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The Examination of a Profitability-Based Four-Factor Model to Explain Stock Returns: Empirical Evidence from the German Stock Market

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ABSTRACT

In a recent publication Novy-Marx (2013) finds evidence that the variable gross profitability has a strong statistical influence on the common variation of stock returns. He also points out that there is common variation in stock returns related to firm profitability that is not captured by the three-factor model of Fama and French (1993). Thus, this thesis augments the three-factor model by the factor gross profitability and examines whether a profitability-based four-factor model is able to better explain monthly portfolio excess returns on the German stock market compared to the three-factor model of Fama and French (1993) and the Capital Asset Pricing Model (CAPM). Based on monthly stock returns of the CDAX over the period July 2008 to June 2014 this thesis documents four main findings. First, a significant positive market risk premium and a significant positive value premium can be identified. No evidence is found for a size or a profitability effect. Second, all included factors have a strong significant effect on monthly portfolio excess returns. Third, the four-factor model clearly outperforms both the three-factor model of Fama and French (1993) and the CAPM in capturing the common variation in monthly portfolio excess returns. The CAPM performs worst. Finally, the results indicate that the three-factor model of Fama and French (1993) is somewhat better in explaining the cross-section of portfolio excess returns than the four-factor model. Again, the CAPM performs worst. Nevertheless, the four-factor model is considered to be an improvement over the three-factor model of Fama and French (1993) and the CAPM in determining stock returns on the German stock market.

LIST OF ABBREVIATIONS

AC	Autocorrelation
AMEX	American Stock Exchange
APT	Arbitrage Pricing Theory
BE/ME	Book-to-market equity ratio
BLUE	Best Linear Unbiased Estimator
C/P	Cash-flow-to-price ratio
CAPM	Capital Asset Pricing Model
CDAX	Composite DAX (Deutscher Aktienindex)
COGS	Cost of goods sold
DW	Durbin Watson
E/P	Earnings-to-price ratio
EURIBOR	European Interbank Offered Rate
FF3FM	Fama and French three-factor model
GP/A	Gross profitability-to-assets ratio
GRS	Gibbons, Ross and Shanken
HC	Heteroscedasticity
HML	High minus low
ICAPM	Intertemporal Capital Asset Pricing Model
KKMDB	Karlsruher Kapitalmarktdatenbank
MPT	Modern Portfolio Theory
NASDAQ	National Association of Securities Dealers Automated Quotation
NYSE	New York Stock Exchange
OLS	Ordinary Least Square
OP	Operating profitability
P/E	Price-to-earnings ratio

PMU	Profitable minus unprofitable
R&D	Research and development
S&P	Standard & Poor's
SG&A	Selling, general and administrative expenses
SLB	Sharpe, Lintner and Black
SMB	Small minus big
t	Month
US	United States
VIF	Variance Inflation Factor
y	Year

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1 INTRODUCTION

Explaining and predicting stock returns represents one of the most challenging fields of research in modern finance. In this context, Fama and French published an extraordinary influential study in 1992, which in fact, was awarded with a prize for the best paper in the Journal of Finance in the same year. In their work they highly criticize the predictions of the Capital Asset Pricing Model (CAPM) and thus, contributed valuable insights that strongly affected subsequent research in this area. According to the CAPM, only one single risk factor, the market beta (β), is sufficient to determine stock returns. In their empirical work, Fama and French (1992) examine the effect of several factors on average stock returns and come to the result that "β does not seem to help explain the cross-section of average stock returns" (p. 428). In contrast, they find significant evidence that the combination of firm size and book-to-market equity (BE/ME) absorbs the role of the other tested variables (financial leverage and earnings-to-price ratio) in determining stock returns.

As early as the 1980s, many empirically studies started questioning the beta factor to be the only explanatory variable of stock returns and pointed to the existence of other powerful factors. However, based on their seminal paper from 1992, Fama and French (1993, 1996) argue that a risk-based three-factor model, an extension of the CAPM by the variables firm size and book-to-market equity, captures most of the impact of security characteristics on stock returns missed to explain by the CAPM. Their model builds the overall basis in asset pricing theory on whether to add further variables or to examine the model on stock markets in countries other than the US. However, Fama and French triggered a controversial debate since they hold the view that anomalous patterns in stock returns, in particular firm size and BE/ME, are entirely risk driven. In contrast, other researchers agree that market anomalies can be either attributed to irrational behavior of investors or to errors in the underlying data. Their propositions caused a great stir among researching scholars and thus, their model has been frequently attacked over the years. Besides defending their risk-based approach they regularly had to prove that their model withstands other market anomalies with strong explanatory power.

As for instance, Novy-Marx (2013) demonstrates empirical evidence that firm profitability has a strong statistical influence on the common variation of stock returns and states that his findings are difficult to reconcile with the predictions of the Fama and French (1993) three-factor model (FF3FM). By conducting portfolio tests in earlier studies, Fama and French (2006, 2008) detect that the variable earnings, used as a proxy for profitability, does not contribute incremental information over their pervasive risk factors firm size and BE/ME. Novy-Marx (2013), on the other side, points out that there is common variation in stock returns related to firm profitability that is not captured by the FF3FM.

1.1 Problem statement and objective

Immediately after the publication of Novy-Marx's (2013) influential paper, Fama and French (2013) felt compelled to empirically investigate their three-factor model extended by the variable operating profitability. Their findings turn out not to be statistically conclusive. Novy-Marx (2013), however, performs his analysis by including the variable gross profitability, which he states, "is the cleanest accounting measure of true economic profitability" (p. 2).

To this day, a test of the FF3FM augmented by the variable gross profitability is still pending. Likewise, most studies that examine the effect of gross profitability on stock returns have been carried out using US data only and empirical evidence whether a profitability premium exists in other countries, in particular Germany, is sparse. Given these shortcomings, there is a clear need for research that analyzes the influence of gross profitability on stock returns applying a wide variety of test assets and data from markets outside the US. As a result, this thesis calls attention for two implications: (1) to augment the FF3FM by the variable gross profitability, and (2) to empirically examine the performance of the resulting profitability-based four-factor model[1] by using out-of-sample data from the German stock market. Thus, the defined objective of this thesis can be expressed by the following research question:

Is a profitability-based four-factor model able to better explain monthly portfolio excess returns on the German stock market compared to the FF3FM and the CAPM?

1.2 Organization and structure

The thesis at hand is organized in six sections. Following the introduction, important theoretical frameworks are presented in section 2. Based on their idea the literature review in section 3 aims to contrast different opinions on the discussions in the field of explaining and predicting stock returns. In sections 4 and 5 the research methodology and the empirical results of the time-series regression analyses are unveiled and interpreted, respectively. Section 6 summarizes the main findings, concludes and provides recommendations for future research.

[1] Hereinafter, just called four-factor model to describe the FF3FM extended by the variable gross profitability.

2 THEORETICAL FRAMEWORKS

2.1 Capital Asset Pricing Model

The CAPM, based on Harry Markowitz's (1952, 1959) Modern Portfolio Theory (MPT), is a seminal approach in the theory of finance that delivers predictions about the relationship of expected return on an investment in respect to its risk. William Sharpe (1964), Jack Treynor (1962), John Lintner (1965a, 1965b) and Jan Mossin (1966) independently from each other contributed to the development of the CAPM. The CAPM extends the basic statement of the MPT by assuming that all investors, under market equilibrium and independent of their individual preferences, hold the same portfolio, that is, the market portfolio[2] of all risky assets in the economy. Its central prediction is that the market portfolio is mean-variance-efficient. This implies (a) "that differences in expected return across securities and portfolios are entirely explained by differences in market beta; other variables should add nothing to the explanation of expected return" (Fama and French 2004, p. 33), and (b) that "expected returns on securities are a positive linear function of their market βs" (Fama and French 1992, p. 427). The model is based on the idea that expected returns are only influenced by systematic risk.[3] Other than unsystematic risk systematic risk cannot be eliminated through diversification. It is measured by the market beta[4], which describes to what extent a particular asset is exposed to non-diversifiable risk compared to the overall market portfolio (Perold 2004).

The CAPM underlies a stringent set of assumptions. Sharpe (1964) and Lintner (1965a) add two very restrictive assumptions to Markowitz's model, obtaining the Sharpe-Lintner version of the CAPM. These assumptions are (1) *complete agreement*, meaning that among all investors, the probability distribution of future asset payoffs (expected return, variance and covariance) is known, and (2) *unrestricted risk-free borrowing and lending* is possible for all investors (Fama and French 2004, 2007). Consequently, the famous equation of the Sharpe-Lintner CAPM is expressed in its basic form as *(i = 1, …, I)*:

$$E(r_{it}) = r_{ft} + \beta_i \cdot \left[E(r_{mt}) - r_{ft}\right] \quad \text{(F2.1)}$$

[2] The market portfolio includes all assets traded in the economy such as traded financial assets, consumer durables, real estate and human capital (Fama and French 2004).

[3] In asset pricing theory overall risk consists of systematic and unsystematic risk. Systematic risk affects the entire market or a market segment and is neither predictable nor possible to fully prevent. For example, it is caused by changes in interest rates, political events and so on. Unlike unsystematic risk, it cannot be eliminated through portfolio diversification.

[4] Technically speaking, the market beta is the covariance between the stock return and the market return divided by the variance of the market return.

where $E(r_{it})$ is the expected rate of return of asset i over a single time-period, r_{ft} the risk-free interest rate, $ß_i$ the risk exposure of asset i to the market and $E(r_{mt})$ the expected rate of return of the market portfolio (hence, $E(r_{mt}) – r_{ft}$ represents the expected market premium). The conjunction between the CAPM and the "market model" of Fama (1968, 1976) and Sharpe (1963, 1970) results in the following equation in order to run time-series regression analyses: $(i = 1, \ldots, I; t = 1, \ldots, T)$:[5]

$$r_{it} - r_{ft} = \alpha_i + \beta_i \cdot [r_{mt} - r_{ft}] + \varepsilon_{it} \quad \text{(F2.2)}$$

where $r_{it} – r_{ft}$ is the excess return of portfolio i, α_i and ε_{it} represent the intercept and the error term of the regression, respectively.[6]

2.2 Three-factor model of Fama and French

Fama and French (1992) augment the CAPM by the factors firm size, earnings-to-price, financial leverage and BE/ME using data from the US stock market. They document empirical evidence that the sole use of the market beta only provides little information in determining the cross-section[7] of average stock returns. The variables firm size and BE/ME, however, show strong statistical explanatory power. Thus, Fama and French (1993) propose their well-known three-factor model, demonstrated in its basic form as $(i = 1, \ldots, I; t = 1, \ldots, T)$:

$$E(r_{it}) - r_{ft} = \beta_{i1} \cdot [E(r_{mt}) - r_{ft}] + \beta_{i2} \cdot E(SMB_t) + \beta_{i3} \cdot E(HML_t) \quad \text{(F2.3)}$$

where $E(r_{it}) – r_{ft}$ is the expected excess return of portfolio i, $E(r_{mt} – r_{ft})$ the expected excess return of the market, $E(SMB_t)$ and $E(HML_t)$ the expected returns for the size and BE/ME factors of asset i, respectively. The three factor loadings $ß_{i1}$, $ß_{i2}$ and $ß_{i3}$ are the slopes for running the time-series-regression with the equation $(i = 1, \ldots, I; t = 1, \ldots, T)$:

$$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \varepsilon_{it} \quad \text{(F2.4)}$$

where α_i represents the intercept and ε_i the error term of the regression.

The FF3FM finds application whenever estimates of expected stock returns are required. Fama and French (1993) point out that this „includes (a) selecting portfolios, (b) evaluating portfolio

[5] The term "market model" goes back to Fama (1968, 1976). Resulting variants are the Diagonal Model (Sharpe 1963) and the Single Index Model (Sharpe 1970), according to Ziegler et al. (2007).

[6] The error term (ε_{it}) is a random term to account for the part of variation of the dependent variable that is not explained by the independent variables.

[7] Fama and French (1993) highlight that in Merton's (1973) ICAPM and Ross's (1976) APT a simple test is conducted of whether the included explanatory variables in the model suffice to explain the cross-section of average stock returns, that is, the alphas (intercepts) of the time-series regressions should be close to zero. It demonstrates how well a model is specified.

performance, (c) measuring abnormal returns in event studies, and (d) estimating the cost of capital" (p. 53).

3 LITERATURE REVIEW

3.1 Empirical validity of the CAPM

It is Roll (1977) who first points out that the CAPM has never been empirically tested and most likely never will be. With this statement Roll refers to the so-called "market proxy problem". Both theoretically and empirically the market portfolio applied in the CAPM is deceptive. In theory it is not directly observable which assets to exclude from the market portfolio and due to data availability the inclusion of necessary assets can be highly restrictive (Fama and French 2004). As a result, the used market portfolio is surrogated in empirical investigations by market proxies such as the S&P 500 and the CDAX for the US and German stock market, respectively (e.g. Mayers 1972 or Stambaugh 1982). According to Black (1993), however, applying a market proxy rather than using the true market portfolio might lead to errors in estimating the market betas. Jagannathan and Wang (1996) argue that the usage of a market proxy "might be the reason for the poor performance of the CAPM under empirical examination" (p. 12). Thus, the market proxy problem leads to a joint test problem, that is, (1) the identification of the true market portfolio, and (2) the examination of the CAPM's empirical validity (Basse Mama 2010).

However, in early empirical studies the model finds somewhat supportive contributions as scholars attempt to verify the predicted consistency of an asset's risk and return relationship (Black et al. 1972 and Fama and MacBeth 1973). Yet, early tests reveal that stocks with higher betas turn out to show systematically lower rates of return (vice versa) than initially predicted by the Sharpe-Lintner model (Dempsey 2013). In other words, the resulting relationship of the Sharpe-Lintner CAPM is simply "too flat".[8] This is also confirmed by Douglas (1968), Miller and Scholes (1972) and Blume and Friend (1973) who unveil contradictory statements and thus, reject the Sharpe-Lintner CAPM. In a more recent study by Fama and French (1992) no positive relation for the time-period 1963-1990 can be found anymore, although the same cross-section regression approach as Fama and MacBeth (1973) is applied.

The bottom line is that the predictions of Black's (1972) CAPM, that beta suffices as sole explanatory variable and that beta's risk premium is positive, occur to hold, at least for a short period in the early 1970s. Unlike the more restricted CAPM version by Sharpe (1964) and

[8] Scholars like Friend and Blume (1970), Black et al. (1972) or Stambaugh (1982) analyze the Sharpe-Lintner CAPM in time-series regressions and present evidence that the relationship between beta and stock returns is too flat. Among others, these findings have become famous as the conjecture: "beta is dead" (van Dijk 2011).

Lintner (1965), which is rejected in every aspect. Fama and French (2004) emphasize that the early success of Black's (1972) CAPM generated the belief that the model is solid in explaining stock returns and that "these early results, coupled with the model's simplicity and intuitive appeal, pushed the CAPM to the forefront of finance" (p. 35).

3.2 CAPM-anomalies

Starting in the early 1980s, numerous scholars continue to empirically examine the CAPM and find important evidence for inconsistencies with the main predictions of the model. On the one hand, evidence is reported that stock returns only demonstrate little relation to the market beta (Reinganum 1981). On the other hand, many scholars point to the existence of other variables that show more statistical significance than the market beta in explaining stock returns.[9] Under rational asset pricing explanations, these newly explored variables "suggest that stock risks are multidimensional" (Fama and French 1992, p. 428). This means, that "when the CAPM market factor is used along with the presumable omitted variables, the resulting model tends to better capture the very nature of the return-generation process of common stocks" (Basse Mama 2010, p. 173). In the broad literature the effects of these factors are called anomalies since they are left unexplained by the CAPM (Fama and French 1996). Schwert (2003) describes anomalies as "empirical results that seem to be inconsistent with maintained theories of asset-pricing behavior" (p. 940).

In general, the deficiencies of the CAPM have led to an increase of potential explanations concerning the existence of anomalies. In the literature possible explanations are deeply divided and can be differentiated to be (1) data-based, (2) risk-based or (3) non-risk-based.

For the sake of completeness it is necessary to bring up that the first generation alternatives to the CAPM are Merton's (1973) ICAPM and Ross's (1976) APT. Due to the defined objective of this thesis, however, further investigations on the ICAPM and APT are beyond the scope.

3.2.1 Empirical evidence

In the following sections empirical evidence of the most important CAPM-anomalies is demonstrated using data from the US and German stock markets. Literature on the US market is included since the overall majority of tests were conducted in the US and most anomalies were identified first by using US data. The factors size and BE/ME are part of the examined four-

[9] Among others, this includes authors like Banz (1981), Basu (1977), Bhandari (1988) or DeBondt and Thaler (1985, 1987).

factor model in this thesis and hence, the subsequent publications more strongly concentrate on these variables than on other anomalies.

3.2.1.1 US stock market

Probably the most prominent anomaly in asset pricing theory is the size effect (also often called the small-firm effect). Banz (1981) is first to document a significant negative relation between stock returns and market capitalization, which is empirically confirmed by Reinganum (1981) in the same year. When sorting US-companies according to their market capitalization (share price times shares outstanding), Banz shows that small firms earn, on average, higher risk-adjusted monthly returns (size premium)[10] than large businesses. Several other prestigious scholars find a similar significant size premium studying the US stock market (e.g. Keim 1983, Lamoureux and Sanger 1989 or Fama and French 1992). Although Banz (1981) and Reinganum (1981) are convinced that the size effect is maintained over the investigated time-period in their studies, Brown et al. (1983) use Reinganum's sample and uncover a reversal of the size effect, at least for certain years. More recent papers state that the size anomaly might not be robust over time. In fact, it seems that the size effect has vanished in the US and in a wide range of other countries after the early 1980s.[11] Surprisingly, a comeback of the size effect can be observed after 2000, in particular for the US (van Dijk 2011).

Stattman (1980) and Rosenberg et al. (1985) identify a positive relation between stock returns and the ratio of a firm's book value of equity to its market value of equity for the US stock market. They provide empirical evidence that firms with a high BE/ME ratio (value stocks) earn, on average, higher monthly returns (value premium) than companies with a low BE/ME ratio (growth stocks). Due to the short sample-period (1973-1984) in the study of Rosenberg et al. (1985), however, the results do not seek much attention at first. Only after Chan et al. (1991) discover similar findings on the Japanese stock market, the factor BE/ME is considered to be a serious market anomaly, and from that point on, included in many influential studies (e.g. Fama and French 1992, Davis et al. 2000).

Besides the size and value anomalies, Basu (1977) demonstrates that firms with low price-to-earnings (P/E) ratios earn, on average, higher risk-adjusted returns than companies with high

[10] Roll (1981) attributes these higher returns to an improper risk measurement of small companies and Banz (1981) to insufficient information provided to investors.

[11] van Dijk (2011) lists the following exemplary studies that document empirical evidence for the size effect to be gone away over time: Eleswarapu and Reinganum (1993), Dichev (1998), Chan et al. (2000), Horowitz et al. (2000a, 2000b), Amihud (2002), Hirshleifer (2001) and Schwert (2003).

P/E ratios. Bhandari (1988) finds evidence for a positive relation between stock returns and leverage (debt-to-equity ratio). Others, like DeBondt and Thaler (1985, 1987), document proof for long-term mean reversions, that is, shares with a negative (positive) performance during the previous three to five years generate higher (lower) excess returns over the subsequent three to five years in the future.

Fama and French (1992, 1993, 1996) conduct analyses with all of the aforementioned variables simultaneously and conclude that the parameters firm size and BE/ME suffice to capture most of the variation in determining stock returns, except for the factor momentum. The momentum effect, first identified by Jegadeesh (1990) and Jegadeesh and Titman (1993), occurs when stocks with a positive (negative) performance in the previous three to twelve months proceed to have high (low) stock returns over the subsequent three to twelve months.

3.2.1.2 German stock market

The studies demonstrated in the previous section are based on US data. Hence, the chance that the presented anomalies are simply an artifact of this data may not be ruled out. Analyses in many different countries, however, prove the existence of these anomalies in markets apart from the US. In the late 1980s the size effect is first confirmed by Domke (1987) and Schnittke (1989); in a later study also by Stehle (1997). Although another paper demonstrates the classical negative relation between stock returns and market value, the author points out that the findings strongly dependent on the investigated time-period and underlying data (Beiker 1993). The majority of empirical investigations, however, document evidence that the size effect disappears (e.g. Schulz and Stehle 2002, Heston et al. 1999, Oertmann 1994, Schlag and Wohlschieß 1997 or Jaron and Romberg 2009). This pattern seems to maintain in even more current studies (e.g. Artmann et al. 2012 and Hanauer et al. 2013). These findings are in line with the current heated debate about the actual existence of the size effect as reported by van Dijk (2011).

Fama and French (1998) analyze international data solely focusing on the value effect. The results for the German dataset indicate statistical significance, even though in a rather weak scope. Similarly, Capaul et al. (1993) investigate European stock markets (including Germany) and confirm, that the value premium is pervasive in all of these stock markets. Bunke et al. (1998), Stock (1998) and Sattler (1994) include the factors firm size and BE/ME in their examinations. In all of the mentioned studies BE/ME significantly influences the cross-section of German stock returns, however, this cannot be concluded for the variable firm size. Another paper states that the ratios BE/ME and C/P show statistical significance and clearly dominate the parameter firm size (Wallmeier 2000). The value effect is still found in current studies (e.g. Ziegler et al. 2007 and Hanauer et al. 2013). Thus, unlike the size effect, the BE/ME anomaly seems to have a consistent and strong effect on German stock returns over time.

In terms of rather current studies, Artmann et al. (2011) examine two technical (stock momentum and stock reversal) and certain fundamental firm characteristics (size, BE/ME, E/P, market leverage, book leverage, return on assets and asset growth). A modified four-factor model including the variables market beta, BE/ME, E/P and momentum outperforms the Carhart (1997) four-factor model, the FF3FM and the CAPM. They report evidence of a strong momentum effect, however, do neither find a value nor a size effect. In a more recent study, Artmann et al. (2012) find evidence that the Carhart (1997) four-factor model, the FF3FM and the CAPM are not able to consistently explain the cross-section of returns. Ziegler et al. (2007) and Hanauer et al. (2013) publish very similar studies investigating the performance of the FF3FM compared to the CAPM. The work of Hanauer et al. (2013) additionally examines the Carhart (1997) four-factor model. Both studies document that the FF3FM captures the common variation in portfolio excess returns and explains its cross-section better than the CAPM. Hanauer et al. (2013) report that the FF3FM extended by the momentum factor reveals a rather marginal improvement.

3.2.2 Summary

The shortcomings of the CAPM's predictions have induced many authors to further empirically investigate the model. So far many significant variables have been identified that show more explanatory power than the market beta of the CAPM and hence, the body of literature on these anomalies is tremendous. Heavily researched is the US stock market, however, much evidence is also contributed for stock markets other than the US, in particular for the German stock market. Even though significant evidence for the existence of the size effect in Germany is delivered in the late 1980s it seems that it vanished soon after. The value premium, on the other side, appears to sustain over time on the German stock market.

3.3 Importance of firm profitability

"Gross profits is the cleanest accounting measure of true economic profitability. The farther down the income statement one goes, the more polluted profitability measures become, and the less related they are to true economic profitability" (Novy-Marx 2013, p. 2-3). With this statement, cited from the recently published paper: "The other side of value: The gross profitability premium", and the pioneering finding that the factor gross profitability has just about the same explanatory power as BE/ME in predicting the cross-section of stock returns, Novy-Marx (2013) has pushed the accounting variable firm profitability to a topical and much discussed subject in asset pricing theory as of today. His empirical results find tremendous enthusiasm and advocacy, ranging from a market commentator (DeMuth 2013) of Forbes Magazine to the examination of firm profitability as a potential variable for the extension of the famous three-factor model of Fama and French (2013).

3.3.1 Selected profitability measures

Firm profitability clearly does not belong to the most heavily researched anomalies in literature. The subject has rather gained attention since Novy-Marx (2013) published his influential paper. There are different ways to measure firm profitability. However, this thesis focuses on two selected indicators: (1) gross profitability and (2) operating profitability.

3.3.1.1 Gross profitability

Gross profitability is defined as the difference between annual total revenues and cost of goods sold (COGS) or services the firm sells. Novy-Marx (2013) scales gross profitability by total assets and demonstrates a gross profitability premium yielding from the transaction of purchasing profitable firms and selling unprofitable firms. The profitability factor is reflected by portfolio PMU_t (Profitable minus unprofitable), which describes the difference between the returns of a portfolio with profitable and unprofitable firms. Even return on equity, the indicator often applied for measuring profitability in earlier conducted studies, is outperformed by gross profitability in predicting stock returns (Novy-Marx 2012).

As the accounting components total revenues and COGS literally appear on top of the income statement, Novy-Marx (2013) argues that gross profitability is less influenced by a firm's actions, that dramatically change the bottom line income, than earnings or free cash-flows. In other words, earnings and free cash-flows contain more noise. For example, aggressive investments in advertising or research and development (R&D) usually increase sales, however, lead to decreasing earnings on the bottom of the income statement. Yet, Novy-Marx (2010) considers gross profits-to-assets, earnings and free-cash flows in his study and concludes that, "in a horse race between these three measures of productivity, gross profits-to-assets is the clear winner" (p. 3).

Ball et al. (2014) examine the predictive power of gross profitability and net income. They stress that it has to be accounted for all components along the income statement, not only for

COGS, as shareholder's cash-flow rights are not on gross profits but rather on net income. Their results confirm, that gross profitability outperforms net income only because it is "usually deflated by either the market or book value of equity, whereas gross profitability deflates gross profit (revenue minus cost of goods sold) by book value of total assets" (Ball et al. 2014, p. 27). Earlier studies show that certain income statement items between gross profits and net income reveal statistical significance. Eisfeldt and Papanikolaou (2013) and Chan et al. (2001) prove that selling, general and administrative (SG&A) expenses and expenditures on R&D show significant power in predicting stock returns, respectively.

In his paper, Novy-Marx (2013) presents, that when sorting on gross profits-to-assets, the most profitable firms earn substantially higher returns than unprofitable businesses, valid for both US (1963-2010) and international stocks (1990-2009)[12]. A similar outcome is achieved when controlling for BE/ME. Even though gross profitability has about the same predictive power as BE/ME, Novy-Marx (2013) emphasizes that profitable firms entirely differ from value companies. Profitable firms usually have higher returns, a lower BE/ME ratio and are larger in size than unprofitable firms. This is due to the pursued growth strategies by profitable firms, which in fact, extend the investment scope of a value investor. Novy-Marx (2013) stresses, "because the value and profitability strategies' returns are negatively correlated, the two strategies work extremely well together" (p. 16). As a result, investors in value stocks can benefit from the profitability premium without bearing any other additional risk.

Novy-Marx's (2013) findings and conclusions are problematic to reconcile with earlier studies of Fama and French (1993, 2006, 2008). By conducting portfolio tests, using earnings as a proxy for profitability, Fama and French (2006, 2008) detect little or no predictive power in returns of future profitability provided by size and BE/ME. Fama and French (1993) attribute the high returns of value stocks to their low profitability. They further argue that "low-BE/ME firms have persistently high earnings and high-BE/ME firms have persistently poor earnings" and the return difference between these kinds of businesses captures large variation (p. 53). Without a doubt Novy-Marx (2013) questions the findings of the FF3FM by asserting that there is variation in returns related to profitability that is left unexplained by their model.

[12] The dataset for international stocks includes the following countries: Australia, Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Hong Kong, Italy, Japan, the Netherlands, New Zealand, Norway, Singapore, Spain, Sweden and Switzerland. However, individual results are not presented in his paper.

It seems that the conducted research on the gross profitability effect mostly concentrates on the US stock market for the moment. However, empirical tests with out-of-sample data are of high relevance to alleviate the concern of data snooping. According to current knowledge, Sun et al. (2014) appear to be the only source, next to Novy-Marx (2013), investigating the gross profitability effect outside the US stock market. In their paper, they perform portfolio and regression analyses covering 41 countries over the period 1980 to 2010. They find a positive relation between gross profitability and stock returns in about two-thirds of the analyzed countries. In particular for the German stock market, they report a significant value-weighted gross profitability return spread of 0.70% per month.

3.3.1.2 Operating profitability

Alternatively, profitability can be measured by taking more income statement items into account. Operating profitability is calculated by subtracting COGS and SG&A expenses, however, not R&D expenditures, from a firm's total revenues (Ball et al. 2014). Soon after Novy-Marx's (2013) assertion that gross profitability is the cleanest measure of true economic profitability, other authors used this as an opportunity to test his statement for validity.

Next to the comparison between gross profitability and net income, Ball et al. (2014) also investigate the predictive power of operating profitability and contrast it to gross profitability. In their analysis they identically recreate the measure gross profitability according to the work of Novy-Marx (2013) and perform Fama and MacBeth (1973) regressions. They exhibit that operating profitability outperforms gross profitability and also find empirical evidence that operating profitability "is significantly informative about expected returns for horizons as long as ten years" (Ball et al. 2014, p. 4).

The results of Novy-Marx (2013) indicate that there is variation in returns related to profitability that is not captured by the FF3FM. Hence, motivated by the dividend discount model, Fama and French (2013) augment their three-factor model by the variable operating profitability. Although the new four-factor model seems to be an improvement over the FF3FM, it is rejected by the GRS-test (Gibbons et al. 1989), which implies that the alphas are not equal to zero and thus, the explanatory variables do not suffice to perfectly explain the cross-section of average returns.[13] Nevertheless, Fama and French (2013) argue that the model is still solid enough for

[13] The GRS-test (Gibbons, Ross and Shanken), developed by Gibbons et al. (1989), is an F-test used to evaluate the overall performance of asset pricing models; in particular it tests for the cross-section of average stock returns.

most applications. The model also alleviates some of the well-known shortcomings of the FF3FM, that is, the model performs better on explaining the low returns of extreme small growth stocks. An identified weakness of the new model, however, is its increased complexity by constructing three-dimensional sorted portfolios.

Empirical evidence for testing the robustness of the accounting measure operating profitability by using out-of-sample data is extremely rare. Regarding to current knowledge, there has been no research conducted on the German stock market so far.

3.3.2 Summary

Both reviewed profitability measures show strong empirical evidence for an existing positive relation with expected stock returns. The outcomes of existing studies do not permit a final assessment of whether gross profitability or operating profitability is the better measure for firm profitability. In fact, the respective variables have to be aligned with the data and factor specific conditions of the underlying asset pricing model in order to achieve significant results. Even though the subject firm profitability has gained much attention since Novy-Marx's (2013) paper, it is surprising that rather alternative profitability measures have been analyzed instead of the factor gross profitability.

3.4 Interim conclusion

After reviewing the current state of literature it becomes clear that the empirical validity of the CAPM is extremely weak. The FF3FM predicts that the variables firm size and BE/ME suffice to capture most variation in stock returns. Only the variation in returns related to the factor momentum is left unexplained by the FF3FM. This gap, however, is closed by Carhart (1997), who adds the parameter momentum to the FF3FM. Over time the FF3FM has been frequently attacked by many critical researchers, which is why Fama and French had to regularly prove that their model withstands other anomalies with strong explanatory power.

In an early study by Ball and Brown (1968), for example, evidence is documented that earnings, a proxy for firm profitability, show power in predicting the cross-section of average stock returns. In contrary, Fama and French (1996, 2006, 2008) demonstrate that earnings do not contribute incremental information in portfolio tests over their pervasive risk factors size and BE/ME. However, the recent results presented by Novy-Marx (2013) confirm that gross profitability has just about the same explanatory power as BE/ME in predicting the cross-section of returns and thus, clearly questions the success of the FF3FM. Novy-Marx (2013) argues that his findings are difficult to reconcile with the FF3FM and that the model does not capture variations in returns related to profitability. Novy-Marx (2013), however, states that “gross profits is the cleanest accounting measure of true economic profitability” (p. 2).

As a matter of fact, the FF3FM has not been analyzed including the factor gross profitability so far. Also, only little evidence exists for the gross profitability effect to be tested in markets other than the US. The rationales of Novy-Marx (2013) to entitle gross profitability as the cleanest of all profitability measures motivate this thesis rather to study the factor gross profitability in greater detail than the other indicators. As a result, this literature review calls attention for two implications: (1) to augment the FF3FM by the variable gross profitability, and (2) to empirically examine the performance of the resulting profitability-based four-factor model by using out-of-sample data from the German stock market. Thus, the defined objective of this thesis is to empirically analyze whether a profitability-based four-factor model is able to better explain monthly portfolio excess returns on the German stock market compared to the FF3FM and the standard CAPM.

4 RESEARCH METHODOLOGY

4.1 Dataset

In this section the underlying dataset is presented. First, the source of the dataset and the subsequent retrieval of specific data are demonstrated. In a second step the adjustment of the sample is described in greater detail. The same section outlines several limitations of the applied sample and its probable effects on the empirical outcomes.

4.1.1 Selection and collection

The basis for the illustration of the German stock market is provided by the performance index CDAX (Composite DAX (Deutscher Aktienindex)). This index contains the full spectrum of the German stock landscape, that is, all German equities listed on the Frankfurt Stock Exchange in the General and Prime Standard. It measures the performance of the overall German stock market. As of November 2014 the CDAX is composited of 470 stocks.

All company data are retrieved from the commercial database FactSet and further processed in Microsoft Excel. For the proxy of the monthly risk-free rate of return the European Interbank Offered Rate (EURIBOR) is used, reported by the Deutsche Bundesbank (series BBK01.SU0310).

4.1.2 Sample description and limitations

In table 3.1 the exact number of firms for the examined period is illustrated.[14] The number of firms is equal to the number of firms used to construct the factors.

Period	Average number of firms
2008/09	324
2009/10	323
2010/11	324
2011/12	330
2012/13	335
2013/14	341

Table 4.1: Average number of firms per examined period

[14] A period is considered to last from the beginning of July of year *y* to the end of June of year *y* + 1.

The underlying sample in this thesis comprises 341 German companies over the period July 2008 to June 2014 (T = 72 months). This number is lower than the initial 470 companies due to adjustment-specific reasons. First, for the analysis only non-financial firms are considered because financial firms (e.g. banks, insurances or investment companies) are subject to special accounting standards and different risk factors.[15] Second, only firms are taken into account for which all of the aforementioned data (section 3.1.1) are available. Last, analogously to Fama and French (1993), companies with a negative book value of equity are excluded.

The underlying dataset is exposed to certain limitations. First, the composition of the CDAX cannot be retrieved from the database FactSet and is only publically available for 2014. Compositions for previous years have to be purchased from the Deutsche Börse AG. This means, the dataset does not contain firms that were removed from the CDAX between the analyzed period. Each observed period is based on the same index composition of 2014.

Second, the examined period of only six years is also influenced by the prior mentioned limitation. The further one goes into the past and only considers the CDAX composition of 2014, the less accurate the results will be. Besides the composition, most studies design their investigated periods over several decades. For this reason, it is difficult to directly compare the findings in this thesis with those of prestigious papers.

Last, very few authors retrieve their data for the German stock market from the commercial provider FactSet. Brückner et al. (2014) provide a current overview which dataset is best for the German stock market, in particular for the Fama and French (1993) factors $r_{mt} - r_{ft}$, SMB_t and HML_t. The majority clearly uses the database Karlsruher Kapitalmarktdatenbank (KKMDB). Its main advantage is that it covers all German stock exchanges and all market segments since 1974.

4.2 Data analysis

After adjusting the dataset from the criteria mentioned above the first step of the data analysis is to calculate the respective monthly stock returns. In the light of the following portfolio construction for both, explanatory and dependent variables, each period ranges from the beginning of July at year y to the end of June at year $y + 1$, analogously to Fama and French (1992, 1993). On this basis monthly discrete stock returns are computed in the form of:

[15] For the determination of stock returns of financial firms, please refer to Viale et al. (2009).

$$r_{it} = \frac{s_{it}}{s_{it-1}} - 1 \tag{F3.1}$$

where r_{it} is the discrete return of stock i at month t, s_{it} the closing price of stock i at month t and s_{it-1} the closing price of stock i at month t – 1.

4.2.1 Explanatory variables

The four-factor model tested in this thesis comprises four explanatory variables: (1) a market factor ($r_{mt} - r_{ft}$) of the standard CAPM, (2) and (3) a size (SMB_t) and a value factor (HML_t) of the FF3FM and (4) a profitability factor (PMU_t) examined by Novy-Marx (2013). As this thesis empirically investigates the performance of the four-factor model over the FF3FM and the CAPM the respective variables of the four-factor model are equal to the parameters used in the other two models.

4.2.1.1 Determination of beta and the firm characteristics

For the determination of the size and BE/ME factors the same methodology of Fama and French (1992, 1993) is applied. The factor firm size in each period is measured by a firm's market value of equity at the end of June at each year *y* and is computed as the product of the stock price and shares outstanding. Some firms of the sample have issued both common and non-voting preferred stocks. In that particular case the market values of both share classes are put together, however, only the stock prices of the common stocks are used.

The BE/ME factor in each period is computed through a division of the book value of equity for the fiscal year ending in calendar year *y* – 1 and the market value of equity at the end of December of calendar year *y* – 1.

For the construction of gross profitability it is followed Novy-Marx (2013). Gross profitability in each period is retrieved from the simple subtraction of a firm's total revenues and a firm's COGS. The division of this number by a firm's total assets results in the variable gross profit-ability-to-assets (GP/A) in year *y*. All components of GP/A refer to the fiscal year ending in calendar year *y* – 1.

The market beta in each period is measured at the end of June of each year *y* as the covariance between the stock return and the market return divided by the variance of the market return. In this case the CDAX represents the proxy for the market portfolio.

4.2.1.2 Construction of the factors

For the construction of SMB_t and HML_t this thesis follows the same methodology of Fama and French (1993). For each period all firms in the sample are independently ranked on market value at the end of June of year *y* and on BE/ME for the fiscal year ending in calendar year *y* – 1. The reason for the six-month lag is to make sure that the required data for the calculation of BE/ME are available at the time of the ranking. In a next step all firms are split up in two size-groups and three BE/ME-groups through independent sorts. First, the median of the market value is computed and used as the breakpoints to allocate all firms into the group of small stocks (S) or the group of big stocks (B). Second and independent of size, the 30th and 70th percentiles of BE/ME are calculated, which function as breakpoints to classify the sample into three BE/ME groups: stocks with a low BE/ME (L) are in the bottom 30% group, stocks with a high BE/ME (H) are in the top 30% group and stocks with a medium BE/ME (M) are in the middle 40% group.

From the intersection of the two size-groups and the three BE/ME-groups the following six portfolios are formed (2x3 matrix): S/H, S/M, S/L, B/H, B/M and B/L. For example, portfolio S/H refers to a portfolio of stocks with small market values and high BE/MEs.

The corresponding monthly value-weighted portfolio returns ($r_t^{S/H}$, $r_t^{S/M}$, $r_t^{S/L}$, $r_t^{B/H}$, $r_t^{B/M}$ and $r_t^{B/L}$) are computed for each period using the following equation:[16]

$$r_{pt} = \sum_{i=1}^{n} w_{it} \cdot r_{it} \qquad \text{(F3.2)}$$

where r_{pt} is the value-weighted return of portfolio *p* in month *t*, r_{it} the return of stock *i* in month *t*, w_{it} the ratio of the market value of stock *i* on the total market value of portfolio *p* in month *t* and *n* the number of stocks in portfolio *p*.

Finally, SMB_t and HML_t can be constructed. The variable SMB_t is defined as the equally weighted difference between the monthly returns of the three small stock and the three big stock portfolios:

$$SMB_t = \frac{r_t^{S/H} + r_t^{S/M} + r_t^{S/L}}{3} - \frac{r_t^{B/H} + r_t^{B/M} + r_t^{B/L}}{3} \qquad \text{(F3.3)}$$

[16] At the end of a period the portfolios are resorted based on the same criteria and the whole procedure is repeated.

HML_t, which is independent of size, describes the equally weighted difference between the monthly returns of the two high BE/ME and the two low BE/ME portfolios:

$$HML_t = \frac{r_t^{S/H} + r_t^{B/H}}{2} - \frac{r_t^{S/L} + r_t^{B/L}}{2} \quad \text{(F3.4)}$$

Due to this construction SMB_t and HML_t should be mostly uncorrelated with each other.

Following Novy-Marx (2013), the variable PMU_t is constructed similar to the factor HML_t. The breakpoints and the corresponding independent allocation of the sample are analogously performed to SMB_t and HML_t. Through the intersection of the two size-groups and the three profitability-groups (2x3 matrix) six portfolios are formed: S/P, S/N, S/U, B/P, B/N and B/U.

With equation F3.2 the monthly value-weighted portfolio returns ($r_t^{S/P}$, $r_t^{S/N}$, $r_t^{S/U}$, $r_t^{B/P}$, $r_t^{B/N}$ and $r_t^{B/U}$) are computed for each period. Thus, the variable PMU_t is defined as the equally weighted difference between the monthly returns of the two profitable and the two unprofitable portfolios:

$$PMU_t = \frac{r_t^{S/P} + r_t^{B/P}}{2} - \frac{r_t^{S/U} + r_t^{B/U}}{2} \quad \text{(F3.5)}$$

Unlike these three explanatory variables the excess return of the market ($r_{mt} - r_{ft}$) does not yield from two-dimensional sorted portfolios. It is rather the difference between the monthly return of the value-weighted market portfolio (r_{mt}) and the monthly risk-free rate of return (r_{ft}) (EURIBOR).

4.2.2 Construction of the test portfolios

The design of the test portfolios is very similar to the procedure of the six portfolios constructed to determine SMB_t and HML_t. This step follows the methodology of Fama and French (1993) and Hanauer et al. (2013). Fama and French (1993) form 25 test portfolios (5x5 matrix) through the intersection of size and BE/ME quintiles. By using independent sorts, all firms are allocated to five size-groups and five BE/ME-groups correspondingly.

Instead of using 25 test portfolios, however, in this thesis only 16 test portfolios (4x4 matrix) are constructed, analogously to Hanauer et al. (2013). On the one hand, this approach ensures that the respective test portfolios contain enough stocks as the sample is significantly smaller than of Fama and French (1993), and on the other hand, a possible comparison of the results with German papers (Ziegler et al. 2007 and Hanauer et al. 2013) is easier.

The size and BE/ME quartiles serve as breakpoints to split the sample to the corresponding four size and four BE/ME-groups and to form the subsequent 16 portfolios from their intersection. In the further course of this thesis the 16 test portfolios, based on independent size and BE/ME sorts, are denoted as the following: 1-1 (Small-Low), ..., 1-4 (Small-High), ..., 4-1 (Big-Low), ..., 4-4 (Big-High).

4.3 Time-series regression analyses

After the factor construction the next step is to run time-series regression analyses from July 2008 to June 2014. Thereby, the monthly excess returns of the 16 test portfolios ($r_{it} - r_{ft}$) are used as dependent variables and the factors $r_{mt} - r_{ft}$, SMB_t, HML_t and PMU_t as explanatory variables. In the following the investigated models are demonstrated in the version to conduct time-series regressions in IBM SPSS Statistics through the Ordinary Least Square (OLS) method *(i = 1, …, I; t = 1, …, T)*:

$$r_{it} - r_{ft} = \alpha_i + \beta_i \cdot [r_{mt} - r_{ft}] + \varepsilon_{it} \qquad \text{(F2.2)}$$

$$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \varepsilon_{it} \qquad \text{(F2.4)}$$

$$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \beta_{i4} \cdot PMU_t + \varepsilon_{it} \qquad \text{(F3.6)}$$

At first, the parameters for the 16 test portfolios of the CAPM are estimated in time-series regression tests by means of equation F3.6. In a next step, the CAPM is augmented to the FF3FM and the four-factor model and once again, the parameter estimation procedure for each of the 16 test portfolios is performed based on equations F2.2 and F2.4, respectively.[17] Following Fama and French (1993), Ziegler et al. (2007) and Hanauer et al. (2013), the results for each model are then analyzed in two steps.

The first step is to examine whether the four variables $r_{mt} - r_{ft}$, SMB_t, HML_t and PMU_t describe actual factors that explain the common variation in monthly portfolio excess returns for the German stock market over the analyzed overall period. For this, the respective factor loadings[18] and their corresponding statistical significance as well as the adjusted R^2 values (Coefficient of determination) are considered. Statistical significance is given when the null hypothesis in a

[17] In total, 48 (3x16) individual time-series regression tests are performed.

[18] The term factor loading is used synonymously for slope or (regression) coefficient.

two-tailed t-test is rejected, that is, the slopes are significantly different from zero (both positively or negatively) at a level of 1%.[19]

For examining the model's goodness of fit the adjusted R^2 is measured. It provides information to what proportion the factors explain the total common variation of the model's dependent variable. Thereby, the higher the adjusted R^2 the better the model's explanation of the common variation in monthly portfolio excess returns.

In the second step the focus lies on the estimated intercepts (α_i) from the time-series regressions. The intercepts are used to analyze whether the set of explanatory variables is sufficient to explain the cross-section of portfolio excess returns, which indicates how well a model is specified. This can be investigated through a simple test, that is, the intercepts of time-series regressions should not be significantly different from zero in a two-tailed t-test.[20]

The more intercepts are significantly different from zero the worse the model's ability to explain the cross-section and the worse the model's specification.

[19] Decision rule: If the null hypothesis (H_0) is rejected β_i is significantly different from zero (H_1) and thus, considered to be statistically significant. The tests are conducted at a 10%, 5% and 1% significance level, respectively. The same test applies for analyzing the statistical significance of the monthly mean returns (H_0: $\mu_i = 0$, H_1: $\mu_i \neq 0$).

[20] See footnote 20 for the decision rule.

5 EMPIRICAL RESULTS

5.1 Descriptive statistics

This section addresses the illustration of descriptive statistics for all factors and its components. First, summary statistics and correlation coefficients for beta and the firm characteristics are shown. Next, the monthly mean returns, return standard deviations as well as correlation coefficients for the explanatory factors are provided. Last, the monthly mean returns and standard deviations for the average monthly excess returns of the test portfolios are presented.

5.1.1 Beta and the firm characteristics

Table 5.1 shows that the average market beta is clearly below the value 1. This is mainly due to the fact that smaller firms in Germany tend to have smaller betas compared to the US, reported by Stehle (1997). Artmann et al. (2012) and Artmann (2011) document similar low betas in their studies for the German stock market.

Summary statistics for beta, size, BE/ME and GP/A

Characteristics	Mean	Std. Dev.	Median	25th Percentile	75th Percentile
Beta	0.64***	1.01	0.61	0.14	1.11
Size (million €)	2502.11***	8,691.36	131.16	37.83	806.59
BE/ME	0.89***	0.73	0.70	0.43	1.10
GP/A	0.25***	0.23	0.22	0.12	0.32

Significance levels: 10% (*), 5% (**) and 1% (***).

Table 5.1: Summary statistics for beta, size, BE/ME and GP/A

More importantly, however, is that the distribution of the size factor is skewed to a great degree. This means, the sample of this thesis contains a large number of small firms as 25% of the annually firm size observations are less than €38 million. Even the 75th percentile of size (€806.59 million) is substantially below the monthly mean return (€2,502.11 million). As the monthly mean return of BE/ME (0.89) is below 1, the stocks of the underlying sample are, on average, slightly undervalued. Also, the monthly mean return of the parameter GP/A (0.25) demonstrates that companies in Germany are rather profitable than unprofitable on an average basis. All firm characteristics and beta are statistically significant at a 1% level.

As can be seen in table 5.2, the *Pearson* correlation coefficients between beta, size, BE/ME and GP/A do not show strong abnormalities and are overall very low. The correlation coefficients between the parameters size and beta, BE/ME and size as well as GP/A and BE/ME are even significantly different from zero at a level of 1%. Noticeable but rather neglectable is that all correlation coefficients have negative signs, except for the size and beta relation.

Correlation coefficients between beta, size, BE/ME and GP/A				
Characteristics				
	Beta	Size	BE/ME	GP/A
Beta	1			
Size	0.080***	1		
BE/ME	−0.008	−0.123***	1	
GP/A	−0.019	−0.008	−0.162***	1
Significance levels: 10% (*), 5% (**) and 1% (***).				

Table 5.2: Correlation coefficients between beta, size, BE/ME and GP/A

5.1.2 Explanatory variables

The average monthly return of the market portfolio (r_{mt}) amounts 1.134% and the average monthly excess return ($r_{mt} - r_{ft}$) yields 1.061%. Ziegler et al. (2007) and Hanauer et al. (2013) document average monthly excess returns of 0.265% and 0.554% over the periods 1968-1995 and 1996-2011, respectively. The higher value within this thesis can be explained through the rather short period of the underlying sample, which is mainly characterized through a low interest rate policy resulting from the most recent financial crises in 2007. Both comparative studies show average monthly risk-free interest rates (r_{ft}) of 0.536% and 0.232%, respectively, while the risk-free interest rate in this thesis averages 0.073% (see table 5.3).

Descriptive statistics for the explanatory variables						
Variables			*Pearson* correlation coefficients			
	Mean	Std. Dev.	$r_{mt} - r_{ft}$	SMB_t	HML_t	PMU_t
r_{mt}	1.134*	5.159				
r_{ft}	0.073***	0.091				
$r_{mt} - r_{ft}$	1.061*	5.182	1			
SMB_t	0.553	3.845	−0.529***	1		
HML_t	0.701*	3.072	0.250**	−0.285**	1	
PMU_t	0.441	4.078	0.016	0.319***	0.048	1
Significance levels: 10% (*), 5% (**) and 1% (***).						

Table 5.3: Descriptive statistics for the explanatory variables

Also, the monthly premium of $r_{mt} - r_{ft}$, which is statistically significant at a 10% level and reveals the highest standard deviation of all factors, accounts for the overall highest value of 1.061% over the other three factors SMB_t, HML_t and PMU_t. Interestingly, all four factors indicate positive average monthly premiums. Even the size effect generates a positive value of 0.553% per month. This is surprising, since previous studies on the German stock market report the size effect to be negative or to have disappeared. Nevertheless, the size effect in this thesis is not significantly different from zero, which contributes to the current debate about the existence of the size effect in Germany, reported by van Dijk (2011). Ziegler et al. (2007) provide evidence for a slightly positive but insignificant monthly size premium of 0.083% and Hanauer et al. (2013) show a significant negative value of –0.705% per month at a 5% level. Also, both authors find significant monthly premiums for HML_t of 0.402% and 0.735% at a 1% level, respectively. Similarly, the value effect in this thesis averages 0.701% per month and is also significantly different from zero, however, only at a 10% level. Finally, it is surprising that no significant profitability effect can be identified in Germany. Its value averages 0.441% per month and thus, illustrates the lowest premiums of all factors.

The *Pearson* correlation coefficients, demonstrated in table 5.3, are mostly rather low, which suggests that each variable represents an independent influencing factor of stock returns. Noticeable is the high negative correlation between SMB_t and $r_{mt} – r_{ft}$ of –0.529, which is significantly different from zero at a 1% level. According to Hanauer et al. (2013), this is a common coherence in Germany and is attributable to the negative consideration of stocks with high market capitalizations in SMB_t, which simultaneously dominate the value-weighted excess returns of the market portfolio. Ziegler et al. (2007) and Hanauer et al. (2013) uncover similar high negative values of –0.597 and –0.550, respectively. The correlation between PMU_t and the other variables is low and even significantly different from zero at a 1% level between SMB_t. It is surprising that the correlation between PMU_t and HML_t is positive since Novy-Marx (2013) documents a negative correlation. Further, statistical significance is also observed for the correlation coefficients of HML_t and $r_{mt} – r_{ft}$ as well as of HML_t and SMB_t at a level of 5%. Overall, the correlation coefficients are quite low due to their independent construction methodology and are mostly in line with the comparative descriptive statistics reported by Ziegler et al. (2007) and Hanauer et al. (2013).

5.1.3 Dependent variables

Table 5.4 shows that the average monthly excess returns of the 16 test portfolios are throughout positive and range from 0.487% (portfolio 4-1) to 3.754% (portfolio 1-1).

Excess returns $r_{it} - r_{ft}$ of $i = 1, ..., 16$ test portfolios: mean return and (return standard deviation)								
	Book-to-market equity							
Firm size	1 (Low)		2		3		4 (High)	
1 (Small)	3.754***	(8.61)	2.145***	(6.38)	2.373***	(5.73)	2.648***	(5.42)
2	1.473**	(5.47)	1.162**	(4.93)	1.518**	(5.22)	1.967***	(6.08)
3	1.397**	(4.87)	1.309*	(5.95)	1.846**	(6.88)	1.849*	(8.60)
4 (Big)	0.487	(5.52)	0.850	(6.26)	1.918*	(8.49)	1.730*	(7.43)

Significance levels: 10% (*), 5% (**) and 1% (***).

Table 5.4: Summary statistics of the 16 test portfolios

This range is considerably higher compared to the statistics of Ziegler et al. (2007) and Hanauer et al. (2013). They report average monthly excess returns of their 16 test portfolios ranging from 0.002% to 0.668% and –0.656% to 1.094%, respectively. Interesting to note, 14 out of 16 monthly mean returns are significantly different from zero. Out of these 14 values, five are significant at a 1% level, another five at a 5% level and four at a 10% level. This might result from the large spread of the stock returns in the portfolios, although it seems that the level of significance mitigates with increasing firm size (Hanauer et al. 2013).

Similar to the findings documented by Ziegler et al. (2007) and Hanauer et al. (2013), the average monthly excess returns increase with growing BE/ME ratios within the size sorted quartiles, except for portfolios 1-1, 2-1 and 3-1. This implies an existing positive relation between BE/ME and stock returns and confirms the results for HML_t shown in the previous section. A similar pattern can be observed within the quartiles sorted on BE/ME. Stock returns decrease with accumulating firm size, besides for portfolios 3-1, 3-3 and 3-4. Even though SMB_t is not statistically significant, this finding shows evidence for a negative relation between firm size and stock returns and confirms its positive value illustrated above. This also explains why the highest average monthly excess returns appear in the small size portfolios 1-1 to 1-4. However, this result is surprising, since Ziegler et al. (2007) and Hanauer et al. (2013) do not find a similar systematic relation of firm size in Germany.

5.2 Time-series regression analyses

After presenting the four explanatory factors $r_{mt} - r_{ft}$, SMB_t, HML_t and PMU_t this section conducts time-series regression analyses to verify the revealed coherence between the factors and stock returns. It is first investigated whether the underlying variables demonstrate actual influencing factors that explain the common variation in monthly portfolio excess returns for the German stock market. The second step is to examine whether the explanatory variables of the models are sufficient to determine the cross-section of portfolio excess returns.

5.2.1 Common variation in portfolio excess returns

In order to find out whether the explanatory variables represent influencing factors that explain the common variation in monthly portfolio excess returns the respective estimated coefficients and their corresponding statistical significance as well as the values of the adjusted R^2 are examined. Each model is considered individually, however, the performance of the four-factor model is compared over the FF3FM and the standard CAPM.

5.2.1.1 CAPM

By means of equation F2.2 time-series regressions of the CAPM are performed. The CAPM contains only the monthly excess return of the market (βi) to explain the monthly excess returns of the test portfolios. It can be seen, that the signs for all coefficients are positive. Thus, the coefficients affect the dependent variables throughout positively in the course of time.

$$r_{it} - r_{ft} = \alpha_i + \beta_i \cdot [r_{mt} - r_{ft}] + \varepsilon_{it}$$

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	Estimator for β_i			
1 (Small)	0.523***	0.434***	0.653***	0.565***
2	0.568***	0.598***	0.646***	0.730***
3	0.630***	0.826***	0.990***	1.093***
4 (Big)	0.907***	1.071***	0.958***	1.157***
	Adjusted R^2			
1 (Small)	0.086	0.112	0.339	0.281
2	0.280	0.386	0.403	0.379
3	0.441	0.511	0.550	0.425
4 (Big)	0.722	0.784	0.333	0.647

*, ** and *** refer to a rejection of the null hypothesis H_0: $\beta_i = 0$ at a significance level of 10%, 5% and 1%, respectively.

Table 5.5: Time-series regression results for the CAPM

Table 5.5 shows that the estimated coefficients range from 0.434 (portfolio 1-2) to 1.157 (portfolio 4-4) and average 0.772. Similarly, Ziegler et al. (2007) and Hanauer et al. (2013) document their coefficients ranging from 0.470 to 1.074 and 0.533 to 1.077, respectively. Among the coefficients two patterns can be reported: (1) by holding BE/ME constant, the estimated coefficients increase with growing firm size, except for portfolios 2-3 and 4-3, (2) within the firm size quartiles, the coefficients accumulate with increasing BE/ME, besides for portfolios 1-2, 1-4 and 4-3. Both, Ziegler et al. (2007) and Hanauer et al. (2013) confirm the first pattern among the coefficients, however, only Ziegler et al. (2007) finds evidence for the second pattern. Finally, all coefficients are significantly different form zero at a level of 1%, thus, the variable $r_{mt} - r_{ft}$ can be considered to be an influencing factor of monthly portfolio excess returns on the German stock market.

The values of the adjusted R^2 range from 0.086 (portfolio 1-1) to 0.784 (portfolio 4-2) and show an overall mean of 0.417.[21] Ziegler et al. (2007) and Hanauer et al. (2013) report corresponding values from 0.229 to 0.844 (mean: 0.571) and 0.224 to 0.887 (mean: 0.485), respectively. Furthermore, only the first of the mentioned patterns above can be confirmed. That is, when holding BE/ME constant, the values of the adjusted R^2 increase with growing firm size, except for portfolio 4-3. However, no systematic pattern exists with rising BE/ME ratios within the firm size quartiles. This result is in line with the findings demonstrated by Ziegler et al. (2007) and Hanauer et al. (2013).

By taking these findings into account, it can be concluded that the variable $r_{mt} - r_{ft}$ is considered to be an influencing factor, however, the CAPM is only partially able to explain the common variation in monthly portfolio excess returns. As measured by the adjusted R^2, particularly portfolios with small market values leave lots of common variation in monthly portfolio excess returns open that can be captured by other influencing factors.

5.2.1.2 Three-factor model of Fama and French

In this section the CAPM is augmented by the variables SMB_t and HML_t resulting in the FF3FM. Time-series regressions are conducted using equation F2.4. The results of the multiple regression tests are illustrated in table 5.6.

[21] Expressed in words: the CAPM is able to explain 41.7% of the common variation in monthly portfolio excess returns on the German stock market over the period July 2008 to June 2014.

$$r_{it} - r_{ft} = a_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \varepsilon_{it}$$

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	Estimator for β_{i1}			
1 (Small)	1.011***	0.895***	0.921***	0.860***
2	1.026***	0.929***	0.982***	1.072***
3	0.915***	1.171***	1.314***	1.515***
4 (Big)	1.050***	1.216***	0.424***	1.184***
	Estimator for β_{i2}			
1 (Small)	1.085***	1.223***	0.862***	0.960***
2	1.016***	0.905***	0.995***	1.141***
3	0.709***	0.941***	0.964***	1.295***
4 (Big)	0.267***	0.424***	–1.323***	0.363**
	Estimator for β_{i3}			
1 (Small)	–0.418	0.137	0.477***	0.550***
2	–0.394***	0.161	0.372***	0.719***
3	–0.048	0.165	0.368***	0.586***
4 (Big)	–0.253**	0.148	0.095	0.780***
	Adjusted R^2			
1 (Small)	0.281	0.483	0.587	0.635
2	0.742	0.729	0.784	0.798
3	0.665	0.765	0.753	0.664
4 (Big)	0.767	0.828	0.590	0.745

*, ** and *** refer to a rejection of the null hypothesis H_0: $\beta_i = 0$ at a significance level of 10%, 5% and 1%, respectively.

Table 5.6: Time-series regression results for the three-factor model of Fama and French

The values of β_{i1} have throughout positive signs and range from 0.424 (portfolio 4-3) to 1.515 (portfolio 3-4) with a mean of 1.030. Alike Ziegler et al. (2007) and Hanauer (2013), no specific patterns for the coefficients through increasing firm size or growing BE/ME can be reported. Interestingly, the coefficients of portfolios with small cap stocks (1-1 to 1-4) rise closer to the value 1. According to Hanauer et al. (2013), this is mainly due to the high negative correlation between $r_{mt} - r_{ft}$ and SMB_t.

β_{i2} and β_{i3} range from –1.323 to 1.295 (portfolios 4-3 and 3-4) and –0.418 to 0.780 (portfolios 1-1 and 4-4) with means of 0.739 and 0.215, respectively. Some coefficients have negative signs, in particular all values of β_{i3} within the lowest BE/ME quartile. Similarly, Ziegler et al. (2007) and Hanauer et al. (2013) show corresponding values from –0.208 to 1.012 and –0.124 to 1.131 for β_{i2} and from –0.530 to 0.651 and –0.371 to 0.842 for β_{i3}, respectively. In both studies clear tendencies for the values of β_{i2} and β_{i3} are identified. They document that β_{i2} decreases with growing firm size within the BE/ME quartiles. Also, when holding firm size constant, they report β_{i3} to rise with increasing BE/ME ratios. In this thesis the patterns of β_{i2} and β_{i3} are only partly observed. The values of β_{i2} follow the mentioned pattern rather inconsistently since five portfolios (3-2, 2-3, 3-3, 2-4 and 3-4) show contrary movements. However, except for portfolio 4-3, all values of β_{i3} increase with growing BE/ME ratio within the firm size quartiles.

Worthy to note is the high statistical significance of all included factors. Alike in the CAPM, all 16 values of β_{i1} are significantly different from zero at a 1% level. Similarly, all 16 values of β_{i2} show statistical significance, of these, 15 are significantly different from zero at a level of 1%. In nine out of 16 cases β_{i3} is statistically significant, of these, eight are significantly different from zero at a 1% level. As all of the three coefficients show strong statistical significance, the factors $r_{mt} – r_{ft}$, SMB_t, and HML_t are considered to have a clear effect on monthly portfolio excess returns on the German stock market.

In terms of the adjusted R^2, a systematic increase of the adjusted R^2 with growing firm size (when holding BE/ME constant) cannot be observed as previously in the CAPM. Its values range from 0.281 (portfolio 1-1) to 0.828 (portfolio 4-3) and average 0.676. By comparison, Ziegler et al. (2007) and Hanauer et al. (2013) report values ranging from 0.422 to 0.865 and 0.458 to 0.892 with means of 0.694 and 0.725, respectively. Thus, the FF3FM is clearly more advantageous over the CAPM in explaining the common variation. This result is in line with the findings by Ziegler et al. (2007) and Hanauer et al. (2013).

In summary it can be stated, that the investigated variables demonstrate significantly influencing factors and are able to explain 67.6% of the common variation in monthly portfolio excess returns on the German stock market. Even though the FF3FM is an improvement over the CAPM there still exists common variation that is not captured.

5.2.1.3 Profitability-based four-factor model

Finally, this section extents the previous model by the variable PMU_t to a four-factor model. Table 5.7 shows the estimated coefficients and the values of the adjusted R^2 for the variables of the four-factor model over the analyzed period.

$$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \beta_{i4} \cdot PMU_t + \varepsilon_{it}$$

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	Estimator for β_{i1}			
1 (Small)	1.032***	0.876***	0.873***	0.824***
2	0.963***	0.890***	0.946***	1.057***
3	0.845***	1.143***	1.255***	1.467***
4 (Big)	0.948***	1.123***	0.630***	1.117***
	Estimator for β_{i2}			
1 (Small)	1.142***	1.172***	0.733***	0.862***
2	0.848***	0.799***	0.897***	1.100***
3	0.520***	0.865***	0.805***	1.165***
4 (Big)	−0.007	0.172**	−0.766***	0.183
	Estimator for β_{i3}			
1 (Small)	−0.400	0.121	0.434***	0.518***
2	−0.449***	0.127	0.340***	0.706***
3	−0.109	0.140	0.316**	0.544***
4 (Big)	−0.343***	0.065	0.277*	0.721***
	Estimator for β_{i4}			
1 (Small)	−0.111	0.099	0.253**	0.191*
2	0.330***	0.207***	0.193**	0.081
3	0.370***	0.148	0.310***	0.255
4 (Big)	0.538***	0.495***	−1.090***	0.352***
	Adjusted R^2			
1 (Small)	0.272***	0.479***	0.610***	0.648***
2	0.792***	0.751***	0.801***	0.798***
3	0.746***	0.771***	0.779***	0.672***
4 (Big)	0.904***	0.918***	0.827***	0.775***

*, ** and *** refer to a rejection of the null hypothesis H_0: $\beta_i = 0$ at a significance level of 10%, 5% and 1%, respectively.

Table 5.7: Time-series regression results for the profitability-based four-factor model

Noticeable is that the multiple regression results of the four-factor model are very similar to the findings from the previously tested FF3FM. The values of β_{i1}, for example, are throughout positive again and average 0.999 instead of 1.030. Also, the coefficients of portfolios (1-1 to 1-4) with small stocks approach 1 and again no systematic pattern of β_{i1} can be observed.

The inconsistent patterns of β_{i2} and β_{i3} are also still present. When holding BE/ME constant the values of β_{i2} decrease with growing firm size, except for the same portfolios (3-2, 2-3, 3-3, 2-4 and 3-4) as documented in the findings before. The pattern of β_{i3} is slightly different. The values increase with rising BE/ME ratio (within the firm size quartiles), however, in this case without any exceptions. The ranges of β_{i2} and β_{i3} are –0.766 to 1.172 (portfolios 4-3 and 1-2) and –0.449 to 0.721 (portfolios 2-1 and 4-4) with overall means of 0.656 and 0.188 (instead of

0.739 and 0.215), respectively. As before, all signs of β_{i3} are negative in the lowest BE/ME quartile. It is not surprising that the majority of β_{i1}, β_{i2} and β_{i3} are strongly statistically significant within the 16 portfolios. All 16 portfolios of β_{i1} are significantly different from zero at a 1% level again. The coefficients of SMB_t, and HML_t are statistically significant in 14 instead of 16 and ten instead of nine portfolios, respectively. Therefore, also in the four-factor model the variables, $r_{mt} - r_{ft}$, SMB_t, and HML_t, represent influencing factors.

The factor loadings of β_{i4} from the new added variable PMU_t do not point to a systematic tendency. Its values range from –1.090 (portfolio 4-3) to 0.538 (portfolio 4-1) and average 0.164. Thus, of all coefficients β_{i4} has the lowest mean. This means that the monthly portfolio excess return increases with the lowest amount for every one per cent increase of PMU_t per month. Nevertheless, the coefficients show strong statistical significance among the 16 portfolios. In 11 cases statistical significance is observed, of these, eight portfolios are significantly different from zero at a 1% level and hence, likewise the other variables, PMU_t can be considered to be a factor that has a strong effect on monthly portfolio excess returns.

The values of the adjusted R^2 range from 0.272 (portfolio 1-1) to 0.918 (portfolio 4-2). Interestingly, each of the 16 portfolios reveals enhanced values for the adjusted R^2 over the FF3FM, except for portfolio 1-1 (0.272 over 0.281). This shows that portfolio 1-1 has the greatest amount of unexplained common variation. Furthermore, the overall average of the adjusted R^2 increases from 0.676 to 0.721 over the FF3FM.[22] This gives evidence that the variables of the four-factor model have a significant influence on monthly portfolio excess returns and are able to better explain the corresponding common variation over the investigated overall period compared to both the FF3FM and the CAPM.

5.2.2 Cross-section of portfolio excess returns

This last section analyzes whether the explanatory variables of each model are sufficient to explain the cross-section of portfolio excess returns and thus, indicate how well the models are specified. This can be investigated through a simple test, that is, the intercepts of time-series regressions should not be significantly different from zero in a two-tailed t-test.[23]

[22] Expressed in words: the four-factor model is able to explain 72.1% of the common variation in monthly portfolio excess returns on the German stock market over the period July 2008 to June 2014.

[23] Two-tailed t-test: H_0: $\alpha_i = 0$, H_1: $\alpha_i \neq 0$.

According to table 5.8 the range of the CAPM's intercepts reach from –0.476% (portfolio 4-1) to 3.199% (portfolio 1-1). From an economic standpoint, this indicates a tremendously high variation, mainly documented in the small size portfolios. Ziegler et al. (2007) and Hanauer et al. (2013) present corresponding lower ranges from –0.282% to 0.480% and –1.050% to 0.562%, respectively. Furthermore, when holding BE/ME constant, the intercepts decrease with growing firm size. No systematic relation is detected within the firm size quartiles, though. In six out of 16 test portfolios the intercepts are statistically significant and in even three cases significance is given at a 1% level. Four of the significant alphas occur in the small size portfolios (1-1 to 1-4) and the other two in portfolios 2-3 and 2-4. This indicates that the CAPM fails to properly explain the stock returns in these portfolios.

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	Estimator for α_i			
	$r_{it} - r_{ft} = \alpha_i + \beta_i \cdot [r_{mt} - r_{ft}] + \varepsilon_{it}$			
1 (Small)	3.199***	1.684**	1.680***	2.049***
2	0.870	0.528	0.832*	1.192**
3	0.729	0.433	0.796	0.690
4 (Big)	−0.476	−0.287	0.901	0.502
	$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \varepsilon_{it}$			
1 (Small)	2.374**	0.423	0.585	0.819*
2	0.098	−0.437	−0.336	−0.305
3	0.067	−0.569	−0.339	−0.885
4 (Big)	−0.598*	−0.779**	2.133***	−0.274
	$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \beta_{i4} \cdot PMU_t + \varepsilon_{it}$			
1 (Small)	2.357**	0.439	0.625	0.849**
2	0.151	−0.405	−0.305	−0.293
3	0.126	−0.546	−0.290	−0.845
4 (Big)	−0.513**	−0.700***	1.960***	−0.218

*, ** and *** refer to a rejection of the null hypothesis H_0: $\alpha_i = 0$ at a significance level of 10%, 5% and 1%, respectively.

Table 5.8: Estimators for the intercepts α_i of the regression models

For the FF3FM the range of the intercepts becomes smaller from –0.779% to 2.374%. Still, the variation remains very high. Ziegler et al. (2007) and Hanauer et al. (2013) report ranges reaching from –0.129% to 0.143% and –0.513% to 0.537%, respectively. In none of the cases a systematic relation can be determined anymore. Also, in five out of 16 test portfolios statistical significance is given. Of these, only one portfolio is significantly different from zero at a level of 1%. The concerned portfolios primarily consist of big size stocks (4-1 to 4-3) but also portfolios 1-1 and 1-4. Even though the FF3FM implies an improvement over the CAPM, it also fails to accurately explain the cross-section in the mentioned portfolios. These results are in line with the findings by Hanauer et al. (2013). Ziegler et al. (2007) find no portfolio significantly different from zero and thus, revealing a tremendously well-specified FF3FM.

Finally, the alphas for the four-factor model are analyzed and compared. It is important to point out that the values and the distribution of the intercepts are very similar to the results of the FF3FM. Although the range of the intercepts slightly becomes smaller from –0.700% to 2.357%, still no systematic relations within the firm size or BE/ME quartiles are observed. The frequency and distribution of the statistically significant intercepts also remain the same. However, it is very surprising that the intercepts are minimally more significant than the alphas of the FF3FM. In the case of the four-factor model statistical significance at a 1% level is given in two out of six cases, rather than in only one.

In summary, none of the examined models is capable to consistently explain the cross-section of portfolio excess returns over the observed period and thus, none of the models is perfectly specified. Nevertheless, both the FF3FM and the four-factor model clearly outperform the CAPM. Also, the FF3FM does marginally a better job than the four-factor model in explaining the cross-section of portfolio excess returns.

5.3 Diagnostic tests

The empirical results of the four-factor model are tested for validity based on the six assumptions of the Gauss-Markov theorem listed in table 5.9.

Assumption	Description	Method
1	The regression model is linear in the coefficients, correctly specified and has an additive error term.	$Y_i = \beta_0 + \beta_i X_i + \varepsilon_i$
2	The mean of the error term is zero.	$E(\varepsilon_i) = 0$
3	None of the independent variables are correlated with the error term.	$Cov(X_i, \varepsilon_i) = 0$
4	None of the independent variables have a perfect relationship with any of the other independent variables (no multicollinearity).	$VIF(\beta_i) < 10$
5	The error term observations are independent of each other, so they are not correlated with each other (no autocorrelation).	*Durbin Watson test*
6	The error term has a constant variance (no heteroscedasticity).	*White test*

Table 5.9: Assumptions of the Gauss-Markov theorem

If assumptions 1 to 6 hold true then the OLS method is considered to be the Best Linear Unbiased Estimator (BLUE), that is, of all linear, unbiased methods used to estimate a regression model, OLS works best.

Assumptions 1 to 3 are perfectly complied and thus, hold true. Assumption 4 tests for multicollinearity.[24] For this, the Variance Inflation Factors (VIF) of the coefficients are considered. A value below 10 indicates no existence of multicollinearity. In this case none of the VIFs are larger than the value of 10. This means, the regression model is not affected by multicollinearity and hence, assumption 4 is complied.

Assumption 5 implies that the residuals are not correlated with each other. In this thesis the existence of first-order autocorrelation is empirically examined through the Durbin Watson (DW) test. It tests the null hypothesis whether the error terms from an OLS regression are not autocorrelated at a 1% significance level. The results confirm that negative first-order autocorrelation is given in one case (portfolio 2-2). Four DW values lie in the uncertainty zone. Yet, in this case the null hypothesis is not rejected to ones favor, which means no autocorrelation is present. Figure 5.1 graphically illustrates the results of the DW test. Since the residuals of portfolio 2-2 are autocorrelated to a very small extent only, it is further retained on the assumption of an unbiased model. Thus, assumption 5 is considered to be satisfactory.

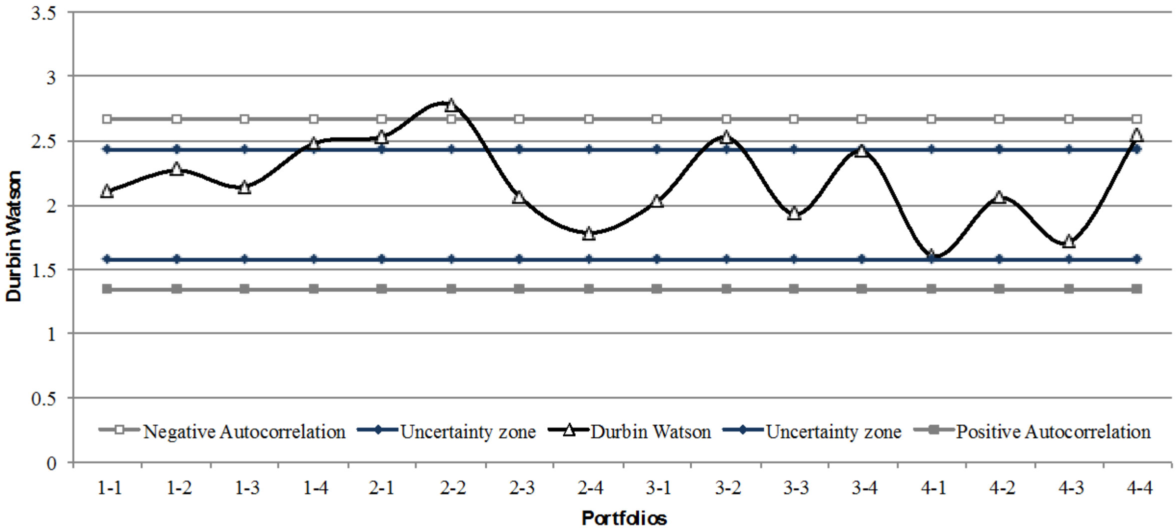

Figure 5.1: Durbin Watson test to analyze for the presence of autocorrelation

[24] In section 4.1.2 the presence of multicollinearity was already examined through the *Pearson* correlation coefficients.

The last assumption tests for the presence of homoscedasticity. Therefore, the White test is conducted. In the White test the squared residuals are used as dependent variables and are regressed on the four factors, the four factors squared and the cross products of all factors. The null hypothesis tests for no heteroscedasticity at a 1% significance level. The empirical results of the White test indicate that heteroscedasticity is present in two out of 16 cases (portfolios 4-1 and 4-3). Figure 5.2 depicts the values of the performed White test against the critical values.

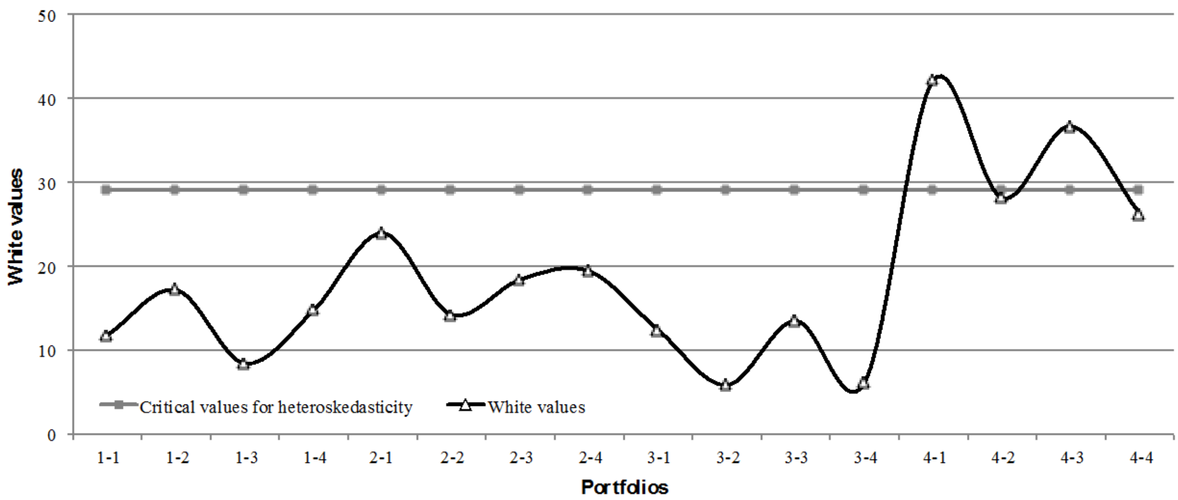

Figure 5.2: White test to analyze the for presence of heteroscedasticity

Even though heteroscedasticity is present in two cases it is still retained on the linearity of the regression model for the following reasons. First, the existence of heteroscedasticity does not affect two successive portfolios. Second, heteroscedasticity might result in biased significance tests, although it does not lead to biased parameter estimates. Since all portfolios are based on individual regressions, the results of the remaining 14 test portfolios are not influenced by the two heteroscedastic portfolios at all. For these reasons assumption 6 is also considered to hold true.

To sum up, assumptions 1 to 6 seem to hold true for the most part. Thus, the OLS method is considered to be BLUE.

6 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary of the main findings

Based on monthly stock returns of the CDAX over the period July 2008 to June 2014 this thesis documents four main findings. Table 6.1 provides an overview of the empirical results.

Summary of the main findings				
Factor/ measure	CAPM	Three-factor model of Fama and French	Profitability-based four-factor model	Monthly avg. premiums
$r_{mt} - r_{ft}$	16/16 portfolios***	16/16 portfolios***	16/16 portfolios***	1.061%*
SMB_t		15/16 portfolios*** 1/16 portfolio**	13/16 portfolios*** 1/16 portfolio**	0.553%
HML_t		8/16 portfolios*** 1/16 portfolio**	8/16 portfolios*** 1/16 portfolio** 1/16 portfolio*	0.701%*
PMU_t			8/16 portfolios*** 2/16 portfolios** 1/16 portfolio*	0.441%
Average adjusted R^2	0.417	0.676	0.721	
Intercepts (α_i)	3/16 portfolios*** 2/16 portfolios** 1/16 portfolio*	1/16 portfolios*** 2/16 portfolios** 2/16 portfolios*	2/16 portfolios*** 3/16 portfolios**	

Significance levels: 10% (*), 5% (**) and 1% (***).

Table 6.1: Summary of the main findings

First, the monthly average premiums for the factors $r_{mt} - r_{ft}$, SMB_t, HML_t and PMU_t amount 1.061%, 0.553%, 0.701% and 0.441%, respectively. Of these, only $r_{mt} - r_{ft}$, and HML_t are significantly different from zero at a 10% level. Interestingly, the monthly premium of PMU_t, which is not significantly different from zero, represents the lowest of all values while $r_{mt} - r_{ft}$ represents the highest. The results for $r_{mt} - r_{ft}$ and HML_t are in line with the findings by Ziegler et al. (2007) and Hanauer et al. (2013). Furthermore, it is surprising that all monthly premiums are positive, in particular SMB_t. Although the premium identified for SMB_t implies the classical size effect, prior studies on the German stock market document a negative size premium.[25] These studies and the findings in this thesis, however, have an insignificant size premium in

[25] Artmann et al. (2012) or Jaron and Romberg (2009) document an insignificant negative premium for size in Germany.

common. This contributes to the current debate about the existence of the size effect in Germany as reported by van Dijk (2011).

Second, each of the four factors demonstrates high statistical significance. The factor $r_{mt} - r_{ft}$ is significantly different from zero at a 1% level in all possible cases and models. SMB_t, and HML_t are statistically significant in 16 and nine portfolios for the FF3FM and in 14 and ten portfolios for the four-factor model, respectively. The factor PMU_t illustrates statistical significance in 11 cases, of these, eight portfolios are significantly different from zero at a 1% level. Thus, it can be concluded that all four factors have a strong influence on monthly portfolio excess returns over the examined period on the German stock market.

Third, the FF3FM performs substantially better than the classical CAPM in explaining the common variation in monthly portfolio excess returns. The values of the average adjusted R^2 of the 16 test portfolios amount 0.417 and 0.676 for the CAPM and the FF3FM, respectively. The four-factor model shows additional improvement over the CAPM and the FF3FM, that is, 72.1% of the common variation in monthly portfolio excess returns is captured by the mutual interaction of the factors $r_{mt} - r_{ft}$, SMB_t, HML_t and PMU_t.

Finally, none of the investigated models is able to consistently explain the cross-section of portfolio excess returns. As expected the CAPM performs worst. Surprisingly, the FF3FM does slightly better in explaining the cross-section of portfolio excess returns than the four-factor model since its estimated intercepts are marginally less significant. However, neither provides a satisfactory explanation and thus, none of the models is perfectly well specified.

The results of the four-factor model were tested for validity through the six assumptions of the Gauss-Markov theorem. By means of several empirical test procedures the analyzed assumptions hold true for the most part. Thus, it can be concluded that the linear approach of OLS is appropriate to conduct the estimations of the examined regression models.

6.2 Conclusion

Based on the reported empirical results it can be concluded that an extension of the CAPM is reasonable in every sense. In the light of the examined period, the CAPM performs worse in capturing the common variation in monthly portfolio excess returns and in explaining its cross-section compared to the FF3FM and the four-factor model.

The situation between the FF3FM and the four-factor model, however, is not as distinct. Even though no evidence is found for a gross profitability effect in Germany, the four-factor model clearly outperforms the FF3FM in capturing the common variation in portfolio returns.

The four-factor model explains 72.1% of the common variation in portfolio returns, however, there is still a certain amount of variation unexplained. Most likely this is captured by more or even other factors. Indeed, the FF3FM is best to explain the cross-section of portfolio returns, although, still far from perfect. It is important to mention that the FF3FM does explain the cross-section only somewhat better than the four-factor model. Based on these findings and in order to answer the examined research question, the four-factor model is considered to be an improvement over the FF3FM in determining stock returns, even if the presented evidence is not as obvious as for the US stock market as revealed by Novy-Marx (2013).

Nevertheless, the ambiguous results documented in this thesis are no reason for despair. Since stock returns are usually very noisy and the results strongly depend on the examined period, the identification of a perfect model is rather scarce. But yet, in terms of practical applications, the four-factor model is versatile. For instance, the model qualifies for the estimation of capital costs in alternative to the CAPM. Next to the return of the risk-free rate and the market, the variables SMB_t, HML_t and PMU_t are classified and implemented as non-stock specific factors. Furthermore, the four-factor model might also find application in managing portfolios of financial assets including the assessment of their performance.

6.3 Recommendations for future research

Since the results indicate an extension of the FF3FM by the variable gross profitability to be reasonable, several recommendations for future research can be identified that are of interest.

As the underlying dataset is faced to certain limitations, a first recommendation for future research would be to enlarge the sample period and to use the exact annual composition of the CDAX. In that case it could be examined whether the results of the four-factor model are similar to the findings in this thesis and whether they show stability over time.

Based on this, another recommendation would be to investigate whether the same four-factor model is able to explain monthly portfolio excess returns without being based on size and BE/ME sorts but rather on size and GP/A, BE/ME and GP/A or even on the basis of a three-dimensional sort like size, BE/ME and GP/A, as similarly performed by Fama and French (2013), for example. It would also be interesting to apply a totally different basis such as sales growth, the P/E or C/P ratio. The reason for these modifications is to examine whether the four-factor model does also capture anomalies that are not based on size and BE/ME.

In fact, another basis and/or sample period might also improve the capability of the four-factor model to better explain the cross-section of portfolio excess returns over the FF3FM.

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Appendix

Part A: Literature Review (section 3)

Relevant market anomalies and empirical evidence of prestigious authors

Market anomaly	Description of the anomalous effect	Pioneering author(s)
Anomalies in terms of the efficient market hypothesis		
Momentum effect	Stocks with high returns in the previous three to twelve months continue to have, on average, high future returns (vice versa)	Jegadeesh (1990), Jegadeesh and Titman (1993)
Long-term mean reversion	Stocks with low returns in the previous three years tend to have, on average, high future returns (vice versa)	DeBondt and Thaler (1985)
Short-term mean reversion	Stocks with extremely low returns on the last trading day tend to have, on average, high future returns (vice versa)	DeBondt and Thaler (1989)
Anomalies based on company key indicators		
Firm size	Small firms earn, on average, higher returns than large companies (vice versa)	Banz (1981)
Book-to-market ratio	Firms with a low BE/ME-ratio earn, on average, higher returns than businesses with a high BE/ME-ratio (vice versa)	Stattman (1980), Rosenberg et al. (1985)
Price-earnings ratio	Companies with a low P/E-ratio earn, on average, higher returns than firms with a high P/E-ratio (vice versa)	Basu (1977, 1983)
Dividend yield	Businesses with a high dividend yield earn, on average, higher returns than firms with a low dividend yield (vice versa)	Keim (1985)
Financial leverage	Firms with a low debt/equity ratio earn, on average, higher returns than businesses with a high debt/equity ratio (vice versa)	Bhandari (1988)
Anomalies based on seasonal events		
January effect	Stock returns are, on average, higher in January than in other months, especially on the first trading days (vice versa)	Rozeff and Kinney (1976)
Weekend effect	Stock returns are, on average, larger on Fridays than on the following Monday (vice versa)	French (1980)

Appendix 1: Overview of the most relevant market anomalies

Source: Own illustration, based on Roßbach (2001)

Author(s)	Data	Relevant anomaly	Method	Relevant empirical findings
Banz (1981)	NYSE (1936-1975)	Size	Regression analyses, including four sub-periods	For all examined periods it is shown that stocks with high market values have, on average, lower returns than stocks with low market values
Reinganum (1981)	NYSE/AMEX (1963-1977)	Size	Formation of 10 portfolios sorted on size	Average monthly excess returns: - smallest size portfolio: 0.500% - largest size portfolio: -0.343% Not dependent on P/E-ratio
Keim (1983)	CRSP (1963-1979)	Size	Formation of 10 portfolios sorted on size	Average daily excess returns: - smallest size portfolio: 0.082% - largest size portfolio: -0.038% Size effect is mainly found in January
Brown et al. (1983a)	NYSE/AMEX (1962-1978)	Size	Formation of 10 portfolios sorted on size, 1st sample: Reinganum (1981) dataset, 2nd sample: NYSE/AMEX stocks	Average daily excess returns: - smallest size portfolio: 0.79%/0.58% (1st/2nd) - largest size portfolio: -0.85%/-0.30% (1st/2nd) Finds reversal of size effect for certain years
DeBondt and Thaler (1985)	CRSP (1926-1982)	Long-term return reversal	Portfolios with 35 stocks, respectively, over 36 months ranking and testing period	Cumulative average return: - Portfolio (losers minus winners) 24.6% - loser stocks outperform market by 19.6% - winner stocks underperform market by 5.0%
DeBondt and Thaler (1987)	CRSP (1926-1982)	Long-term return reversal	Portfolios with 50 stocks, respectively, over a five-year ranking and testing period	Cumulative average return: - Portfolio (losers minus winners) 31.9%
Lamoureux and Sanger (1989)	NYSE AMEX NASDAQ (1973-1985)	Size	Formation of 20 portfolios sorted on size, 1st sample: NASDAQ stocks, 2nd sample: NYSE/AMEX stocks	Average monthly raw returns: - smallest size portfolio: 3.00% (1st) - largest size portfolio: 1.00% (1st) - smallest size portfolio: 2.50% (2nd) - largest size portfolio: 0.80% (2nd)
Jegadeesh (1990)	CRSP (1934-1987)	Momentum	10 equally-weighted portfolios over a 1 and 12-month ranking and testing period	Average monthly excess returns: - 1/12m portfolio from Jan. - Dec.: 1.99%/0.93% - 1/12m portfolio in Jan.: 3.89%/1.73% - 1/12m portfolio from Feb. - Dec.: 1.75%/0.73%
Chan et al. (1991)	Tokyo Stock Exchange (1971-1988)	BE/ME	Formation of 64 portfolios sorted on P/E, size, BE/ME and C/P	Average monthly returns: - low BE/ME portfolio: 1.33% - high BE/ME portfolio: 2.43%
Fama and French (1992)	NYSE AMEX NASDAQ (1962-1989)	Size BE/ME	Formation of 12 portfolios sorted on BE/ME, size and E/P	Average monthly returns: - smallest size portfolio: 1.96% - largest size portfolio: 0.93% - lowest BE/ME portfolio: 0.64% - highest BE/ME portfolio: 1.63%
Jegadeesh and Titman (1993)	NYSE/AMEX (1965-1989)	Momentum	10 equally-weighted portfolios over a 3, 6, 9 and 12-month ranking and testing period	Average monthly returns: (winner minus loser) - 3-month rank between 0.32% and 0.69% - 6-month rank between 0.84% and 1.02% - 9-month rank between 0.82% and 1.21% - 12-month rank between 0.68% and 1.31%
Fama and French (1993)	NYSE AMEX NASDAQ (1963-1991)	Size BE/ME	Formation of 25 Portfolios sorted on size and BE/ME	Average monthly excess returns: - small minus big (SMB) portfolio: 0.27% - high minus low (HML) portfolio: 0.40%
Lakonishok et al. (1994)	NYSE/AMEX /NASDAQ (1963-1990)	BE/ME	Formation of 10-decile portfolios sorted on BE/ME, C/P and E/P	Average annual returns: - Portfolio with glamour stocks: -4.30% - Portfolio with value stocks: 3.50%
Davis et al. (2000)	NYSE/AMEX (1929-1997)	BE/ME	Formation of 9 portfolios sorted on size and BE/ME	Average monthly excess returns: - high minus low (HML) portfolio: 0.46%
Fama and French (2012)	North America, Europe, Japan and Asia Pacific (1990-2011)	Size BE/ME Momentum	Formation of 25 portfolios sorted on size and BE/ME; size and momentum	Average annual excess returns: - SMB/HML/WML (North America): 0.24%/0.33%/0.64% - SMB/HML/WML (Europe): -0.06%/0.55%/0.92% - SMB/HML/WML (Japan): -0.09%/0.48%/0.08% - SMB/HML/WML (Asia Pacific): -0.21%/0.62%/0.69% - SMB/HML/WML (Global): 0.10%/0.45%/0.62%

Appendix 2: Relevant empirical results of the US stock market

Appendix

Author(s)	Data	Relevant anomaly	Method	Relevant empirical findings
Meyer (1994)	Frankfurt Stock Exchange (1961-1990)	Long-term return reversal	Ranking and testing period between one and nine years	Cumulative average return: - Portfolio (losers minus winners) 25% For five-year ranking and testing period Returns are significantly higher in January
Sattler (1994)	Frankfurt Stock Exchange (1954-1991)	Long-term return reversal	Portfolios with 20 stocks, respectively, over a five-year ranking and testing period	Cumulative average return: - Portfolio (losers minus winners) 67%
Fama and French (1998)	13 global countries (1975-1995)	BE/ME	Formation of value and growth portfolios sorted on BE/ME, E/P, C/P and D/P	Average monthly excess returns: - HML portfolio (Germany): 2.75%
Schiereck et al. (1999)	Frankfurt Stock Exchange (1961-1991)	Momentum	Portfolios with 10, 20 and 40 stocks, respectively, over rank periods of 1, 3, 6, and 12 months	Cumulative excess returns: - 1-month rank (20 W-L): 23.61% - 3-month rank (20 W-L): 40.35% - 6-month rank (20 W-L): 59.51% - 12-month rank (20 W-L): 92.95%
Heston et al. (1999)	12 European countries (1978-1995)	Size	Formation of 25 portfolios sorted on size and beta	Average monthly excess returns: - SMB portfolio (Germany): 0.11% The result is statistically insignificant
Wallmeier (2000)	Frankfurt Stock Exchange (1967-1994)	BE/ME	Formation of 6 one-dimensional portfolios sorted on beta, size, leverage, BE/ME, C/P and E/P	Average monthly returns: - low BE/ME portfolio: 0.0780% - high BE/ME portfolio: 0.2037% - low C/P portfolio: 0.1034% - high C/P portfolio: 0.1758%
Glaser and Weber (2003)	Frankfurt Stock Exchange (1988-2001)	Momentum	5 equally-weighted portfolios over a 3, 6, 9 or 12-month ranking and testing period	Average monthly returns: (winner minus loser) - 3-month rank between 0.21% and 0.52% - 6-month rank between 0.46% and 0.71% - 9-month rank between 0.77% and 0.96% - 12-month rank between 0.71% and 1.07%
Ziegler et al. (2007)	Frankfurt Stock Exchange (1967-1995)	Size BE/ME	Formation of 16 Portfolios sorted on size and BE/ME	Average monthly returns: - SMB portfolio: 0.083% - HML portfolio: 0.402%
Jaron and Romberg (2009)	CDAX (1990-2007)	Size	Formation of 6 Portfolios sorted on size and P/B-ratio	Average monthly excess returns: - small minus big (SMB) portfolio: -0.59%
Artmann et al. (2011)	Frankfurt Stock Exchange (1963-2006)	Size BE/ME E/P Momentum	Six different (4x4) double-sorted portfolios on size, BE/ME, E/P and momentum	Average monthly returns: - SMB portfolio: -0.167% - HML portfolio: 0.575% - E/P portfolio: 0.632% - WML portfolio: 0.943%
Hanauer et al. (2013)	CDAX (1996-2011)	Size BE/ME Momentum	Formation of 16 Portfolios sorted on size and BE/ME	Average monthly returns: - SMB portfolio: -0.705% - HML portfolio: 0.735% - WML portfolio: 1.187%

Appendix 3: Relevant empirical results of the German stock market

Novy-Marx (2013) US: AMEX stocks over the period 1963-2010 International: Stocks of 19 countries over the period 1990-2009		
Variables	**Portfolio construction**	**Summary of empirical findings**
Independent variables: - Excess market return - SMB - HML - UMD (up minus down) risk factor related to momentum - PMU (profitable minus unprofitable) risk factor related to profitability **Dependent variables:** - Monthly portfolio excess returns	**Independent variables:** - Portfolios are sorted on gross profits-to-assets and BE/ME, respectively - Portfolios are formed by using NYSE breakpoints	**US market:** Monthly average excess returns: - Unprofitable stocks: 0.31% (t = 1.65) - Profitable stocks: 0.62% (t = 3.12) - Low BE/ME stocks: 0.39% (t = 1.88) - High BE/ME stocks: 0.80% (t = 3.88) **International evidence:** Monthly average excess returns: - Unprofitable stocks: -0.16% (t = -0.37) - Profitable stocks: 0.60% (t = 1.95) - Low BE/ME stocks: 0.09% (t = 0.25) - High BE/ME stocks: 0.61% (t = 1.79)

Appendix 4: Key data of the work of Novy-Marx (2013)

Part B: Descriptive statistics (section 5.1)

Two-tailed t-statistics to test for the statistical significance of the monthly mean returns

Key data	Significance levels	Critical values (t)	Two-tailed t-test
	10%*	1.645	
Sample (n): 72	5%**	1.960	H_0: $\mu_i = 0$
Degrees of freedom (n–1): 71	1%***	2.576	H_1: $\mu_i \neq 0$

Decision rule If $| t | > t_{1-\alpha/2} \rightarrow H_0$ is rejected. Thus, the monthly mean return of the variable is statistically significant.

Firm char.	Mean	Std. Dev.	t-values	Decision rule
Beta	0.64	1.01	28.226	$\| 28.226 \| > 2.576$ H_0 is rejected ***
Size (million €)	2,502.11	8,691.36	12.800	$\| 12.800 \| > 2.576$ H_0 is rejected ***
BE/ME	0.89	0.73	54.385	$\| 54.385 \| > 2.576$ H_0 is rejected ***
GP/A	0.25	0.23	47.187	$\| 47.187 \| > 2.576$ H_0 is rejected ***

Appendix 5: Two-tailed t-statistics for beta and the firm characteristics

Key data	Significance levels	Critical values (t)	Two-tailed t-test
	10%*	1.667	
Sample (n): 72	5%**	1.994	H_0: $\mu_i = 0$
Degrees of freedom (n–1): 71	1%***	2.647	H_1: $\mu_i \neq 0$

Decision rule If $| t | > t_{1-\alpha/2} \rightarrow H_0$ is rejected. Thus, the monthly mean return of the variable is statistically significant.

Variable	Mean	Std. Dev.	t-values	Decision rule
r_{mt}	1.134	5.159	1.866	$\| 1.866 \| > 1.667$ H_0 is rejected *
r_{ft}	0.073	0.091	6.777	$\| 6.777 \| > 2.647$ H_0 is rejected ***
$r_{mt} - r_{ft}$	1.061	5.182	1.738	$\| 1.738 \| > 1.667$ H_0 is rejected *
SMB_t	0.553	3.845	1.221	$\| 1.221 \| < 1.667$ H_0 is not rejected
HML_t	0.701	3.072	1.936	$\| 1.936 \| > 1.667$ H_0 is rejected *
PMU_t	0.441	4.078	0.918	$\| 0.918 \| < 1.667$ H_0 is not rejected

Appendix 6: Two-tailed t-statistics for the explanatory variables

Key data	Significance levels	Critical values (t)	Two-tailed t-test
	10%*	1.667	
Sample (n): 72	5%**	1.994	H_0: $\mu_i = 0$
Degrees of freedom (n–1): 71	1%***	2.647	H_1: $\mu_i \neq 0$

Decision rule If $|t| > t_{1-\alpha/2} \rightarrow H_0$ is rejected. Thus, the monthly mean return of the variable is statistically significant.

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	t-values			
1 (Small)	3.754	2.853	3.513	4.143
2	2.287	2.000	2.467	2.747
3	2.433	1.868	2.278	1.824
4 (Big)	0.749	1.153	1.917	1.977

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	Decision rule			
1 (Small)	$\|3.699\| > 2.647$ H_0 is rejected ***	$\|2.853\| > 2.647$ H_0 is rejected ***	$\|3.513\| > 2.647$ H_0 is rejected ***	$\|4.143\| > 2.647$ H_0 is rejected ***
2	$\|2.286\| > 1.994$ H_0 is rejected **	$\|2.000\| > 1.994$ H_0 is rejected **	$\|2.467\| > 1.994$ H_0 is rejected **	$\|2.747\| > 2.647$ H_0 is rejected ***
3	$\|2.433\| > 1.994$ H_0 is rejected **	$\|1.868\| > 1.667$ H_0 is rejected *	$\|2.278\| > 1.994$ H_0 is rejected **	$\|1.824\| > 1.667$ H_0 is rejected *
4 (Big)	$\|0.748\| < 1.667$ H_0 is not rejected	$\|1.153\| < 1.667$ H_0 is not rejected	$\|1.917\| > 1.667$ H_0 is rejected *	$\|1.917\| > 1.667$ H_0 is rejected *

Appendix 7: Two-tailed t-statistics for the dependent variables

Part C: Time-series regression analyses (section 5.2)

Two-tailed t-statistics to test for the statistical significance for the coefficients

Key data	**Significance levels**	**t-values ($t_{n-k;\,1-\alpha/2}$)**	**Two-tailed t-test**
Sample (n): 72	10%*	1.667	
Explanatory variables (k): 1	5%**	1.994	$H_0: \beta_i = 0$
Degrees of freedom (n–k): 71	1%***	2.647	$H_1: \beta_i \neq 0$

Decision rule If $|t| > t_{n-k;\,1-\alpha/2} \rightarrow H_0$ is rejected. Thus, the slope is statistically significant.

$$r_{it} - r_{ft} = \alpha_i + \beta_i \cdot [r_{mt} - r_{ft}] + \varepsilon_{it}$$

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	t-values for β_i and two-tailed t-tests for its statistical significance			
1 (Small)	$\mid 2.775 \mid > 2.647$ H_0 is rejected ***	$\mid 3.155 \mid > 2.647$ H_0 is rejected ***	$\mid 6.114 \mid > 2.647$ H_0 is rejected ***	$\mid 5.362 \mid > 2.647$ H_0 is rejected ***
2	$\mid 5.347 \mid > 2.647$ H_0 is rejected ***	$\mid 6.755 \mid > 2.647$ H_0 is rejected ***	$\mid 6.993 \mid > 2.647$ H_0 is rejected ***	$\mid 6.659 \mid > 2.647$ H_0 is rejected ***
3	$\mid 7.545 \mid > 2.647$ H_0 is rejected ***	$\mid 8.668 \mid > 2.647$ H_0 is rejected ***	$\mid 9.370 \mid > 2.647$ H_0 is rejected ***	$\mid 7.317 \mid > 2.647$ H_0 is rejected ***
4 (Big)	$\mid 13.605 \mid > 2.647$ H_0 is rejected ***	$\mid 16.099 \mid > 2.647$ H_0 is rejected ***	$\mid 6.032 \mid > 2.647$ H_0 is rejected ***	$\mid 11.443 \mid > 2.647$ H_0 is rejected ***

Appendix 8: Two-tailed t-statistics for the coefficients of the CAPM

Key data	**Significance levels**	**t-values ($t_{n-k;\,1-\alpha/2}$)**	**Two-tailed t-test**
Sample (n): 72	10%*	1.667	
Explanatory variables (k): 3	5%**	1.995	$H_0: \beta_i = 0$
Degrees of freedom (n–k): 69	1%***	2.649	$H_1: \beta_i \neq 0$

Decision rule If $|\,t\,| > t_{n-k;\,1-\alpha/2} \rightarrow H_0$ is rejected. Thus, the slope is statisticalyl significant.

$$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \varepsilon_{it}$$

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	t-values for β_{i1} and two-tailed t-tests for its statistical significance			
1 (Small)	| 5.091 | > 2.649 H_0 is rejected ***	| 7.169 | > 2.649 H_0 is rejected ***	| 9.193 | > 2.649 H_0 is rejected ***	| 9.652 | > 2.649 H_0 is rejected ***
2	| 13.575 | > 2.649 H_0 is rejected ***	| 13.312 | > 2.649 H_0 is rejected ***	| 14.894 | > 2.649 H_0 is rejected ***	| 14.432 | > 2.649 H_0 is rejected ***
3	| 11.939 | > 2.649 H_0 is rejected ***	| 14.930 | > 2.649 H_0 is rejected ***	| 14.138 | > 2.649 H_0 is rejected ***	| 11.176 | > 2.649 H_0 is rejected ***
4 (Big)	| 14.497 | > 2.649 H_0 is rejected ***	| 17.241 | > 2.649 H_0 is rejected ***	| 2.872| > 2.649 H_0 is rejected ***	| 11.614 | > 2.649 H_0 is rejected ***

	t-values for β_{i2} and two-tailed t-tests for its statistical significance			
1 (Small)	| 4.011 | > 2.649 H_0 is rejected ***	| 7.199 | > 2.649 H_0 is rejected ***	| 6.323 | > 2.649 H_0 is rejected ***	| 7.909 | > 2.649 H_0 is rejected ***
2	| 9.879 | > 2.649 H_0 is rejected ***	| 9.518 | > 2.649 H_0 is rejected ***	| 11.085 | > 2.649 H_0 is rejected ***	| 11.283 | > 2.649 H_0 is rejected ***
3	| 6.790 | > 2.649 H_0 is rejected ***	| 8.810 | > 2.649 H_0 is rejected ***	| 7.615 | > 2.649 H_0 is rejected ***	| 7.019 | > 2.649 H_0 is rejected ***
4 (Big)	| 2.712 | > 2.649 H_0 is rejected ***	| 4.419 | > 2.649 H_0 is rejected ***	|–6.574 | > 2.649 H_0 is rejected ***	| 2.615 | > 1.995 H_0 is rejected **

	t-values for β_{i3} and two-tailed t-tests for its statistical significance			
1 (Small)	|–1.410 | < 1.667 H_0 is not rejected	| 0.736 | < 1.667 H_0 is not rejected	| 3.187 | > 2.649 H_0 is rejected ***	| 4.137 | > 2.649 H_0 is rejected ***
2	|–3.495 | > 2.649 H_0 is rejected ***	| 1.546 | < 1.667 H_0 is not rejected	| 3.781 | > 2.649 H_0 is rejected ***	| 6.486 | > 2.649 H_0 is rejected ***
3	|–0.415 | < 1.667 H_0 is not rejected	| 1.408 | < 1.667 H_0 is not rejected	| 2.650 | > 2.649 H_0 is rejected ***	| 2.897 | > 2.649 H_0 is rejected ***
4 (Big)	|–2.336 | > 1.995 H_0 is rejected **	| 1.406 | < 1.667 H_0 is not rejected	| 0.432 | < 1.667 H_0 is not rejected	| 5.123 | > 2.649 H_0 is rejected ***

Appendix 9: Two-tailed t-statistics for the coefficients of the three-factor model

Key data	**Significance levels**	**t-values ($t_{n-k;\,1-\alpha/2}$)**	**Two-tailed t-test**
Sample (n): 72	10%*	1.667	
Explanatory variables (k): 4	5%**	1.994	$H_0: \beta_i = 0$
Degrees of freedom (n–k): 68	1%***	2.647	$H_1: \beta_i \neq 0$

Decision rule If | t | > $t_{n-k;\,1-\alpha/2}$ → H_0 is rejected. Thus, the slope is statistically significant.

$$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \beta_{i4} \cdot PMU_t + \varepsilon_{it}$$

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	t-values for β_{i1} and two-tailed t-tests for its statistical significance			
1 (Small)	| 5.045 | > 2.650 H_0 is rejected ***	| 6.827 | > 2.650 H_0 is rejected ***	| 8.755 | > 2.650 H_0 is rejected ***	| 9.194 | > 2.650 H_0 is rejected ***
2	| 13.864 | > 2.650 H_0 is rejected ***	| 12.990 | > 2.650 H_0 is rejected ***	| 14.591 | > 2.650 H_0 is rejected ***	| 13.879 | > 2.650 H_0 is rejected ***
3	| 12.350 | > 2.650 H_0 is rejected ***	| 14.406 | > 2.650 H_0 is rejected ***	| 13.955 | > 2.650 H_0 is rejected ***	| 10.695 | > 2.650 H_0 is rejected ***
4 (Big)	| 19.899 | > 2.650 H_0 is rejected ***	| 22.466 | > 2.650 H_0 is rejected ***	| 6.413 | > 2.650 H_0 is rejected ***	| 11.380 | > 2.650 H_0 is rejected ***

	t-values for β_{i2} and two-tailed t-tests for its statistical significance			
1 (Small)	| 3.843 | > 2.650 H_0 is rejected ***	| 6.295 | > 2.650 H_0 is rejected ***	| 5.063 | > 2.650 H_0 is rejected ***	| 6.624 | > 2.650 H_0 is rejected ***
2	| 8.402 | > 2.650 H_0 is rejected ***	| 8.030 | > 2.650 H_0 is rejected ***	| 9.528 | > 2.650 H_0 is rejected ***	| 9.949 | > 2.650 H_0 is rejected ***
3	| 5.229 | > 2.650 H_0 is rejected ***	| 7.509 | > 2.650 H_0 is rejected ***	| 6.165 | > 2.650 H_0 is rejected ***	| 5.852 | > 2.650 H_0 is rejected ***
4 (Big)	| –0.104 | < 1.668 H_0 is not rejected	| 2.368 | > 2.000 H_0 is rejected **	| –5.371 | > 2.650 H_0 is rejected ***	| 1.286 | < 1.668 H_0 is not rejected
	t-values for β_{i3} and two-tailed t-tests for its statistical significance			
1 (Small)	| –1.328 | < 1.668 H_0 is not rejected	| –0.639 | < 1.668 H_0 is not rejected	| 2.962 | > 2.650 H_0 is rejected ***	| 3.934 | > 2.650 H_0 is rejected ***
2	| –4.398 | > 2.650 H_0 is rejected ***	| 1.256 | < 1.668 H_0 is not rejected	| 3.567 | > 2.650 H_0 is rejected ***	| 6.304 | > 2.650 H_0 is rejected ***
3	| –1.087 | < 1.668 H_0 is not rejected	| 1.201 | < 1.668 H_0 is not rejected	| 2.388 | > 2.000 H_0 is rejected **	| 2.696 | > 2.650 H_0 is rejected ***
4 (Big)	| –4.887 | > 2.650 H_0 is rejected ***	| 0.890 | < 1.668 H_0 is not rejected	| 1.920 | > 1.668 H_0 is rejected *	| 4.993 | > 2.650 H_0 is rejected ***
	t-values for β_{i4} and two-tailed t-tests for its statistical significance			
1 (Small)	| –0.111 | < 1.668 H_0 is not rejected	| –0.676 | < 1.668 H_0 is not rejected	| 2.220 | > 2.000 H_0 is rejected **	| 1.868 | > 1.668 H_0 is rejected *
2	| 4.158 | > 2.650 H_0 is rejected ***	| 2.643 | > 2.650 H_0 is rejected ***	| 2.611 | > 2.000 H_0 is rejected **	| 0.929 | < 1.668 H_0 is not rejected
3	| 4.736 | > 2.650 H_0 is rejected ***	| 1.637 | < 1.668 H_0 is not rejected	| 3.017 | > 2.650 H_0 is rejected ***	| 1.625 | < 1.668 H_0 is not rejected
4 (Big)	| 9.881 | > 2.650 H_0 is rejected ***	| 8.661 | > 2.650 H_0 is rejected ***	| –9.715 | > 2.650 H_0 is rejected ***	| 3.136 | > 2.650 H_0 is rejected ***

Appendix 10: Two-tailed t-statistics for the coefficients of the four-factor model

CAPM	**Significance levels**	**t-values ($t_{n-k;\,1-\alpha/2}$)**	**Two-tailed t-test**
Sample (n): 72	10%*	1.668	
Explanatory variables (k): 1	5%**	2.000	$H_0: \alpha_i = 0$
Degrees of freedom (n–k): 71	1%***	2.650	$H_1: \alpha_i \neq 0$

Three-factor model	**Significance levels**	**t-values ($t_{n-k;\,1-\alpha/2}$)**	**Two-tailed t-test**
Sample (n): 72	10%*	1.667	
Explanatory variables (k): 3	5%**	1.995	$H_0: \alpha_i = 0$
Degrees of freedom (n–k): 69	1%***	2.649	$H_1: \alpha_i \neq 0$

Four-factor model	**Significance levels**	**t-values ($t_{n-k;\,1-\alpha/2}$)**	**Two-tailed t-test**
Sample (n): 72	10%*	1.667	
Explanatory variables (k): 4	5%**	1.994	$H_0: \alpha_i = 0$
Degrees of freedom (n–k): 68	1%***	2.647	$H_1: \alpha_i \neq 0$

Decision rule If $|\,t\,| > t_{n-k;\,1-\alpha/2} \rightarrow H_0$ is rejected. Thus, the intercept is statistically significant.

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	Estimator for α_1			
	$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \varepsilon_{it}$			
1 (Small)	| 3.230 | > 2.650 H_0 is rejected ***	| 2.328 | > 2.000 H_0 is rejected **	| 2.997 | > 2.650 H_0 is rejected ***	| 3.703 | > 2.650 H_0 is rejected ***
2	| 1.559 | < 1.668 H_0 is not rejected	| 1.135 | < 1.668 H_0 is not rejected	| 1.714 | > 1.668 H_0 is rejected *	| 2.070 | > 2.000 H_0 is rejected **
3	| 1.662 | < 1.668 H_0 is not rejected	| 0.865 | < 1.668 H_0 is not rejected	| 1.434 | < 1.668 H_0 is not rejected	| 0.879 | < 1.668 H_0 is not rejected
4 (Big)	| –1.359 | < 1.668 H_0 is not rejected	| –0.820 | < 1.668 H_0 is not rejected	| 1.080 | < 1.668 H_0 is not rejected	| 0.946 | < 1.668 H_0 is not rejected
	$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \varepsilon_{it}$			
1 (Small)	| 2.527 | > 1.995 H_0 is rejected **	| 0.717 | < 1.667 H_0 is not rejected	| 1.235 | < 1.667 H_0 is not rejected	| 1.942 | > 1.667 H_0 is rejected *
2	| 0.275 | < 1.667 H_0 is not rejected	| –1.324 | < 1.667 H_0 is not rejected	| –1.076 | < 1.667 H_0 is not rejected	| –0.869 | < 1.667 H_0 is not rejected
3	| 0.186 | < 1.667 H_0 is not rejected	| –1.534 | < 1.667 H_0 is not rejected	| –0.771 | < 1.667 H_0 is not rejected	| –1.381 | < 1.667 H_0 is not rejected
4 (Big)	| –1.746 | > 1.667 H_0 is rejected *	| –2.344 | > 1.995 H_0 is rejected **	| 3.050 | > 2.649 H_0 is rejected ***	| –0.567 | < 1.667 H_0 is not rejected
	$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \beta_{i4} \cdot PMU_t + \varepsilon_{it}$			
1 (Small)	| 2.492 | > 1.994 H_0 is rejected **	| 0.740 | < 1.667 H_0 is not rejected	| 1.356 | < 1.667 H_0 is not rejected	| 2.049 | > 1.994 H_0 is rejected **
2	| 0.469 | < 1.667 H_0 is not rejected	| –1.277 | < 1.667 H_0 is not rejected	| –1.018 | < 1.667 H_0 is not rejected	| –0.831 | < 1.667 H_0 is not rejected
3	| 0.389 | < 1.667 H_0 is not rejected	| –1.488 | < 1.667 H_0 is not rejected	| –0.696 | < 1.667 H_0 is not rejected	| –1.333 | < 1.667 H_0 is not rejected
4 (Big)	| –2.328 | > 1.994 H_0 is rejected **	| –3.031 | > 2.647 H_0 is rejected ***	| 4.315 | > 2.647 H_0 is rejected ***	| –0.480 | < 1.667 H_0 is not rejected

Appendix 11: Two-tailed t-statistics for the intercepts of the regression models

Part D: Diagnostic tests (section 5.3)

Diagnostics tests

Estimator	**VIF**	**Decision rule**
β_{i1}	1.479	1.479 < 10 → no MC*
β_{i2}	1.717	1.717 < 10 → no MC*
β_{i3}	1.124	1.124 < 10 → no MC*
β_{i4}	1.195	1.195 < 10 → no MC*

* Multicollinearity

Appendix 12: Variance Inflation Factors to test for the presence of multicollinearity

Key data	**DW bounds (1% significance level)**	**Hypothesis tests**
Sample (n): 72 (≈ 70)	d_{Lower} = 1.343	H_0: No autocorrelation
Explanatory variables (k): 4	d_{Upper} = 1.577	H_1: Positive first-order autocorrelation

Decision rules (if d is < 2)

If d is < d_{Lower} → H_0 is rejected. Thus, positive first-order autocorrelation is given.

If d is > d_{Upper} → H_0 is not rejected. Thus, no autocorrelation is given.

If $d_{Lower} < d < d_{Upper}$ → hypothesis test is inconclusive. Thus, no autocorrelation is given.

If d is > 2 then it is tested for negative first-order autocorrelation. To do this, 4 – d has to be computed and, hence, the same d bounds and decision rules as for positive first-order autocorrelation are applied.

$$r_{it} - r_{ft} = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \beta_{i4} \cdot PMU_t + \varepsilon_{it}$$

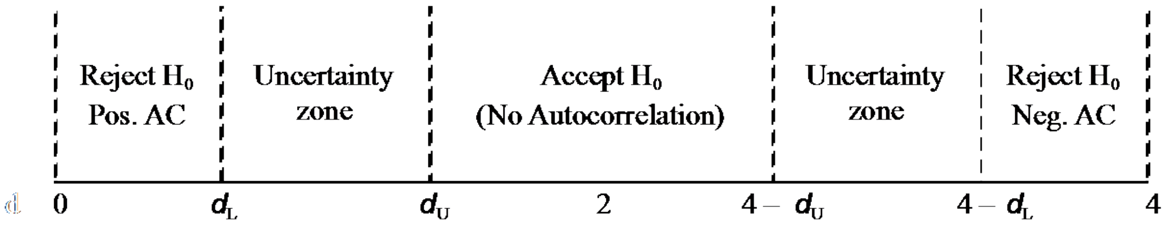
	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	Durbin Watson values and hypothesis tests for first-order autocorrelation (AC)*			
1 (Small)	**1.897**** > 1.577 H_0 is not rejected → no AC	**1.732**** > 1.577 H_0 is not rejected → no AC	**1.858**** > 1.577 H_0 is not rejected → no AC	1.343 < **1.522**** < 1.577 inconclusive → no AC
2	1.343 < **1.469**** < 1.577 inconclusive → no AC	**1.223**** < 1.343 H_0 is rejected → neg. AC	**1.941**** > 1.577 H_0 is not rejected → no AC	**1.783** > 1.577 H_0 is not rejected → no AC
3	**1.973**** > 1.577 H_0 is not rejected → no AC	1.343 < **1.474**** < 1.577 inconclusive → no AC	**1.928** > 1.577 H_0 is not rejected → no AC	**1.585**** > 1.577 H_0 is not rejected → no AC
4 (Big)	**1.605** > 1.577 H_0 is not rejected → no AC	**1.944**** > 1.577 H_0 is not rejected → no AC	**1.710** > 1.577 H_0 is not rejected → no AC	1.343 < **1.463**** < 1.577 inconclusive → no AC

* The value for d is expressed in bold.

** Test for negative first-order autocorrelation. 4 – d has already been computed.

Appendix 13: Durbin Watson test to analyze for the presence of autocorrelation

Decision rule of the Durbin Watson test



Appendix 14: Decision rule of the Durbin Watson test

Key data	**Critical value** (1% significance level)	**Hypothesis tests**
Sample (n): 72	29.141	H_0: No heteroscedasticity
Explanatory variables (k): 4		H_1: Heteroscedasticity
Degress of freedom: 14		

Decision rule If n^*R^2 > Critical value of Chi-square → H_0 is rejected. Thus, heteroscedasticity is present.

$$\varepsilon^2 = \alpha_i + \beta_{i1} \cdot [r_{mt} - r_{ft}] + \beta_{i2} \cdot SMB_t + \beta_{i3} \cdot HML_t + \beta_{i4} \cdot PMU_t + \beta_{i5} \cdot [r_{mt} - r_{ft}]^2 + \beta_{i6} \cdot SMB_t^2 + \beta_{i7} \cdot HML_t^2 + \beta_{i8} \cdot PMU_t^2 + \beta_{i9} \cdot ([r_{mt} - r_{ft}] \cdot SMB_t) + \beta_{i10} \cdot ([r_{mt} - r_{ft}] \cdot HML_t) + \beta_{i11} \cdot ([r_{mt} - r_{ft}] \cdot PMU_t) + \beta_{i12} \cdot (SMB_t \cdot HML_t) + \beta_{i13} \cdot (SMB_t \cdot PMU_t) + \beta_{i14} \cdot (HML_t \cdot PMU_t) + u$$

	Book-to-market equity			
	1 (Low)	2	3	4 (High)
Firm size	White values and hypothesis tests for the presence of heteroscedasticity (HC)*			
1 (Small)	**11.736** < 29.141 H_0 is not rejected → no HC	**17.208** < 29.141 H_0 is not rejected → no HC	**8.424** < 29.141 H_0 is not rejected → no HC	**14.760** < 29.141 H_0 is not rejected → no HC
2	**23.976** < 29.141 H_0 is not rejected → no HC	**14.256** < 29.141 H_0 is not rejected → no HC	**18.432** < 29.141 H_0 is not rejected → no HC	**19.440** < 29.141 H_0 is not rejected → no HC
3	**12.456** < 29.141 H_0 is not rejected → no HC	**5.832** < 29.141 H_0 is not rejected → no HC	**13.536** < 29.141 H_0 is not rejected → no HC	**6.120** < 29.141 H_0 is not rejected → no HC
4 (Big)	**42.192** > 29.141 H_0 is rejected → HC	**28.152** < 29.141 H_0 is not rejected → no HC	**36.720** > 29.141 H_0 is rejected → HC	**26.280** < 29.141 H_0 is not rejected → no HC

* The values of the White test are expressed in bold.

Appendix 15: White test to analyze for the presence of heteroscedasticity

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