1 for the vector of six individual assets using daily (panel A), weekly (panel B) and monthly (panel C) data series[4]. Also here from casual inspection it is apparent that these autocorrelation matrices are not symmetric. We repeat the exercise from the indices and report $\Gamma_1 - \Gamma'_1$ in the lower part of each panel for all three return intervals. From these matrices it is evident that elements below the diagonal dominates those above it. Hence, returns from frequently traded assets lead those of less liquid assets.

{Insert Table 3 about here}

In summary, the Norwegian stock market is a relative thinly traded market, which exhibits a high degree of span in trading volume among individual stocks. Note especially, that the Norwegian value weighted index is an all asset index, which implies that the index contains extremely thinly traded assets. The index may therefore exhibit non-synchronous trading and non-trading characteristics, which may follow characteristics from analyses of thinly traded assets. However, the fifteen largest companies in Norway weights approximately 60% of the value weighted index. As we know that the relative thinness of the market for any give stock is highly correlated with the stock's total market value (Cambell et al., 1997), the influence from thinly traded assets may show ignorable effects. This dissertation hypotheses that characteristics from non-synchronous trading or non-trading effects in individual assets follow through to the Norwegian indices.

[3] See Solibakke (1997) for an unconditional and conditional probability of trading (duration models) using Norwegian individual asset trading volume information.

The first to recognize the non-synchronous trading or non-trading effects was Fisher (1966). More recently, Atchison et al. (1987), Cohen et al. (1978, 1979), Cohen et al. (1983), Dimson (1979), Lo and MacKinlay (1988, 1990a, 1990b) and Scholes and Willians (1977) have developed explicit models of non-synchronous trading and non-trading effects. The dissertation will pay attention to non-synchronous trading and non-trading effects, which suggest (1) spurious autocorrelation and cross-autocorrelation in return series, (2) spurious co-variances and betas for multivariate series in empirical applications of the Capital Asset Pricing model (CAPM) and (3) abnormal return effects for multivariate series of the event studies discipline. Hence, we will do empirical research trying to show effects of these specification errors outside and inside market equilibrium models. Note that the specified asset pricing models may differ in specification, but they all have the common theme of modeling the behavior of asset returns that are mistakenly assumed measured at evenly spaced time intervals when in fact they are not.

[4] As far as possible we have tried to exclude days where trading is halted for “news pending” or other stock exchange regulations.

1.3 The dissertation's governing idea

The governing idea of this dissertation is model implications from thinly traded return series. By applying ARMA-GARCH specification for the return series the main focus is mean and volatility price processes and importantly, model misspecifications. Thin trading may influence two important return characteristics. The first is non-synchronous trading and non-trading effects in the conditional mean and the second is conditional heteroscedasticity and volatility clustering in the conditional volatility. The ARMA lag specification for the conditional mean should capture non-synchronous trading and the GARCH lag specification for the conditional volatility should capture volatility clustering. For an efficient lag specification in both mean and volatility, we apply the Bayes Information Criterion (BIC) (Schwarz, 1978). Consequently, the focus is BIC preferred ARMA-GARCH lag structures investigating trading frequency effects.

All essays in the dissertation, except the first, apply BIC preferred ARMA-GARCH lag specifications to specify market dynamics in univariate and bivariate model estimations. The first essay studies mean and volatility processes for continuous versus 1, 2 and 3 days of non-trading, which is an important contributor to mean and volatility modeling in the ARMA-GARCH specification mode. For all estimations and trading frequency series we employ elaborate specification test statistics to find any potential ARMA-GARCH model misspecifications. Any rejection of the ARMA-GARCH lag specification suggests a need for more elaborate ARMA-GARCH models or refined specifications of the mean and volatility process as suggested by Gallant et al. (1992) applying Efficient Method of Moments (EMM). Moreover, our results may induce the source of the misspecifications that may suggest ideas for elaborations and model changes to obtain a more correctly specified model across trading frequency series. We give a short overview of the essays' general ideas below.

The first essay studies non-synchronous trading and non-trading effects applying mean and variance ratio tests. We hypothesis mean and volatility based on a "Brownian Motion" return process specification of continuous trading versus 1, 2 and 3 days of non-trading. The results from this investigation may give insight into the modeling of the mean and volatility processes and therefore may enhance the ARMA-GARCH specifications. Moreover, applying this essay's findings, any potential ARMA-GARCH misspecifications in succeeding essays, may suggest reasons for model failure. The second and third essays apply univariate BIC preferred ARMA-GARCH lag specifications to investigate mean and volatility characteristics as well as misspecification in the ARMA-GARCH model residuals. Hence, we study whether the ARMA-GARCH model controls adequately for non-synchronous trading effects and volatility clustering across trading frequency series. Any misspecification results reject the ARMA-GARCH specifications for the observed mean and latent volatility processes. The first essays and the specification test statistics may suggest causes for model failures. Essay four and five apply the insights from the three first essays and investigate non-synchronous trading and volatility clustering in a one-factor market equilibrium model (CAPM) applying the ARMA-GARCH-in-Mean specifications. The results found in univariate series should also be found in bivariate series. Hence, we control for non-synchronous trading and volatility clustering and apply elaborate specification tests for model misspecification. Also for equilibrium models any misspecification results reject the ARMA-GARCH-in-Mean specifications for the mean and volatility processes. Essay one and the specification test statistics may suggest causes for model failures. Moreover, the investigation studies the ARMA-GARCH-in-Mean specifications relative to unconditional studies (i.e. OLS). Finally, in essay six and seven, non-synchronous trading and volatility clustering effects are investigated in classical event studies for a sample of mergers and acquisitions in the Norwegian market of corporate control. Essay six investigates whether volatility seem to change from non-event to event period firm samples. Adjusting for non-synchronous trading applying BIC preferred ARMA lag specifications and volatility clustering applying GARCH lag specifications we obtain conditional volatility series for event and non-event periods. Assuming no model misspecifications, any signs of changes in conditional volatility from non-event to event samples suggest a need for new methodologies in event studies. Essay seven applies a bivariate and BIC preferred ARMA-GARCH lag specification together with an OLS specification and perform a comparative event study employing the same mergers and acquisitions sample as applied in the previous essay. Note that we focus on a comparative study, as our intention is not to replicate the original OLS study (Eckbo and Solibakke, 1992).

In summary, the general idea of the dissertation is to investigate non-synchronous trading and non-trading effects as well as conditional heteroscedasticity and volatility clustering effects in thinly traded markets applying BIC preferred ARMA-GARCH lag specification models. To see if the model matches the observed return series, elaborate specification tests are employed to test for ARMA-GARCH model misspecifications. Any significant misspecification results suggest model failures and the employed specification tests together with the Brownian Motions results from the first essay may give suggestive causes for model failures. As characteristics from thin markets are found in the majority of the world's equity markets, the dissertation may have international interests and may influence the way of performing empirical analyses in the future for these markets.

1.4 Main hypotheses of the dissertation's essays

The dissertation consists of seven essays, which are all empirical work that employ data series from the Norwegian relatively thinly traded equity market (see section 1.2). The two main issues in this empirical dissertation are non-synchronous trading and non-trading effects and volatility clustering. All essays investigate these issues in the Norwegian market divided into three main sections. We control for these issues in (1) univariate series finding mean and volatility characteristics, (2) in bivariate series investigating factor models, and (3) in classical event studies (bivariate) investigating the market model's abnormal return and statistical significance calculations.

The first essay extends and investigates a model from Scholes and Williams (1977 applying Brownian Motions for hypothesis testing and interpretation. We hypothesise mean and volatility ratios for continuous returns versus *k* non-trading day(s) returns (k=1, 2, 3). The second and third essays apply univariate ARMA-GARCH lag specifications to specify non-synchronous trading and volatility clustering. The second essay specifies the BIC preferred ARMA and GARCH model structures and investigates specification test significance from frequently to thinly traded asset series as well as equal-weighted and value-weighted index series. The third essay includes individual asset series as well as portfolio and market index series and tests for data-dependence in these univariate series. Any significant dependence suggests rejection of the ARMA-GARCH model specification (misspecification). The fourth and fifth essays control for non-synchronous trading and volatility clustering in one-factor models (CAPM). The fourth essay tests the CAPM by applying univariate index excess return series, testing for in-Mean effects and a significant mean equation constant. A close to zero and insignificant constant parameter and a significant in-Mean parameter in the conditional mean, characterises the conditional CAPM. Significant shock and lagged volatility parameters induce GARCH and volatility clustering. The fifth essay applies individual asset and portfolio series together with the value-weighted index series to perform a bivariate ARMA-GARCH-in-Mean lag specification estimation. We control for non-synchronous trading and volatility clustering in both asset and index series and specify several alternative models for the risk measure in the conditional mean. The sixth and seventh essays control for non-synchronous trading and volatility clustering in classical event studies applying the market model. We focus on event-induced volatility and trading frequency changes. Hence, we specify a BIC preferred bivariate ARMA-GARCH lag specification for market model abnormal return calculations. As the sixth model specification reports strongly increased conditional volatility in event periods, the seventh essay performs a bivariate ARMA-GARCH versus OLS investigations of abnormal returns and statistical significance for a firm sample from the Norwegian market of corporate control. Below we give a short overview and specify the main hypotheses of our seven essays. Section 1.5 describes the main findings of the dissertation.

1.4.1 Essay no. 1 (Applied Financial Economics, 10 (3), pp. 299-310)[5]

The first essay (chapter 2), calculates mean and variance ratios employing the Scholes and Williams (1977) non-trading specifications. Based on an arithmetic Brownian motion specification for the return dynamics and an extended model specification that explicitly specifies the time between observed trades, we hypotheses mean and variance ratios for continuous versus one, two and three days of non-trading in open and closed markets. Moreover, to account for information surprises we extend the model variance with an assumption that trades arrive according to a Poisson distribution, which imply a simple waiting time function (λ) for the next trade to arrive. Accounting for this variance change we again hypotheses variance ratios.

The main hypothesis for the mean process becomes:

[5] See Solibakke (2000a)

$$\left.\begin{aligned} H_0 &: \quad E(R^{obs} \mid k_{O/C}) = (k_{O/C} + 1)\,\mu, && \text{for } k_O = 1, 2, 3, \text{ and } k_C = 1, 2, \\ H_A &: \quad E(R^{obs} \mid k_{O/C}) \neq (k_{O/C} + 1)\,\mu, && \text{for } k_O = 1, 2, 3, \text{ and } k_C = 1, 2. \end{aligned}\right\} \quad 1$$

where k_o is number of non-trading days in an open market and k_c is the number of non-trading days in a closed market. The null hypothesis cannot be rejected, which suggest that the mean is not affected due to non-synchronous trading and non-trading effects. Hence, the first result in Campbell et al. (1997) p. 129 seems to be valid for the Norwegian market. For the variance process the main hypothesis becomes:

$$\left.\begin{aligned} H_0 &: \quad \frac{\mathrm{Var}(R^{obs} \mid k_{O/C})}{\mathrm{Var}(R^{obs} \mid k = 0)} = k + 1, && \text{for } k_O = 1, 2, 3, \text{ and } k_C = 1, 2, \\ H_A &: \quad \frac{\mathrm{Var}(R^{obs} \mid k_{O/C})}{\mathrm{Var}(R^{obs} \mid k = 0)} \neq k + 1, && \text{for } k_O = 1, 2, 3, \text{ and } k_C = 1, 2. \end{aligned}\right\} \quad 2$$

where k_o is number of non-trading days in an open market and k_c is the number of non-trading days in a closed market. The null hypothesis cannot be rejected when the market is open but is rejected when the market is closed. Hence the volatility processes are not dependent on trading activity and frequency, rather on an open market.

Moreover, intuitively, applying the above open market result and assuming a Poisson distribution for the variance calculations, our results should not be affected by the trading frequency. Hypothesis no. 2 is repeated applying revised variance numbers for continuous versus one, two and three days of non-trading. The null hypothesis cannot be rejected. In fact, the adjustments to the variances do not materially affect variance ratios. Hence, the empirical results confirm our intuition. The result may have important implications for the modelling of mean and volatility processes in changing and stochastic volatility models.

1.4.2 Essay no. 2

The second essay employs model specifications from the international changing (and stochastic) volatility literature. Our objective is to adequately control for non-synchronous trading and volatility clustering across trading frequency series in the Norwegian market. We employ an ARMA-GARCH lag specification for the conditional mean and volatility processes. The conditional mean equation specify the lag structure in the mean and the conditional volatility equation specify the lag structure in the latent volatility. The mean and volatility lag structures are all BIC preferred (Schwarz, 1978). Hence, the ARMA-GARCH model should report trading frequency characteristics for the Norwegian thinly traded market. We employ elaborate specification tests to investigate whether the ARMA-GARCH lag specification adequately control for non-synchronous trading and non-trading effects in the conditional mean as well as conditional heteroscedasticity and volatility clustering in the conditional volatility. Any misspecification results reject the ARMA-GARCH lag specification for Norwegian series and therefore report a wrongly specified non-synchronous trading and volatility-clustering model.

We form four trading frequency portfolio series rebalanced each month based on average historic trading volume for the last two years. Average trading volume for the latest two years are chosen to avoid too rapid asset shifts in trading frequency portfolio series. Hence, the assets must over a reasonable long period show specific characteristics to justify a change in portfolio classification. Moreover, to investigate the non-synchronous trading and volatility clustering effects at the market level, we incorporate an equal-weighted and a value-weighted market index series. For the Norwegian thinly traded equity market, we expect non-synchronous trading to be more influential in the equal-weighted than in the value-weighted index. This intuition is due to high correlation between market value and trading volume (Campbell et al., 1997) and the fact that approximately 60% of the value-weight in the value-weighted index is contributed by the 20 largest and most frequently traded firms in the Norwegian equity market. Note also that these 20 firms constitute only about 20% of the total number of firms in the equity market.

The second essay introduces an adjustment procedure, which adjust all our time series for systematic calendar, scale and trend effects. Gallant et al. (1992) suggested the procedure for US data series. The results and implications from the adjustment procedures are not reported in any of the essay. Consequently, we report the result for thinly and continuously traded assets in this introduction.

{Insert Table 4 about here}

Table 4 shows that for continuously traded assets, only the two periodic definitions GAP3 and January 1st to January 07th show significant influence on the price process. The volatility series report significant patterns for day of the week and for the month of November. No other factors seem to influence the return and volatility series. For the thinly traded series, Wednesdays and January 8th to January 15th show significant influence on the price process. The volatility series report significant patterns for day of the week and for the month of July. Note, as will be more clearly illustrated later in this dissertation, that the continously traded assets show early January effects (1st to 7th), while thinly traded assets show mid-January effects (8th to 15th). Hence, the continously traded assets leads the thinly traded assets. We plot the raw and adjusted time series for thinly traded and continuously traded assets in Figure 1, panel A and B, respectively.

{Insert Figure 1 about here}

Due to significant parameters in the OLS model, the adjustments to both thinly and frequently traded assets make intuitive sense. However, for both thinly and continuously traded assets the raw and adjusted time series seem to show small differences over time. Even more important for our investigation it seems, as there is no regime shifts in the series.

The investigation that follows first account for non-synchronous trading and therefore ARMA effects in the mean and move on to account for volatility clustering and therefore GARCH effects in the conditional volatility. Hence, we study the lag structure in both mean and volatility. To specify the lag structure in the conditional mean and volatility we apply a BIC preferred ARMA-GARCH lag specification model. For the conditional mean the main hypotheses test for an autocorrelation structure, which induce significant ϕ (AR) or θ (MA) parameters:

$$\left.\begin{array}{lll} H_0: & \phi_i / \theta_i <> 0 & \text{for } i = 1, 2 \\ H_1: & \phi_i / \theta_i = 0 & \text{for } i = 1, 2 \end{array}\right\} \quad 1$$

where ϕ and θ are the autoregressive and the moving average coefficients of the ARMA lag specification of the conditional mean. Due to non-trading and zero returns, intuition suggests spurious negative autocorrelation for thinly traded assets (Campbell et al., 1997). The null hypotheses cannot be rejected for any of the series. The intuition for negative autocorrelation follows from the fact that during non-trading periods the observed return is zero or close to zero and during trading periods the observed return reverts back to its cumulated mean return, and this mean reversion yields negative serial correlation. Note that this zero return property of thinly traded assets may lead to spurious serial correlation and model residuals. Consequently, these serial and residual effects will affect any tests of predictability and data-dependence in asset returns.

Our results show that the Norwegian thinly traded series show significant negative autocorrelation while the frequently traded series show significant positive autocorrelation. Consequently, applying trading frequency for portfolio classifications we obtain a negative autocorrelation, which Campbell et al. (1997) show for individual assets, but expect a positive autocorrelation equal to their non-trading probability for portfolio series. Our results from the ARMA-GARCH lag specifications therefore contradict their model findings at the portfolio level. Hence, negative autocorrelation results for thinly traded series seem to be applicable at both individual[6] and portfolio level in thin markets.

Secondly, in the conditional mean process we test for cross-autocorrelation structure in portfolio returns by the following hypothesis

$$\left.\begin{array}{lll} \mathrm{H}_0: & \gamma_{i,j,1} <> 0 & \text{for j = 1, 2, 3 and 4 and i <> j} \\ \mathrm{H}_1: & \gamma_{i,j,1} <= 0 & \text{for j = 1, 2, 3 and 4 and i <> j} \end{array}\right\} \quad 2$$

[6] Thinly traded assets also show negative autocorrelation.

The null hypotheses cannot be rejected for any of the relative thinly traded portfolio series. It seems as the more frequently traded series leads the returns of the more thinly traded series. Consequently, the continuously traded series show no cross-autocorrelation.

Thirdly, we investigate the weight to the average long run volatility (unconditional volatility), the ARCH coefficient measuring effects form past squared shocks and the GARCH coefficient measuring past conditional volatility in the conditional volatility. The changing volatility and volatility clustering hypothesis becomes

$$\left.\begin{aligned} H_0&: \quad a_0, a_1, b_1 > 0 \\ H_1&: \quad a_0, a_1, b_1 = 0 \end{aligned}\right\} \qquad 3$$

The null hypotheses cannot be rejected for any of six series. Hence, conditional heteroscedasticity and volatility clustering cannot be rejected for any series. Moreover, across trading frequency series several interesting features from the volatility process are now available.

Finally, we employ several specification tests for ARMA-GARCH model misspecification. We apply the ARCH (Engle, 1982), RESET (Ramsey, 1969) and BDS (Brock et al. 1988, 1991 and Scheinkman, 1990) for the following hypotheses

$$\left.\begin{aligned} &H_0\text{: ARCH (6), RESET(12;6) and BDS } (m=1,..,8;\varepsilon=1) \text{ test statistic} < 2.0 \\ &H_1\text{: ARCH (6), RESET(12;6) and BDS } (m=1,..,8;\varepsilon=1) \text{ test statistic} > 2.0 \end{aligned}\right\} \qquad 4$$

The null hypotheses can be rejected for the most thinly traded and the equal-weighted index series. Hence, series showing heavy influences from non-traded asset series report serial correlation (ARCH) and general data dependence (BDS). However, series exhibiting a relative higher trading frequency cannot reject the hypothesis. Note that the thinly traded assets seem to influence the equal-weighted index to a degree that causes non-linearity at the index level. Moreover, as the result from the value-weighted index rejects the null hypothesis, the results suggest that the thinly traded assets show low market value and receive small weights in the value-weighted index.

Consequently, the ARMA-GARCH lag specification seems to represent the dynamic structure in the Norwegian thinly traded market well, but does not adequately account for the effects from non-synchronous trading and non-trading as well as volatility clustering in the most thinly traded series. Hence, trading frequency seems to be the major contributor to misspecification. Moreover, as the RESET test statistics do not report significant data-dependence in the conditional mean, it seems as it is the mean residuals and consequently the GARCH volatility modelling that induces the model misspecification (ARCH and BDS). The first essay in the dissertation suggests that the trading frequency and mean effects should not affect the volatility modelling. Hence, GARCH lag specification of thinly traded asset residuals may be generally a wrong model to apply.

In summary, this essay shows that ARMA-GARCH modelling in thinly traded markets may not account for all data dependence. For relatively frequently traded assets the ARMA-GARCH model controlling for non-synchronous trading, volatility clustering, asymmetric volatility and leptokurtosis in mean and volatility, seems to adequately model the time series. However, the essay reports the important result that thinly traded series seem to exhibit ARMA-GARCH misspecification. Hence, thinly traded series report spurious mean and volatility parameter results. Applying results from the first essay together with the ARMA-GARCH results in this essay induce that thinly traded series seems not applicable to especially GARCH volatility modelling.

1.4.3 Essay no. 3 (European Journal of Finance, forthcoming)

The data-dependence results from essay 2 may be further investigated by applying individual asset series as well as portfolio and index series. Hence, the third essay extends the ARMA-GARCH lag specification from essay no. 2 into individual asset series, trading frequency portfolio series, highly correlated with market value portfolio[7] series, and an equal-weighted and a value weighted index series. We focus especially on non-synchronous trading and non-trading effects, volatility clustering and potential ARMA-GARCH model misspecification. We assume that trading volume is a proxy for the degree of trading frequency. In particular, we assume that thinly traded assets show low to zero trading volume while continuously traded assets show high relative trading volume.

Employing seven individual asset, two portfolio and two index series (a total of eleven return series), we perform an investigation of model misspecifications from the ARMA-GARCH lag specification. We apply three elaborate test statistics, the ARCH (Engle, 1982), the RESET (Ramsey, 1969) and the BDS (Brock et al. 1988, 1991, and Scheinkman, 1990) test statistics for model misspecifications. Note that any data-dependence in model residuals implies spurious mean and volatility parameters and consequently ARMA-GARCH rejection in the Norwegian equity market.

For the BIC preferred (Schwarz, 1978) lag structure in the ARMA-GARCH model, identical to the lag structure in the second essay, we apply the ARCH (Engle, 1982), RESET (Ramsey, 1969) and BDS (Brock et al. 1988, 1991 and Scheinkman, 1990) and perform the following hypothesis

$$\left.\begin{array}{l} H_0\text{: ARCH (12), RESET(12;6) and BDS } (m=1,..,8;\varepsilon=1) \text{ test statistic} < 2.0 \\ \\ H_1\text{: ARCH (12), RESET(12;6) and BDS } (m=1,..,8;\varepsilon=1) \text{ test statistic} > 2.0 \end{array}\right\} \qquad 1$$

[7] The results from market value portfolios are close to the results from trading volume portfolios. Results from market value portfolios are readily available form the author upon request.

Intuition and the second essay induce ARMA-GARCH misspecification in the most thinly traded and the equal-weighted index series, both series heavy influenced by the observed zero returns. Firstly, our results show that both a linear and a non-linear ARMA lag specification are unable to remove all non-linear dependence applying the elaborate test statistics. All test statistics report significant specification test values. Consequently, modelling non-synchronous trading assuming conditional homoscedasticity seems not worth the effort. Moreover, a non-linear mean specification and departure from the Martingale hypothesis, is rejected.

Secondly, a (non-)linear ARMA-GARCH specification is rejected for series showing thin trading[8]. The BDS test statistics reject linearity in model residuals while the ARCH and the RESET test statistics report insignificant values. Hence, thinly traded series show ARMA-GARCH model misspecification due to general non-linear dependence. Moreover, we reject the independence hypothesis but we cannot reject the Martingale hypothesis. However, all series showing higher relative trading frequency fail to reject misspecification in model residuals. Thirdly, introduction of a non-linear ARMA-GARCH specification does not materially change our results. Hence, for continuously traded assets applying ARMA-GARCH filters, we can reject the independence hypothesis but not the Martingale hypothesis. Consequently, for thinly traded series more elaborate ARMA-GARCH models employing virtual returns and number of non-trading days may give new information to the non-linearity literature[9]. Moreover, the first essay suggests a stochastic volatility specification that is independent of the model mean[10]. The specifications are left to future research.

1.4.3 Essay no. 4 and 5

The fourth and fifth essay moves our investigation from univariate ARMA-GARCH lag filters, to factor models and non-synchronous trading non-trading effects and volatility clustering in bivariate ARMA-GARCH-in-Mean lag specifications. In particular, we investigate whether thin trading may influence empirical investigations of the Capital Asset Pricing Model (CAPM). Our objective is to investigate thin trading effects applying trading frequency series proposing market equilibrium models. Hence, the investigation focuses on biases in the moments and the co-moments of asset and index series.

1.4.4.1 Essay no. 4

The first essay (essay no. 4) applies two equal-weighted and two value-weighted index series from the thinly traded Norwegian market. Intuition and essay 2 and 3, implies higher influence from thin trading

[8] Solibakke (2000b) show that employing temporal aggregation and continuous time GARCH modelling remedy the non-synchronous trading and non-trading effects and report no mis-specifications in the thinly traded Norwegian equity market for individual non-trading stocks. However, this work is not part of my dissertation.
[9] Solibakke (2000b) show that the non-linearity disappears applying virtual returns and a continuous time GARCH model for estimation of lag structures.
[10] See Gallant et al., 1992, 1996 and efficient method of moments (EMM)

in equal-weighted indices than in value-weighted indices. As the investigation test the conditional CAPM and the series apply excess returns, the first main hypothesis in the essay becomes

$$\left.\begin{array}{lll} H_0: & \mu_i = 0 & \text{for i = Pindx, Nhhvw, Pequl and Nhhew} \\ H_1: & \mu_i \neq 0 & \text{for i = Pindx, Nhhvw, Pequl and Nhhew.} \end{array}\right\} \quad 1$$

where $\mu_i = 0$, is the conditional CAPM formulation. In the first specification we investigate four indices in the Norwegian market; two value-weighted and two equal-weighted indices. The main objective is to control for non-synchronous trading and non-trading as well as conditional heteroscedasticity and volatility clustering for CAPM formulation in ARMA-GARCH-in-Mean estimation. We find that the conditional CAPM formulation is rejected at 5% (not at 1%) for weekly returns for only the value-weighted indices. All other series cannot reject the conditional CAPM. Hence, the results weakly suggest that for weekly value-weighted index series, the drift is higher than the risk free interest rate.

The CAPM advocates that only the covariance with the market portfolio describes the relevant risk (β). Hence, the second main hypothesis is

$$\left.\begin{array}{lll} H_0: & \lambda_i \neq 0 & \text{for i = Pindx, Nhhvw, Pequl and Nhhew} \\ H_1: & \lambda_i = 0 & \text{for i = Pindx, Nhhvw, Pequl and Nhhew.} \end{array}\right\} \quad 2$$

where $\lambda_i \neq 0$ is the conditional CAPM formulation. However, only in restricted and daily series estimations our results suggest positive relevant risk compensation. Hence, only in very short time intervals investors are compensated for relevant risk. From the CAPM specification the time interval should have no effect on our results. Hence, the result from the first hypothesis (1) must be modified by the insignificant result from the second hypothesis (2). The result therefore does not show a consistent validity of the conditional CAPM specification.

We also test the GARCH-in-Mean specification versus an unconditional specification. Hence, the third main hypothesis becomes

$$\left.\begin{array}{lll} H_0: & \lambda_i, a_1, b_1 = 0 & \text{for i = Pindx, Nhhvw, Pequl and Nhhew} \\ H_1: & \lambda_i, a_1, b_1 \neq 0 & \text{for i = Pindx, Nhhvw, Pequl and Nhhew.} \end{array}\right\} \quad 3$$

and apply an likelihood ratio test (LRT) to test for significance. The conditional specification is strongly preferred for daily and weekly series while monthly series show insignificant test values. Hence, the GARCH-in-Mean specification is only recommended for shorter timer intervals. Monthly series show no volatility clustering and a conditional homoscedastic model may be applied.

To test for model misspecification we apply elaborate specification test statistics. Hence, we apply the ARCH (Engle, 1982), RESET (Ramsey, 1969) and BDS (Brock et al. 1988, 1991 and Scheinkman, 1990) test statistics and perform the following and fourth main hypothesis tests

$$\left.\begin{array}{l} H_0\text{: ARCH (12), RESET(12;6) and BDS (m=1,..,8;}\varepsilon\text{=1) test statistic} < 2.0 \\ \\ H_1\text{: ARCH (12), RESET(12;6) and BDS (m=1,..,8;}\varepsilon\text{=1) test statistic} > 2.0 \end{array}\right\} \quad 4$$

Neither ARCH nor RESET report any significance. However, we find that the BDS test statistics is significant for the two equal-weighted daily indices, which suggest data dependence and consequently ARMA-GARCH model misspecification, while weekly and monthly series report insignificance. For the value-weighted index series all time intervals report insignificant test statistics. The result suggests that non-trading may have a too severe effect on the daily equal-weighted return series. Hence, also here as for essay 2 and 3, we find a need for more elaborate and new non-trading specifications in thinly traded markets.

1.4.4.2 Essay no. 5

By applying a vector ARMA-GARCH-in-Mean specification we are able to specify a bivariate asset and value-weighted index series specification. This may be considered as a bivariate test of the conditional capital asset pricing model (CAPM). We employ daily return series for seven individual asset, two portfolio and one value-weighted all-market index series. The conditional mean model specification becomes

$$R_{i,t} = \mu_{i,0} + \sum_{j=1}^{p_i} R_{i,t-j} + \lambda_i \cdot Cov(R_{i,t}, R_{M,t} \mid \Omega_{t-1}) + u_{i,t}$$

$$u_{i,t} = \varepsilon_{i,t} - \sum_{j=1}^{q_i} \theta_{i,j} \cdot \varepsilon_{i,t-j}$$

$$R_{M,t} = \mu_{M,0} + \sum_{j=1}^{p_M} R_{M,t-j} + \lambda_M \cdot Var(R_{M,t} \mid \Omega_{t-1}) + u_{M,t}$$

$$u_{M,t} = \varepsilon_{M,t} - \sum_{j=1}^{q_M} \theta_{M,j} \cdot \varepsilon_{M,t-j}$$

where $\lambda_{i,t-1} = \dfrac{E_t(r_M|\Omega_{t-1})}{Var_t(r_M|\Omega_{t-1})}$. $\mu_{i,0}$ and $\mu_{M,0}$ are the drift terms for the asset and market, respectively.

To determine the lag lengths in the conditional mean equation p_i, q_i and p_M, q_M, we apply the BIC criterion (Schwarz, 1978) on all return series. Note that the employed return series (R) is adjusted return series and not excess return series. Therefore, we must interpret the constant term in the conditional mean as the “zero-beta” returns.

The conditional volatility becomes

$$h_{s,t} = m_{s,0} + \sum_{i=1}^{m_s} (a_{s,i} + \gamma_{s,i,t}) \cdot u_{s,t-i}^2 + \sum_{j=1}^{n_s} b_{s,i} \cdot h_{s,t-j} \qquad s = i, M$$

where the a are the vectors of the weights for the lagged u^2 terms; this is the ARCH process. The b are the weights for the lagged h terms; this is the GARCH process. The m is a constant term for unexplained conditional variance and $\gamma_{s,i,t} = \varepsilon_{t-i}$ if and only if $\varepsilon_{t-i} < 0$. Again, the lag lengths m_s and n_s are determined by applying the BIC (Schwarz, 1978) on the squared standardised residuals from the BIC preferred ARMA conditional mean specification.

Based on these bivariate specifications we are able to perform our main hypothesis test. The first main hypothesis is the GARCH cross-autocorrelation specification:

$$\left.\begin{aligned} H_0&: \quad a_{j,i},\ b_{j,i} = 0 \qquad \text{for j = index and i = 1, 2,....,9} \\ H_1&: \quad a_{j,i},\ b_{j,i} <> 0 \qquad \text{for j = index and i = 1, 2,....,9} \end{aligned}\right\} \qquad 1$$

The hypothesis is strongly rejected and induces that the conditional market volatility is a major force in driving the conditional variance of individual asset series. The second main hypothesis is a test of the in-Mean specification:

$$\left.\begin{aligned} H_0&: \quad \lambda_j,\ \lambda_i,\ \lambda_{j,i} = 0 \qquad \text{for j = index and i = 1, 2,....,9} \\ H_1&: \quad \lambda_j,\ \lambda_i,\ \lambda_{j,i} <> 0 \qquad \text{for j = index and i = 1, 2,....,9} \end{aligned}\right\} \qquad 2$$

The hypothesis cannot be rejected. Hence, the in-Mean specification seems redundant and the conditional CAPM specification is disputed in our ARMA-GARCH-in-Mean model specification. Finally, we apply the ARCH (Engle, 1982), RESET (Ramsey, 1969) and BDS (Brock et al. 1988, 1991 and Scheinkman, 1990) and perform specification tests for model misspecification for the third main hypothesis:

$$\left.\begin{aligned} H_0&: \text{ARCH (12), RESET(12;6) and BDS } (m=1,..,8;\varepsilon=1) \text{ test statistic} < 2.0 \\ H_1&: \text{ARCH (12), RESET(12;6) and BDS } (m=1,..,8;\varepsilon=1) \text{ test statistic} > 2.0 \end{aligned}\right\} \qquad 3$$

We find that only the thinly traded series exhibit ARMA-GARCH model misspecification. Frequently traded assets report insignificant specification test statistics. Hence, also for the bivariate equilibrium models as for univariate models, the specification tests suggest a need for more elaborate non-trading specification in ARMA-GARCH models or an alternative specification.

Finally, as we have estimated the full covariance matrix, the conditional beta series are readily available. We find that the conditional betas cumulative distribution functions unambiguously sort the conditional betas in ascending order of trading frequency. Hence, the conditional beta cumulative distribution is farther to the right the higher the trading frequency in the series. However, as suggested by the specification tests, spurious autocorrelation and cross-autocorrelation may be found for the most thinly traded assets series leading to spurious co-moments and consequently betas.

1.4.5 Essay no. 6 and 7

The sixth and seventh essay investigates event-induced volatility and abnormal return and statistical significance calculations in classical event studies, where we want to control for non-synchronous trading and non-trading effects as well as conditional heteroscedasticity and volatility clustering. As events may increase residual risk and events seem to change trading frequency of assets, the investigation seems worth doing.

1.4.5.1 Essay no. 6

The first essay investigates whether the conditional volatility increases around an event-date by applying ARMA-GARCH methodology based on event and non-event firm samples. The potential change in non-synchronous trading and volatility clustering may stem from increased trading frequency around the events announcement dates. Moreover, a lower probability of non-trading may actually produce a reduction in non-synchronous trading and changing volatility. However, higher information flow may increase the Bid-Ask spread and reduce trading frequency, which induce higher non-synchronous trading. We investigate the conditional mean and volatility of a sample of mergers and acquisitions firms in event and non-event periods. Suggestions of change in non-synchronous trading and volatility suggest a need to apply new methodologies in event studies. As our results suggest considerable change in non-synchronous trading and volatility we propose a Multivariate Vector ARMA-GARCH-in-Mean model to account for non-synchronous trading and conditional heteroscedasticity around event announcements. The main hypothesis for the investigation is a Likelihood Rato Test (LRT) for restricting the ARMA-GARCH parameters from the non-event interval relative to the event interval. We hypothesise that the restricted model with parameters from the non-event period is significantly different from unrestricted model in the event period. Hence, we test

$$2^* [\text{Maximum Likelihood (restricted)/Maximum Likelihood (unrestricted)}] = \chi^2 \ (df)$$

where the (df) is the degrees of freedom and determined by the number of parameter restrictions. We denote the parameter space $\delta_{i,j}$ and the restrictions $c_{i,j}(\delta)$. The restrictions are evaluated at the unrestricted parameter values. Hence, the first main hypothesis is

$$\left.\begin{array}{lll} H_0: \ \delta_{i,j} = c_{i,j}(\delta) & \text{for i = Sellers, Acquirers and periods j=1, 2, 3} \\ H_1: \ \delta_{i,j} <> c_{i,j}(\delta) & \text{for i = Sellers, Acquirers and periods j=1, 2, 3} \end{array}\right\} \quad 1$$

where periods are event periods. We find that for all firm categories, event periods and univariate or bivariate estimations, the null hypothesis of true restrictions is strongly rejected. Hence, the conditional volatility seems to have changed from non-event to event periods. In fact, all volatility estimations suggest higher weight to long-run average volatility, higher shock effects and lower serial correlation and reduced non-synchronous trading effects. Moreover, as for other ARMA-GARCH lag specifications we apply the ARCH (Engle, 1982), RESET (Ramsey, 1969) and BDS (Brock et al. 1988, 1991 and Scheinkman, 1990) test statistics and perform specification tests for model misspecification, which is the second main hypothesis

H_0: ARCH (12), RESET(12;6) and BDS (m=1,..,8;ε=1) test statistic < 2.0

H_1: ARCH (12), RESET(12;6) and BDS (m=1,..,8;ε=1) test statistic > 2.0 } 2

For all event, non-event periods, sellers, acquirers and both series and univariate and bivariate estimations, we cannot reject the null hypothesis.

Hence, the two main hypotheses suggest a need for a new event study methodology. We propose both a univariate and a bivariate ARMA-GARCH lag specification for classical event studies applying the market model and we advocate the use of unadjusted test statistics for abnormal return significance calculations. We apply this methodology in the final essay of the dissertation.

1.4.5.2 Essay no. 7

The seventh essay performs a classical event study applying the market model from a merger and acquisition firm sample in the Norwegian thinly traded market. We apply ARMA-GARCH and the OLS methodologies to perform a simultaneous time dummy-variable event study. The results are compared without statistical significance adjustments. The ARMA-GARCH methodology to control for increased trading frequency causing changes in autocorrelation and changing volatility causing changes in ARCH/GARCH parameter values. Applying a bivariate estimation make it possible to simultaneously apply individual asset and market index series controlling for any cross-autocorrelation in the conditional mean and cross weight, shock and autocorrelation in the conditional volatility. We apply the classical OLS methodologies.

The first main hypothesis becomes (AR=Abnormal Returns)

H_0:	$AR_{i,j}$ (ARMA-GARCH/OLS) =	0	for i = Sellers, Acquirers and Both and event periods j=1, 2, 3
H_1:	$AR_{i,j}$ (ARMA-GARCH/OLS) <>	0	for i = Sellers, Acquirers and Both and event periods j=1, 2, 3

The investigation reports these three main findings. Firstly, the bivariate ARMA-GARCH specification in contrast to OLS, reports no significant prior announcement effects (no insiders). The result applies to both selling and acquiring firms. Secondly, in contrast to OLS the bivariate ARMA-GARCH specification reports sustained higher post announcement abnormal returns and significances for selling firms. Thirdly, the bivariate ARMA-GARCH specification, in contrast to OLS, reports no overall significant abnormal returns for acquiring firms.

Moreover, we employ specification tests to report model misspecifications. We apply the ARCH (Engle, 1982), RESET (Ramsey, 1969) and BDS (Brock et al. 1988, 1991 and Scheinkman, 1990) test statistics. As we perform tests for each individual merger and acqusition we perform a model misspecification test based on proportional results. Hence the second main hypothesis becomes

H_0: $(Q, ARCH, RESET, BDS)_{i,j}(OLS) < (Q, ARCH, RESET, BDS)_{i,j}$ (ARMA-GARCH)
for i = Sellers, Acquirers and Both
and event periods j=1, 2, 3

H_1: $(Q, ARCH, RESET, BDS)_{i,j}(OLS) > (Q, ARCH, RESET, BDS)_{i,j}$ (ARMA-GARCH)
for i = Sellers, Acquirers and Both
and event periods j=1, 2, 3

By measuring the proportion of misspecifications for ARMA-GARCH and OLS, respectively, we apply a Z-test statistic for significant differences. The null hypothesis is strongly rejected, which induce that the ARMA-GARCH specification is preferred relative to the OLS specification.

Consequently, the first hypothesis suggests changes in inference from OLS to ARMA-GARCH model specifications and the second hypothesis suggest higher confidence in ARMA-GARCH model specifications relative to OLS. Overall, the ARMA-GARCH specification should therefore be the preferred model specification in event studies in especially thinly traded markets.

1.5 Main Findings from the thinly traded Norwegian Market

All seven essays contains the same keywords, namely non-synchronous trading and non-trading effects and conditional heteroscedasticity and volatility clustering. Hence, in this dissertation we have performed several univariate and bivariate model estimations controlling for non-synchronous trading and conditional heteroscedasticity. We find that the ARMA-GARCH model specification seem to adequately describe market dynamics with the exception of thinly traded series exhibiting long periods of non-trading and observed zero returns. The classical ARMA-GARCH lag specification seems to misrepresent the zero returns and the non-trading effects. Hence, to account for severe non-trading more elaborate model specifications seem to be needed in our toolbox. Consequently, Solibakke (2000b) develops and estimates a model with virtual returns and number of non-trading days within a continuous ARMA-GARCH lag specification. Moreover, Solibakke (2000c) show a stochastic volatility application applying Efficient Method of Moments (Gallant et al., 1992, 1996). Below we represent the main findings from our non-synchronous trading and volatility clustering investigation in thinly traded markets.

The first essay reports small non-trading effects in both mean and volatility. However, the mean and volatility processes seem to require an open market. In a closed market the processes seem to stop. The investigation finds that non-synchronous trading and non-trading does not affect mean and volatility processes. The model cannot reject that the variance process of thinly traded assets differ from frequently traded assets in an open market. The investigation also shows that the mean and variance processes need an open market. Hence, we interpret this result for an equity market as the drift (μ) and change in time (*dt*) and volatility (σ) and change of time ($\sqrt{dt}$) is only applicable in an open market. In a closed market the change in time seem to be close to zero and the price paths show therefore low to no movements. Hence, the Brownian motion hypothesis cannot be rejected as long as the market is open regardless of trading or non-trading. The result may be applied in formal mean and volatility modelling. Hence, the arguments may be applied in the changing versus stochastic volatility literature. The article is published in Applied Financial Economics (AFE), Vol 3, 2000, pp. 299 –310.

The second essay applies ARMA-GARCH methodology for mean and volatility lag specification, which control for non-synchronous trading and volatility clustering in asset return series. The empirical results suggest clear patterns in both the conditional mean and the conditional volatility across trading frequency return series. Particularly, non-synchronous trading and volatility clustering show consistent patterns across trading frequency series. Interestingly, strong negative autocorrelation due to non-trading induce ARMA-GARCH model misspecification. Hence, the ARMA-GARCH model seems to describe the Norwegian equity market well except for severely thinly traded series. Continuously, relative frequently traded asset and value-weighted index series seem well represented. Moreover, major findings are positive serial correlation, significant volatility clustering, asymmetric volatility and leptokurtosis in all well specified series.

The third paper studies non-linear dependence in the Norwegian thinly traded market. The results suggest that most of the non-linearity we find in all return series seem to originate from conditional heteroscedasticity. However, thinly traded assets still report general data dependence. Hence, the ARMA-GARCH modelling methodology may not represent non-trading adequately. The thinly traded assets report close to integrated GARCH (IGARCH) results. The paper is accepted for the European Journal of Finance.

The fourth paper (chapter 5) is the first of two papers testing the conditional capital asset pricing model (CAPM). Our main results can be summarized in three findings. Firstly, our results suggest that conditional heteroscedasticity is viable only for short time series intervals. Monthly time series show conditional homoscedasticity. Conditional GARCH models for conditional volatility are strongly preferred to unconditional models for daily and weekly sampling intervals, but not monthly. Secondly, the in-Mean parameter (λ) is a poor proxy for risk in the conditional CAPM sense. Thirdly, the conditional CAPM can only be partially rejected, which induce that our tests show mixed results.

The fifth paper (chapter 6) is the second CAPM paper and performs a bivariate test of the capital asset pricing model (CAPM). The main results can be summarised in five points. Firstly, the market is a major force in driving the conditional variance of individual assets. Secondly, the in-Mean specification is redundant. Thirdly, thin trading report ARMA-GARCH model misspecification. Fourthly, thinly traded assets show low market correlation, which out weights high conditional variance and therefore produce low to negative conditional betas (β). Fifthly, the conditional betas cumulative distribution functions unambiguously sort the conditional betas in ascending order of trading frequency. However, the thinly traded asset betas may be spurious because of model misspecification.

Finally, the sixth and seventh papers apply ARMA-GARCH methodology to conduct classical market model event studies. We have so far not been able to find earlier multivariate ARMA-GARCH event studies. We therefore believe that the last work (chapter 8) may have some effect on how event studies will be conducted in the future. The sixth essay establishes a classical and univariate ARMA-GARCH model for univariate models for time series in event and non-event periods. The results report strongly increased conditional variance in event periods relative to non-event periods. In fact, for selling firm portfolios we find a three- to four-fold increase in conditional variance. Acquiring firms show a two- to three-fold increase. Hence, we may conclude a need for new methodologies for event studies. The paper propose a univariate and a bivariate event study ARMA-GARCH specification that account for non-synchronous trading, changing and asymmetric volatility for classical simultaneous event studies. The bivariate specification is recommended as we that also the market index show strong non-synchronous trading and changing and asymmetric volatility.

The seventh essay (chapter 8) applies the proposed new methodology from essay seven (Chapter VII) and performs a simultaneous event study for merger and acquisitions in Norway from 1983 to 1994. Our main results can be summarised in three points. Firstly, we find no prior announcement effects in GARCH specification in contrast to OLS. Secondly, GARCH methodology suggests that selling firms maintain their abnormal return after day 20 relative to announcement day in contrast to OLS. Thirdly, the GARCH specification in contrast to OLS, reports no overall significant abnormal returns for acquiring firms. Hence, our results suggest a need for a rework of classical event studies. Finally, we find that model misspecification is strongly lower in ARMA-GARCH than in OLS specification.

1.6 The target groups for this dissertation

The dissertation focuses on changing volatility models controlling for non-synchronous trading and volatility clustering in univariate series, bivariate factor models and bivariate event studies. Even though some of the essays may be considered technical and may be difficult to access for non-econometrics, the dissertation’s main message is that ignoring non-synchronous trading and volatility clustering may (1) lead to wrong economic implications or (2) ARMA-GARCH model misspecification. Hence, for relative frequently traded assets our results show a need to control for non-synchronous trading and volatility clustering in asset series. For the most thinly traded asset series our results show the ARMA-GARCH model misspecification. Several target groups may have considerable benefit of reading and interpret this dissertation's findings.

The first essays employ arithmetic Brownian motions to hypothesis changes in mean and variance ratios according to individual asset trading frequency. This essay' s readers should firstly be professional model builders building explicit volatility models in financial markets. This essay's main finding is that volatility seem to be independent of trading frequency and non-trading. Hence, thin markets may find the GARCH modeling framework difficult to accept. Based on this article stochastic volatility models independent from the mean process seem plausible for very thinly traded asset series. Importantly the market shows only a volatility process when the market is open. Moreover, the article may be of interest for investors and option traders applying volatility strategies in thin markets. Finally, stock exchange administrators, stock exchange regulators and policy makers may find it of some interest that mean and volatility processes seem unaffected of trading frequency. We find that if trading frequency is reduced by for example a tariff per trade, the price change process seems not to be affected. In fact, the mean and volatility processes seem only dependent on an open market.

The second and third essay treats non-synchronous trading and non-trading effects as well as volatility clustering applying formal models for the conditional mean and volatility. The ARMA-GARCH model is relatively easily accessible modeling both non-synchronous trading in the mean and volatility clustering in the latent volatility. This essay's readers should be investors, portfolio managers and option traders with an interest in formal price and volatility processes in the Norwegian equity market. The ARMA-GARCH lag specifications adequately control for non-synchronous trading and non-trading effects as well as conditional heteroscedasticity and volatility clustering for relatively frequently traded asset series. However, the most thinly traded asset series report ARMA-GARCH model misspecification, which seem to require even more elaborate models. Hence, for stock exchange administrators and policy makers our point is that if trading frequency is reduced by for example a tariff per trade causing more non-trading, the formal ARMA-GARCH model may show spurious residuals and misspecifications. Even more elaborate volatility models may therefore be needed. Furthermore, continuously traded assets seem to report close to normal residuals. For option traders, the Black & Scholes option formula should produce theoretic option values close to market pricing values.

The fourth and fifth essays investigate one-factor models (CAPM) controlling for non-synchronous trading and volatility clustering applying ARMA-GARCH lag specifications. The fourth essay investigate CAPM at the index level alone applying excess returns while the fifth essay investigate CAPM applying bivariate ARMA-GARCH lag specifications for ordinary returns. The essays' report both rejection and support for the CAPM. The ARMA-GARCH model is strongly supported for daily and weekly series but not monthly series. Moreover, daily equal-weighted index series show model misspecification. Hence, investors still believing in the CAPM theory, portfolio managers looking for betas fitting their portfolio and stock exchange policy makers that may be interested in the CAPM, may find these two essays of some interest.

Finally, the sixth and seventh essays investigate non-synchronous trading and volatility clustering in classical event studies applying the market model. This essay' s readers should be investors and portfolio managers believing in abnormal returns in connections to special firm events. Also companies interested in growth through mergers and acquisitions may find the result for acquirers to be interesting reading. Finally, stock exchange administrators and business policy makers that are interested in event effects in equity markets may find our result of some interest. In particular, bureaucrats involved in the Norwegian "konsesjonsloven" may find this investigation interesting.

1.7 Organisation and layout of the dissertation

I have briefly summarised the models and empirical results from seven essays that constitute this dissertation. Each essay applies elaborate econometric techniques to solve some issues in capital market research with a special emphasis on non-synchronous trading and volatility clustering of return series in thinly traded equity markets.

The first essay applies variance ratios to measure non-trading effects in the conditional mean and volatility for individual assets. The methodology may be applied in market that shows non-trading for individual assets. The second and third essay applies ARMA-GARCH methodology and test for conditional mean and volatility characteristics in thinly traded markets. The fourth and firth essay applies ARMA-GARCH methodology to test univariate and bivariate versions of the conditional CAPM in thinly traded markets. The sixth and seventh essay applies ARMA-GARCH methodology to study event induced trading frequency and variance changes in thinly traded markets.

Each of these essays constituting the dissertation is organised in separate chapters. They are grouped into three main subjects. The first is univariate time series and these series' mean and volatility characteristics. The second is factor models (CAPM) and the third is event studies applying the market model. Within these main groups the essays are arbitrarily ordered and therefore cross-referenced. As each essay is intended for publication each essay and chapter is complete and can be read independently of each other. Some of the essays may therefore overlap in especially the data and data adjustment sections, as the employed data series are from the same market and time period. However, considerable effort is made to keep the overlapping to a minimum in the dissertation.

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