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Is there a green bubble developing on the Oslo Stock Exchange?

Testing for explosive behaviour in green stocks

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Abstract

Green investment has never been as relevant as it is today. 2020 and 2021 were record-breaking years for new listings of green companies on the Oslo Stock Exchange and Euronext Growth. The stock prices of green companies have skyrocketed in recent years, although many of the companies do not deliver positive cash flows. Politicians and market participants are focusing on the green transition, while the media is wondering if it is a green bubble. This master's thesis investigates whether there is a green bubble developing on the Oslo Stock Exchange. The OSEBX index is used as a representation of the Oslo Stock Exchange, and the green stocks are retrieved from the Oslo Stock Exchange and Euronext Growth. The methodology used in this thesis is based on several recursive Augmented Dickey-Fuller (ADF) tests. The results from the ADF tests indicate that there is not a bubble in the Norwegian stock market, although several of the ADF tests showed explosive behaviour in some of the green stocks. Furthermore, the thesis addresses macroeconomic factors, and consider market trends.

Preface

This master's thesis is written as a concluding part of Oslo Metropolitan University's MSc in economics and business administration in the spring of 2022. It has been an interesting and educational semester where we have had the pleasure of extensively researching a topic that really interests us.

Our initial plan was to use Stata, but it turned out not to be compatible with our dataset, as there were too many data points. Consequently, we had to learn from scratch how to use the statistical software R, which could handle our dataset. All in all, it has been a challenging process, but we are left with valuable lessons for which we are grateful.

We want to thank our supervisor Johann Reindl for the constructive feedback and guidance he has provided us.

Oslo

20th of May 2022

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Contents

1. Introduction ... 7

2. Background ... 9

3. History of Financial Bubbles ... 13

3.1 The Tulipomania, 1636-37 ... 13

3.2 The Mississippi and South Sea Bubbles, 1719-20 ... 14

3.3 The Wall Street Crash, 1929 ... 15

3.4 The Dot-Com Bubble, 1999-2000 ... 16

3.5 The Financial Crisis, 2008 ... 17

4. Theory/Literature review ... 18

4.1 Asset bubbles ... 18

4.2 The Financial Instability Hypothesis ... 20

4.3 The Five Stages of a Bubble ... 21

4.3.1 Criticism of the Minsky model ... 24

4.4 Classification of Asset Bubbles ... 24

4.4 Irrational Bubble Theory ... 25

4.5 Rational Bubbles ... 28

4.5.1 Rational Valuation Formula and Rational Bubbles ... 29

5. Methodology ... 35

5.2 The ADF test ... 36

5.3 The SADF test ... 37

5.4 The GSADF test ... 37

5.5 Date stamping ... 39

5.6 The panel GSADF test ... 39

5.7 Implementation ... 40

6. Data ... 42

7. Results **45**

7.1 OSEBX 45

7.2 Green stocks 46

7.3 Financial ratio analysis 51

8. Discussion **54**

9. Conclusion **60**

References **62**

Appendix **66**

List of figures

Figure 1: IPOs on Oslo Stock Exchange & Euronext Growth 2016 - Mar 2022........................**9**

Figure 2: Return on green stocks and OSEBX..**10**

Figure 3: The Five Stages of a Bubble – The Minsky Model..**22**

Figure 4: Dividend, present value and stock price relationship..**27**

Figure 5: SADF and GSADF sample interval..**38**

Figure 6: Green companies divided into sectors...**44**

Figure 7: GSADF test statistics OSEBX...**46**

Figure 8: GSADF test statistics green stocks..**49**

Figure 9: USA & Norway CPI April 2020-2022...**55**

Figure 10: Inflation relationship..**55**

Figure 11: Yield USA & Norway 10-Year Treasury Bond...**56**

Figure 12: Global investment in green energy transition...**58**

List of tables

Table 1: Green stocks descriptive statistics..**43**

Table 2: OSEBX descriptive statistics **44**

Table 3: OSEBX test statistics...**45**

Table 4: Green stocks test statistics...**47**

Table 5: Episodes of explosive behavior..**48**

Table 6: Green stocks panel test statistics..**50**

Table 7: Green stocks PE & ROE 01.03.2022..**52**

Table A1: Companies on OSEBX 01.03.2022...**66**

Table A2: Green stocks test statistics for ADF & SADF...**67**

1. Introduction

At the same time as awareness for climate change and investments in sustainable companies are growing like never before, many claim that a green bubble has formed, and many are drawing parallels to the dot-com bubble in the 2000s. NHH-professor Ola Grytten is one of them, and in an interview from 2021 he points to a record number of IPOs, increased attention from the public and rapid high valuations that might not be due to fundamental factors in the market. With low interest rates and an outflow of billions of NOK in crisis packages from the government like we have experienced during the pandemic, there is a danger that the economy may inflate, which leads to higher asset prices and further financial instability, which in the worst case can lead to a bubble. Many fear that this has already happened and are just waiting for a correction or the possible bubble to burst. We will therefore try to answer this question regarding a possible green bubble in the Norwegian stock market. Our research question is:

"Is there a green bubble developing on the Oslo Stock Exchange?"

To answer this question, we apply the ADF, SADF and GSADF tests as presented by Phillips et al. (2011, 2015) to explore if there are signs of explosive behaviour in the green stocks listed on Oslo Stock Exchange. This method is used for detecting if a time series has a stochastic trend by testing for unit root. Our null is that the time series has a unit root, and the alterative hypothesis is that the time series experience explosive behaviour:

$$H_0 : \beta_{r1,r2} = 0 \quad \rightarrow \quad (unit\ root)$$

$$H_1 : \beta_{r1,r2} > 0 \quad \rightarrow \quad (explosive\ behaviour)$$

The thesis has certain limitations. We are only investigating green stocks listed in the Norwegian stock market, that is Oslo Stock Exchange and Euronext Growth which is a part of OSE. Also, the test is limited to a time-period of ten years. For the analysis conducted, we found it sufficient to use a ten-year period with daily observations to explore the possibility of a present-day bubble, which is also backed by Philips et al. (2015) to be a sufficient number of datapoints. Furthermore, the famous and widely accepted “efficient market hypothesis” by Eugene Fama (1970) suggests that asset prices fully reflect all available information and therefore, that bubbles cannot exist. We do not wish to participate in the discussion as to whether bubbles can exist or not but will assume for the purpose of this thesis that they can.

First, we will go through some background information, where we describe current media attention regarding green stocks, recent IPOs, macro trends and the historical returns achieved by green stocks compared to conventional stocks. Furthermore, in Chapter 3 we will present the most important financial bubbles throughout history before we in Chapter 4 go through previous research and theory on financial bubbles. In Chapter 5, we describe the method applied to explore whether the green stocks show signs of explosive behaviour. Chapter 6 provides a description of the dataset used and Chapter 7 displays the results from the various tests we have executed, as well as an analysis of financial ratios for the companies in question. The thesis is finished off with a discussion section in Chapter 8 and a conclusion in Chapter 9.

2. Background

"There is now a wide consensus that climate change is occurring, caused by human-induced greenhouse gas emissions, mainly from fossil fuel combustion and change in land use. Climate change could produce severe negative outcomes and have important macroeconomic consequences. Higher temperatures, rising sea levels, and extreme weather conditions may severely impair output and productivity" (International Monetary Fund, 2008). From the early 2000s, there has been an increasing focus on reducing greenhouse gases. We have never been as concerned about climate change as we are today.

The pressure is now on international organizations, countries, and the global business community on how to implement the transition to green energy and a more sustainable way of life. As a result of the increased focus on the green transition, pressure from the government, and increased incentive to invest in sustainable projects, the listing of green companies on the Oslo stock exchange has skyrocketed in recent years, as displayed in figure 1. Despite the turbulent stock market due to, among other things, the Covid-19 pandemic, there were a total of 58 and 82 IPOs in 2020 and 2021, respectively.

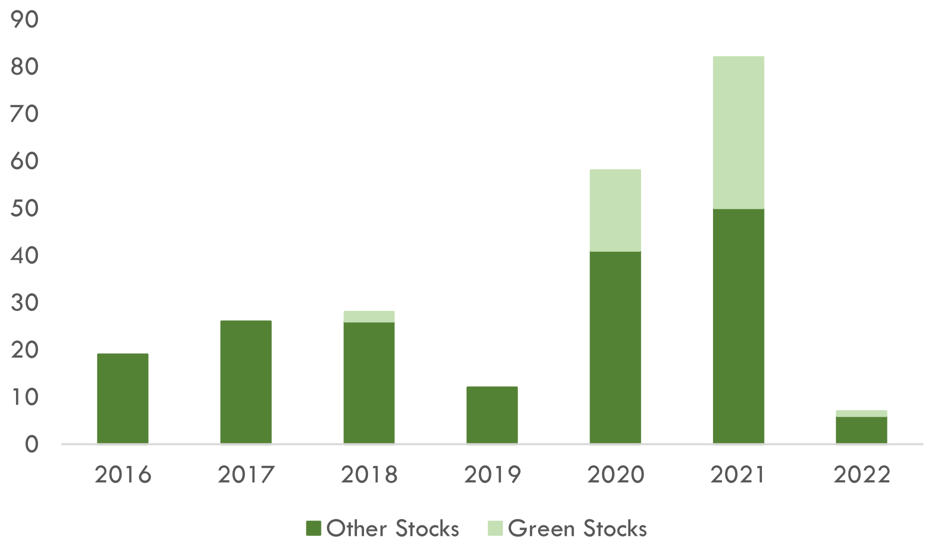


Figure 1: IPOs on Oslo Stock Exchange & Euronext Growth 2016 - Mar 2022, (Euronext, 2022)

To further discuss green companies, we need a clear definition of what green finance are. "Green finance is a broad term that can refer to financial investments flowing into sustainable development projects and initiatives, environmental products, and policies that encourage the development of a more sustainable economy" (Höhne et al., 2012). With this definition in mind, we have chosen not to define emission-neutral companies as green. This will exclude IT companies that can be defined as green, but which provide services to companies that are not necessarily green.

Several of the green companies on Oslo Stock Exchange had an incredibly good return compared to the Norwegian stock market in general the last years. The return has been so good that it is natural to wonder whether there is overpricing given that most of the green companies do not deliver positive cash flows. John McMurdo, chief executive officer at Australian ethical investment Ltd stated the following: “Funds and strategies that focus on environmental, social and governance factors are booming worldwide amid an uptake from investors and companies to own more sustainable investments” (Haigh, 2021). Figure 2 shows the return on green stocks on the Oslo Stock Exchange, and the return on the OSEBX index.

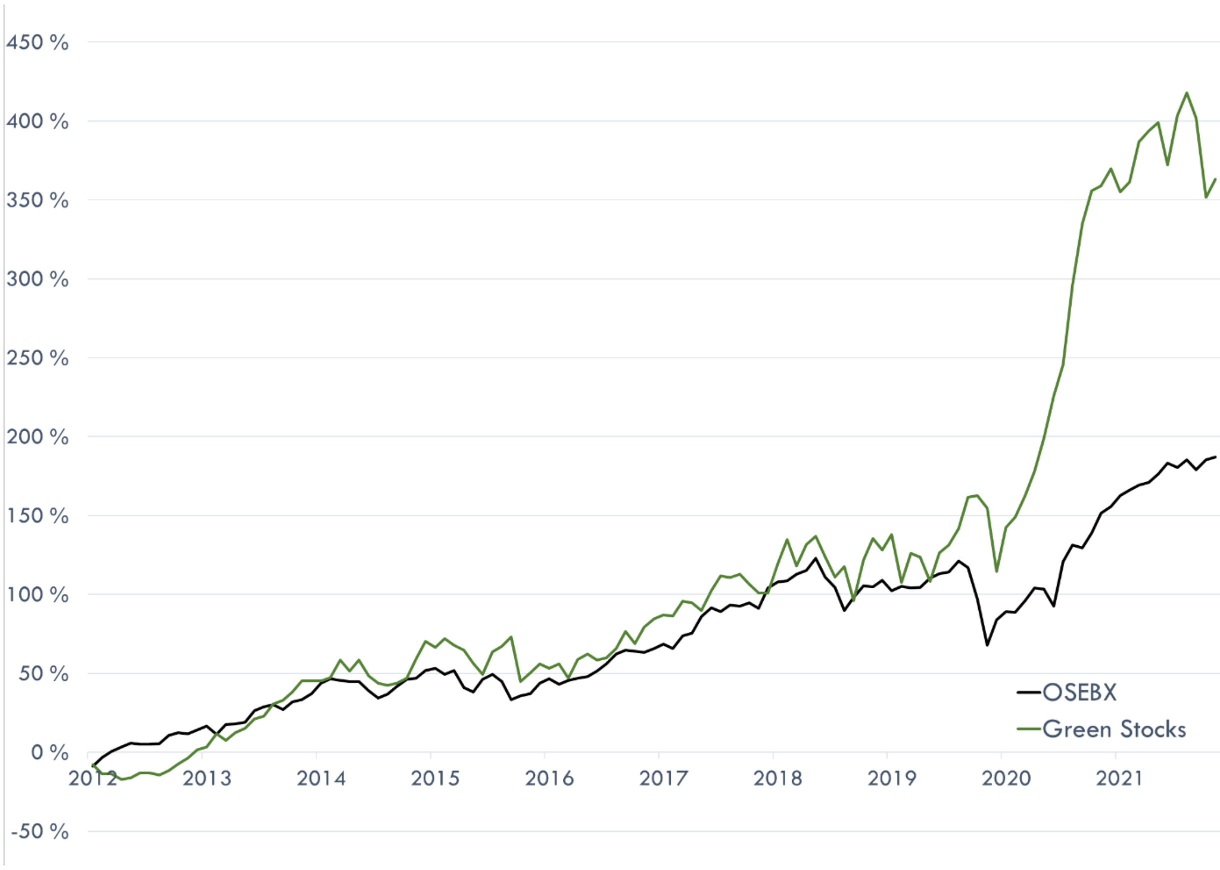


Figure 2: Return on green stocks and OSEBX, (Thomson Reuters)

To explore if an asset bubble is forming, there are certain trends we can observe in the market according to Yale economist Robert J. Shiller. He has prepared the following checklist consider:

1. Sharp increases in the price of an asset like real estate or dot-com shares
2. Great public excitement about said increases
3. An accompanying media frenzy
4. Stories of people earning a lot of money, causing envy among people who aren't
5. Growing interest in the asset class among the general public
6. A decline in lending standards

Studying Figure 2, the first item in Shiller's checklist applies to green stocks on the Oslo Stock Exchange. The return from the green stocks and the OSEBX index is relatively similar in the periods from 2012 to the year 2020, but in the years following, the green stocks return increased drastically in relation to OSEBX. During the ten-year period, the OSEBX index had a return of just under 200%, while the green stocks had a return of just above 350%.

Green stocks and green finance in general are very relevant topics, which are often mentioned in the media. A report from AksjeNorge (Stocks Norway) in 2021 shows that there was almost a doubling of green stocks on the Oslo Stock Exchange in 2021 (Skaug, 2021). Kristin Skaug, general manager of AksjeNorge, stated the following: "It is becoming increasingly popular to talk about sustainability, ESG and green stocks, but it is not just talk. We see that the interest in the green is great" (Nilsen & Lang-Ree, 2021). This report and similar news articles show that items two, tree, and five from Shiller's checklist applies.

At the end of March 2022, the Norwegian financial newspaper E24 authored an article about the well-known Norwegian investor Kjell Inge Røkke's sale of stocks in the green solar energy company Rec Silicon. Røkke sold his stocks with a gain of NOK 1.45 billion (Bøe & Nilsen, 2022). Stories like this match point four of Shiller's checklist.

To obtain a mortgage in Norway has become more difficult in recent years. In 2015, the Norwegian government introduced a mortgage regulation to contribute to a more sustainable development in household debt, with the intention of setting a framework for banks' lending practices. The mortgage regulations have since been continued and amended three times. Each time, the requirements have been tightened. The regulations set requirements for the customer's serviceability of the loan, the customer's total debt in relation to income (debt ratio), the size of the loan in relation to the value of the home (loan-to-value ratio), and installment payments for loans with a high loan-to-value ratio (Regjeringen, 2021).

For credit loans and other types of consumer loans, individual companies operate with different conditions. The common conditions are that the borrower must be 18 years of age and you must be a Norwegian citizen, or resident and taxable in Norway. The requirements for consumer loans have been reduced in recent years, at the same time as marketing has skyrocketed. Conditions became so bad that in 2017, the government implemented a new regulation against aggressive marketing of credit loans. The minister of finance at the time, Siv Jensen, stated the following: "Credit cards and consumer loans can provide financial freedom, but there are many who experience too aggressive marketing, and too many ends up in a debt trap. The government's measures will contribute to the market functioning better" (Hovland, 2017).

Based on Shiller's checklist and the current market situation, it is further interesting to investigate quantitatively whether there is a bubble in green stocks on the Oslo Stock Exchange, but first we will discuss the theory on how financial bubbles arise and look at the history of many of the biggest financial bubbles.

3. History of Financial Bubbles

Common for all large asset price bubbles is that they often start out with rapid growth in asset prices, economic euphoria, and great optimism for the future. Followed by a subsequent quick crash with a massive fall in asset prices, often leading to the failure of financial institutions, a downturn in economic activity and consequently great pessimism for the future. However, there are many different views and opinions on how a financial bubble should be defined and discussion on the topic is widespread. So, to get a picture on how a financial bubble unfolds we will in this section go through some of the largest recorded financial bubbles in history and their characteristics.

3.1 The Tulipomania, 1636-37

According to Garber (1990) and Kindleberger and Aliber (2005), one of the first ever recorded speculative mania is the Dutch tulip mania from the 1630's where the price of Dutch tulips reached extraordinarily prominent levels and increased by several hundred percent in the autumn of 1636. Prices of more exotic varieties reached even higher levels, but in February 1637 there was an abrupt collapse in tulip prices and large values were lost.

Garber (1990) describes that professional growers and wealthy flower fanciers managed to develop new sorts and created a market for these rare varieties of the newly introduced tulip, with beautiful colors and patterns. Such rare tulips became a symbol of status for the rich. Prices increased and tulip bulbs gradually became investment objects and speculators saw opportunities for large and quick profits. Tulip bulbs were bought and sold for the multiple of its actual value. Not only the exotic varieties of bulbs were affected, ordinary garden tulips that were bought by ordinary people also skyrocketed and later dropped in price.

Kindleberger and Aliber (2005) describes that the enthusiasm for tulips began in earnest around September 1636, when bulbs were no longer available for inspection, as tulip bulbs develop for up to eight months before it blooms and was planted to be ready for spring. In the absence of bank credit, collateral and down payments were mostly agreed upon in advance, even though buyers could not see the goods. These payments could consist of land, houses, furniture, silver and gold, paintings, or the like of immense value. Values which in turn were lost when the price collapsed, as bulbs could not be sold at even 10 percent of their peak values (Garber, 1990).

Roy E. Bailey (2005) claims that the exotic varieties had a less rapid increase and decrease over a longer period compared to the more ordinary sorts of tulip bulbs. To the extent that the available evidence can be trusted, he argues that a genuine lack of supply may have affected the exotic bulbs relative to the increasing demand. While price fluctuations for the ordinary kinds were more stimulated by speculative motives and the desire to profit from the price changes.

3.2 The Mississippi and South Sea Bubbles, 1719-20

The South Sea Bubble and Mississippi Bubble are two different events but still have much in common and are both good examples of speculative booms and busts in the years up to 1720. Both involve public share offerings by companies, the Mississippi Company in Paris, and the South Sea Company in London, and both procured monopoly privileges respectively from the French and British governments, in return for taking the responsibility to service government debts (Bailey, 2005).

In 1684 France established the Mississippi Company to develop the economy of the French settlements along the Mississippi River. Scottish adventurer and economist, John Law, acquired several companies, including the Mississippi Company, which subsequently turned into a conglomerate, the "Compagnie des Indes". Most stock of these conglomerate companies was issued in exchange for government debt. Many also initiated various commercial and financial ventures. The prospects for quick, high profits made the stocks popular and the increasing prices reflected their popularity, while supporting the forecast of high potential gains (Bailey, 2005). Increasing demand led Banque Royale, owned by John Law, to introduce and print paper banknotes. Early in 1720 the bubble burst suddenly, when some investors sought to realize their profits, revealing that the banknotes issued by Banque Royale had no coverage in real terms, such as coins, gold, or silver (Kindleberger & Aliber, 2005).

The South Sea Bubble refers to the British financial scandal in 1720 linked to the South Sea Company, where severe speculation in the company's stocks caused its value to collapse. In 1710, the South Sea Company gained monopoly rights on all trade in the Pacific Ocean and on the west coast of South America. The company had acquired new and extensive privileges, in return for taking responsibility over significant amounts of British government debt, that was meant to be highly favourable for the shareholders. As a result, wild speculation in the company's stocks began in the start of 1720, and within six months the share price had increased approximately 700 percent. This in turn led many investors to start offloading their positions and it soon became apparent that it was impossible for the company to secure the profits reflected by the share price. The "bubble" burst the same year, and the share price declined to its early 1720-level (Bailey, 2005).

3.3 The Wall Street Crash, 1929

Following an extended period of economic prosperity and recovery after WW1, the roaring twenties ended abruptly with the stock market crash of 1929, which marks the start of the Great Depression of the 1930s. In only one week in October 1929 the main share price indexes in New York fell by nearly 30 percent (Bailey, 2005).

How the stock market crash of 1929 occurred is disputed by scholars and economic historians, but the popular explanation is deflation, a decline in the general price level of practically all assets, commodities, and services. Consequently, people postponed consumption, anticipating further decline in prices, leading to an even lower consumption and higher levels of unemployment. Kindleberger and Aliber (2005) argues that the rate of increase in US stock prices in the second half of the 1920s was exceptionally high relative to the rate of growth of the money supply, and that the deflation in the United States originated from appreciation of the US dollar and from the reduction of bank reserves. Further, the debt-deflation cycle of the 1930s induced banks to call loans and refuse new ones, causing firms to sell their inventories because of the decreasing prices, which caused even more firms to fail. Business failures in turn led bank loan losses to increase and banks to fail as well (Kindleberger & Aliber, 2005).

According to Bailey (2005) some analysts interpret the crash as a natural outcome of a speculative mania in 1928 and early 1929, while others claim share prices were deliberately forced down by monetary authorities and policymakers and that prices was never too high. "While some models are undoubtedly more plausible than others, the available evidence does not favour any one cause of the crash to the exclusion of others. Almost certainly it never will" (Bailey, 2005).

3.4 The Dot-Com Bubble, 1999-2000

In the late 1990s internet stocks with cutting edge technology became the subject of speculation and begin their rapid ascent, even though many had negative earnings and had never reported any profits. Large leading companies and experienced investors predicted that the internet would revolutionize the entire business world and new companies popped up everywhere.

In December 1996, Alan Greenspan, the then chairman of the US Federal Reserve Board, introduced the phrase "irrational exuberance" in a speech, interpreted by many as a cryptic warning that the stock market might be subject to overvaluation, and in risk of a financial bubble (Phillips et al., 2011). Despite the concerns of cautious but startling analysts, asset prices continued to rise, but in March 2000, the bubble burst and the prices of internet stocks fell precipitately (Bailey, 2005). Kindleberger and Aliber (2005) argues, similarly to the crash of 1929, that the rate of increase in the prices of NASDAQ stocks in the second half of the 1990s was exceedingly high relative to the rate of growth of the US money supply. Stock prices continued to fall through 2001, slowing the US economy toward recession (Bailey, 2005).

3.5 The Financial Crisis, 2008

The financial crisis in 2008 began after a long period of economic prosperity in the US economy. There was an excessively strong belief in continued growth in housing prices, and many households were granted larger mortgages than they could afford. Legislative deregulation made it possible for financial institutions to package high risk mortgages and resell them as securities to investors in the money market. When defaults in the US sub-prime mortgage market began, a total collapse in the housing market was imminent. The bursting of housing market bubble triggered imbalances built up by strong credit growth, extensive mispricing of risk and confusing financial instruments. Consequently, the confidence in the financial markets plummeted and the collapse happened. Some financial institutions, such as the investment bank Lehman Brothers, went bankrupt as they were not saved by government measures and the economic meltdown soon developed into a global crisis.

4. Theory/Literature review

In this chapter we will present different definitions of what an asset bubble is and its main characteristics. Further we will describe the different main classifications on theories regarding bubbles, irrational - and rational bubble theory. Our thesis builds mainly on the theory behind rational bubbles which will therefore be described more in depth, but irrational bubble theory will also be presented.

4.1 Asset bubbles

In general, asset bubbles are associated with a dramatic increase in price followed by an equally dramatic collapse. During the bubble, the price exceeds the assets fundamental value, as speculators and investors believe they can resell the asset at a higher price in the future. The fundamental value is defined as the present value of all future cash flows. The idea of such bubbles or inflations in asset prices has been around since the beginning of organized markets. The literature on the topic is widespread and several definitions and models has been proposed e.g., the following citation by Joseph E. Stiglitz (1990):

> *"If the reason that the price is high today is only because investors believe that the selling price will be high tomorrow - when "fundamental" factors do not seem to justify such a price - then a bubble exists"* (Stiglitz, 1990).

Whether these increases in price have a rational explanation or whether it is due to irrational investor behavior is difficult to answer. But even though there are diverse types of asset bubbles with different causal relationships, they all have several common features. Scheinkman (2014) announce three stylized facts for asset bubbles:

1) Asset price bubbles coincide with increases in trading volume.
2) Asset price bubble implosions seem to coincide with increases in an asset's supply.
3) Asset price bubbles often coincide with financial or technological innovation.

Roy E. Bailey (2005) describes how an asset bubble typically unfolds and what characterizes the different phases. First there is a period of manic optimism where most investors are convinced that rising asset prices are justified by fundamentals. This is later followed by a crisis of confidence. Blatant fraud may trigger this crisis of confidence or is subsequently blamed for the crisis. Finally comes severe pessimism accompanied by financial distress. In this phase the average perception is that the now low prices are again justified by "fundamentals", and thus implicit that the previous optimism was misplaced.

Kindleberger and Aliber (2005) explains that a bubble is present when there is an upward asset price movement over an extended period of time, at a rate that cannot be explained by fundamental factors in the market. They claim such upward price movements is expected to endure for fifteen to forty months before the bubble bursts. Smaller price fluctuations based on fundamentals over shorter periods are called "noise". Further, Kindleberger and Aliber (2005) presents a generic term for manias and bubbles, which is "non-sustainable patterns of financial behavior" meaning that asset prices today do not match and is not consistent with the asset prices in the distant future. The word bubble foreshadows the bursting while a mania emphasizes the irrationality and is related to frenzied pattern of purchases, higher prices, and higher trading volumes, where people want to buy the assets quickly before prices increase even further to earn quick profits.

Describing bubbles, the greater fool theory is presented by Kindleberger and Aliber (2005) and it evolves around the idea that the certain security always can be sold to someone else at an even higher price. Investors ignore the fundamental valuations and other data and are willing to buy such overvalued assets because they believe there will always be a buyer – a greater fool – willing to pay more. The last buyer is the greatest fool because they fail to sell the asset to someone else. The greater fool theory is a central concept when explaining why investors sometimes are willing to purchase overvalued assets, which we will describe more in depth later.

4.2 The Financial Instability Hypothesis

The common opinion in classical finance theory is that capitalist financial markets are stable and that interaction between supply and demand will drive asset prices to a sustainable state of equilibrium, coherent with general equilibrium theory. As long as investors behave rational no excess returns will be made, and should abnormalities occur, rational investor behavior will drive asset prices back to equilibrium.

In 1982, Hyman P. Minsky introduced the financial instability hypothesis, an economic theory emphasizing the financial relations special to capitalism. This theory is contradicting the standard belief that markets are stable and Minsky claimed that if an economy is capitalist, it will be financially unstable. Financial instability is defined as a process where rapid and accelerating changes in the prices of assets take place, relative to the prices of current output (Minsky, 1982). The financial instability hypothesis centers around the idea that when the public believes the economy to be stable, they indulge in risk-taking because they believe that investing in financial markets are safe. Furthermore, both Minsky (1986) and Kindleberger (1978) agree that one of the main factors contributing to such instability and speculative manias is monetary expansion and expansion of credit which is "fueling the flames" of financial instability. According to Kindleberger and Aliber (2005) every recorded mania in history has been linked to expansion of credit in some way, all the way back to the tulip mania of 1636-37, which developed when sellers of the bulbs started to sell on credit. Disturbances like the above mentioned in financial markets over time increase financial instability, resulting in inflated asset prices and lost long-term sustainable equilibriums (Minsky, 1986). Further, an economic correction may in turn lead to panic and crisis as the asset bubble bursts.

Based on the above and the cyclical nature of the economy Minsky claims that booms and busts are unavoidable in a capitalist economy were credit plays a significant role for the growth of the economy. Following the expansion of money and credit, accumulation of debt increases and the total level of risk in the economy also increases. Minsky (1982) introduced a taxonomy of corporate debt with three stages which he called "hedge finance", "speculative finance" and "Ponzi finance". This taxonomy is based on the relationship between incoming cash flow to the borrowers from their operating revenues and their estimated cash flows for debt payments

(Kindleberger & Aliber, 2005). In the first stage, “hedge finance”, projected incoming cash flows from a company’s operating revenue will cover all scheduled debt payments, including both interest and principal. In the second stage, “speculative finance”, projected incoming cash flows will cover interest, but the company would need to borrow cash to cover the principal on maturing loans. And for the third and last stage, “Ponzi finance”, the company’s operating revenue will not be sufficiently large to even pay the cost of interest on its debt. Companies at this stage will need to borrow money or get a capital gain on their assets to cover their obligations, interest, and maturing loans (Minsky, 1982). To begin with, most companies are in the “hedge finance” position, but as the expansion takes place, more and more companies enter the “speculative finance” and “Ponzi finance” phase.

The turning point were the economic boom turns into a crisis is often referred to as the Minsky moment. At this stage increased availability of credit has led to inflated asset prices, which encourage more innovation to fully exploit profit opportunities, all driven by a debt frenzy and even higher levels of leverage. The financial instability hypothesis, the expansion of credit and hence accumulation of debt are central parts in the Minsky model, used to describe the anatomy and the stages of a bubble, which we will present in the following section.

4.3 The Five Stages of a Bubble

Kindleberger (1978) reviews the work of monetary theorist Hyman Minsky and presents the Minsky model (also referred to as the Kindleberger-Minsky model) which addresses the typical anatomy of a crisis and different phases leading up to the bursting of an asset bubble. The model is inspired by the work of economists such as John Stuart Mill, Alfred Marshall, Knut Wicksell, and Irving Fisher and is based on ideas of overtrading, followed by revulsion and discredit, and emphasises the instability of the credit system (Kindleberger, 1978).

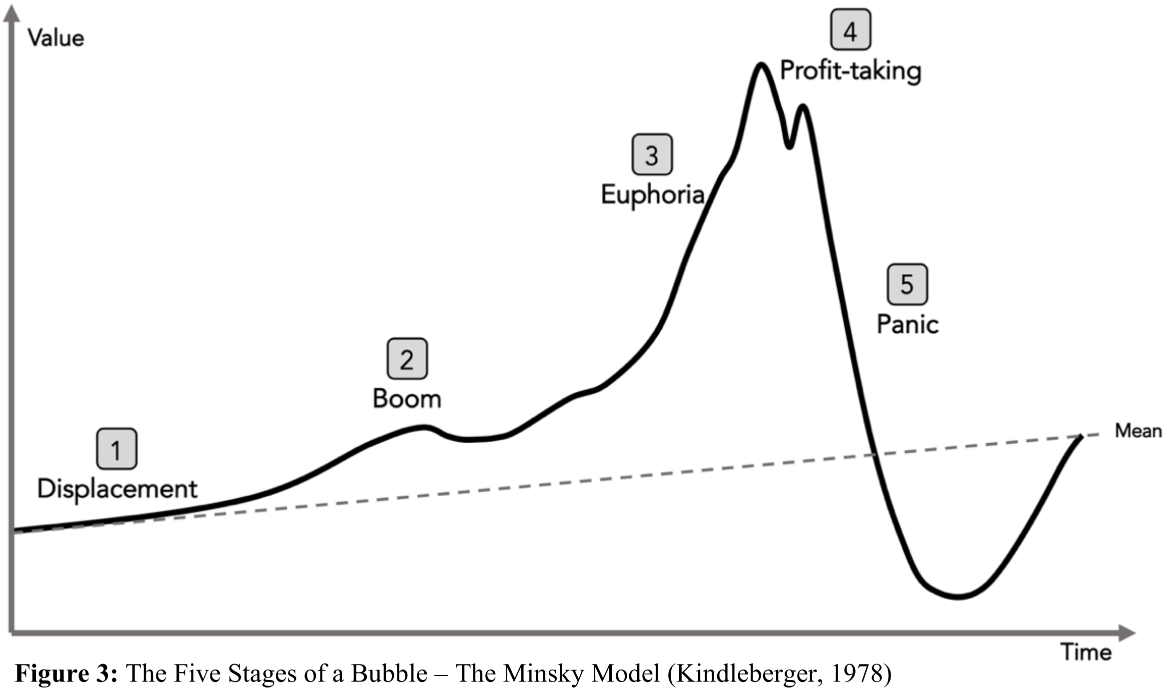


Figure 3: The Five Stages of a Bubble – The Minsky Model (Kindleberger, 1978)

Phase 1: Displacement

Displacement may occur because of an exogenous shock on the macroeconomic system that leads to an economic expansion. This can for example be in the form of new technological advances, the beginning or end of a war, political events, or very low interest rates, which was the case prior to the financial crisis in 2008, when mortgage rates became historically low.

Phase 2: Boom

Following the displacement-phase comes the boom-phase. This phase contains an expansion of bank credit, making the total money supply larger. Credit functions as means of payment to finance the boom. According to Kindleberger (1978) a cornerstone in the Minsky model is that bank credit is, or at least has been, very unstable, and that expansion of such credit is the primary cause of financial crisis. Fuelled by the expansion of credit, new players are constantly entering the market and the number of investors increase significantly. Media coverage is also growing, and investors become afraid of missing out on huge profits and prices gain a momentum.

Phase 3: Euphoria

Followed by a price-boom comes euphoria and prices rise to record levels that open for more profit opportunities and attract more and more investors. More investors and increasing income generated on these investments lead to a positive feedback loop, and people experience euphoria. The valuations of the companies exceed the fundamental value by the multiple and excessive gearing is used to speculate in the assets. In this phase, investors might believe they can resell the asset at an even higher price, luring them to believe the upside is limitless, consistent with the greater fool theory mentioned earlier.

Phase 4: Profit-Taking

At some point, some insiders decide to secure their profits and unexperienced speculators become hesitant when the experienced ones withdraw. Prices start to flat out and a period of "financial distress" can occur. While the distress persists, speculators realize that the market has reached its peak and that its time to retire, and the race for liquidity begins. Consequently, this can leave many speculative borrowers that was expecting to earn big profits incapable of paying their loans.

Phase 5: Panic

The start of this phase is often triggered by an event, such as the failure of a bank or company, the disclosure of fraudulence, or the revelation of the bubble assets true fundamental value. This can cause the bubble to burst and trigger a large price fall. In this phase everyone wants to liquidate their assets, prices fall even more, and bankruptcies often follow. Investors and speculators are margin called and the abundance of supply compared to demand results in steep price drops. Panic grows as there is no longer a greater fool to sell the assets to. Kindleberger (1978) calls this phase “revulsion”, as revulsion for assets and securities among people causes banks to stop lending with such assets as collateral.

4.3.1 Criticism of the Minsky model

Most models face some type of criticism, and the Minsky model is no exception. The model has met mainly three forms of criticism. The first arguing that each financial crises are different and hence, a generic model is useless. The second criticism states that due to changes in the commercial and economic structures and environments, such a model is no longer relevant. The third criticism originates from supporters of the efficient market hypothesis. They argue that bubbles are highly unlikely to exist because "all the information is reflected in the price" (Kindleberger & Aliber, 2005).

4.4 Classification of Asset Bubbles

Further we consider two main categories within bubble theory, rational and irrational bubbles. The rational bubble category builds on classical finance theory and retains the premise of rational behavior, rational expectations, and symmetrical information. If these conditions are met, an assets fundamental value will correspond to the market value. Deviations from the fundamental value is considered a breach of these assumptions of rationality. The second category, irrational bubble theory, is based on that neither the behavior nor the expectations are rational, or that investors fall victim to information asymmetry. Brunnermeier (2001) summarizes the bubble literature and provides a fourfold classification for asset bubbles.

The first class explore bubbles within the assumptions of rationality. All investors are rational in both their behavior and in their expectations and they are all equally informed. This indicates that bubbles must follow a testable explosive path (Linton, 2019). In a rational bubble setting, bubble assets are only held by investors if the bubble grows in expectations indefinitely (Brunnermeier, 2001).

In the other three classes rational investors will only hold an overvalued asset if they believe the asset can be sold at an even higher price sometime in the future, to uninformed, irrational, or biased investors, consistent with the greater fool theory from Kindleberger presented earlier in this chapter. The three classes explore bubbles under information asymmetry, limited arbitrage and heterogenous beliefs.

i. Under information asymmetry, bubbles can emerge without everyone knowing, in contrast to the case of information symmetry where everyone knows there is a bubble going on. In such cases prices serve as an index of scarcity and as informative signals because they partially reveal other investors information (Brunnermeier, 2001). For example, everyone knows an asset is overvalued, but everyone cannot know that everyone else also knows this. Allen, Morris and Postlewaite (1993) argues that it is this lack of higher-order knowledge that makes it possible for finite bubbles to exist.

ii. Under limited arbitrage, bubbles can emerge when rational, informed investors interact with irrational investors that trade on motives which are influenced by psychological biases. In this case, this interaction between different types of investors, prevent rational investors from undoing the price impact that stems from the irrational investors (Brunnermeier, 2001).

iii. Bubbles can emerge because of heterogeneous beliefs among investors. Strong individual beliefs may contain biases, and investors may agree to disagree about the fundamental value of an asset even after all their information are shared and have become officially known.

4.4 Irrational Bubble Theory

One of the most prominent researchers in irrational bubble theory is Robert Shiller and his definition of an asset bubble is somewhat similar other definitions presented earlier but puts extra emphasizes on the aspect of irrationality that can arise among investors. He defined an asset bubble as a situation where temporary high prices are due to excessive enthusiasm among investors rather than consistent estimates of real value (Shiller, 2015). The mixture of psychology and economics has come to be known as behavioral economics and challenges the assumptions of rationality (Thaler, 2016). The theory on irrational bubbles is based on humans not being fully rational in their behavior and contradicts the efficient market hypothesis. Irrational, or speculative bubbles are increases in price or value that is driven by irrational speculative activities and not by the fundamental value.

Shiller has done extensive work on speculative bubbles and the psychological factors affecting the decision making of investors and other participants in the financial markets. Shiller may also have coined the term irrational exuberance, made famous by former chairman of the Federal Reserve Board, Alan Greenspan in a speech in 1996, used to describe the behavior of stock market investors. Shiller (2015) claims that irrational exuberance is the psychological basis of a speculative bubble, and defines such a situation in the following way:

"A situation in which news of price increases spurs investor enthusiasm which spreads by psychological contagion from person to person, in the process amplifying stories that might justify the price increases and bringing in a larger and larger class of investors, who, despite doubts about the real value of an investment, are drawn to it partly through envy of others' successes and partly through a gambler's excitement" (Shiller, 2015).

The bubble bursts when people no longer expect prices to increase. Demand falls, panic spreads and the market ultimately crashes. Thaler (2016) points to overconfidence and "self-control" as factors of bounded rationality among humans when explaining the causes for excessive investor enthusiasm. Overconfidence causes investors to overestimate their chance of success, and "self-control" is linked to "present bias", meaning that pleasure today interests humans more than pleasure ten years from now. Shiller (2015) also points to herd behavior as a cause of such excessive enthusiasm, or irrational exuberance, where investors follow other investors and copies their strategies. According to Shiller, herd behavior occurs due to information cascades, explained as waves of irrational behavior, causing investors to make collective irrational choices. A collective misjudgment of future dividends i.e., fundamental value can then occur, which may result in a bubble. In earlier work Shiller (1984) claims that "mass psychology may well be the dominant cause of movements in the aggregate stock market". Blanchard and Watson (1982) also argued that extraneous events can influence the asset price, if anticipated by other participants to do so, and that "crowd psychology", as they call it, may be an important determinant of asset prices. Mass psychology, herding, greed, and envy among investors are all factors that can lead to overreactions and inflated prices way over what is believed to be the fundamental value of the assets.

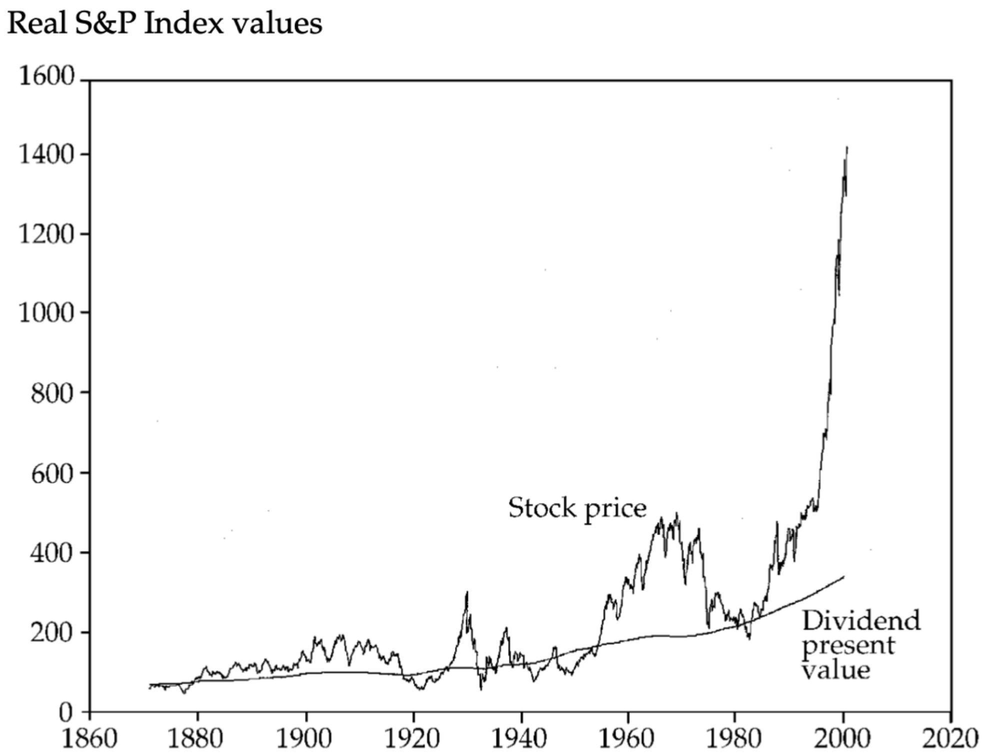


Figure 4: Dividend present value and stock price relationship (Shiller, 2000)

In his book Irrational Exuberance from 2000, Shiller points out that there are large discrepancies between the stock price index and the present value of dividends, which indicates that something is wrong with the classical theory. Figure 4 is presented by Shiller (2000) and shows this development between the share price and the present value of dividends. The graph shows that dividend payments are very stable throughout the period, while the volatility in the stock price index is several times higher than what they "should be", according to classical financial theory.

Keynes was a forerunner in behavioral finance, and while explaining price fluctuations in equity markets, Keynes (1936) compared the stock market to a beauty contest and introduced the concept “Keynesian Beauty Contest”. His theory explains how personal preferences and perceptions affect how we individually make valuations, in everything from the stock market to beauty pageants. He argued that short-run fluctuations in stock prices was not initiated by altered objective beliefs concerning the stocks fundamental value, but rather that such fluctuations were caused by a guessing game among investors about what the “average opinion expects the average opinion to be”:

"It is not a case of choosing those [faces] that, to the best of one's judgment, are really the prettiest, nor even those that average opinion genuinely thinks the prettiest. We have reached the third degree where we devote our intelligences to anticipating what average opinion expects the average opinion to be. And there are some, I believe, who practice the fourth, fifth and higher degrees" (Keynes, 1936).

The model emphasizes important points in behavioral finance and shows that people are not fully rational in their behavior. People's perception of value will vary from the individual investor's point of view, which may make it difficult to collectively agree on fundamental value. Thaler (2016) argues that psychological factors are becoming more and more important in empirical financial research and believes that these factors should be incorporated in economic analysis to achieve more precise analyzes and predictions.

4.5 Rational Bubbles

The common belief is that given the assumptions of rational behavior and rational expectations, the asset price must reflect market fundamentals, meaning that the price of an asset is determined based on information on current and future returns from the asset. Price deviations from fundamentals are commonly considered evidence of irrationality. The theory on rational bubbles stand opposed to this view and is based on the work of Jean Tirole (1982) and Blanchard and Watson (1982) and has later been supported by many others, for example Diba and Grossman (1988). It derives from classical financial theory, with the assumptions of rationality retained: rational behavior, rational expectations, and symmetrical information. The theory claims that there may be, even with perfectly rational behavior and rational expectations, deviations between an assets fundamental value and the market price, as the market price may contain a bubble element, a rational bubble.

Rational expectations and behavior, together with equilibrium prices, must imply that the investor positions are voluntary, and that no investor can increase expected utility by reallocating their portfolio, given available information (Blanchard & Watson, 1982). This leads to the formulation of the no arbitrage condition, or the efficient market condition. Available information is also assumed common to all players. In such a market, a rational bubble can occur if investors are willing purchase an asset at a price greater than what the fundamental value dictates. This situation may arise if the expectation of future price increase for the asset exceeds the investors' required return. The process governing stock prices is encapsulated in the Euler equation, used by Cuthbertson and Nitzsche (2005) to derive rational bubbles, which we will show in next section. This equation determines a sequence of prices but does not provide a unique price level unless a terminal condition is added. This is the transversality condition, which Blanchard, and Watson (1982) removed from the present value formula to admit rational bubbles and obtain this unique solution.

For a rational bubble to survive, there are several necessary conditions, causing some researchers to question and highlight logical issues with the theory. First, for rational bubbles to exist, an infinite horizon is required, meaning that rational bubbles cannot exist on assets that are finite (Linton, 2019). Second, asset prices cannot be negative and therefore negative bubbles cannot exist. Similarly, if there is an upper limit on asset prices, then positive bubbles cannot exist. If negative bubbles cannot exist, but positive bubbles can, then a bubble can never commence (Linton, 2019).

Fundamentals can be tricky to measure as many modern businesses have little or no tangible assets, as the following quote indicates: *"In 2015 Uber, the world's largest taxi company, owns no vehicles; Facebook, the world's most popular media owner, creates no content; Alibaba, the most valuable retailer, has no inventory; and Airbnb, the world's largest accommodation provider, owns no real estate"* (Linton, 2019). However, economists usually accept the present value model, where stock prices are considered rational forecasts of discounted future dividends.

4.5.1 Rational Valuation Formula and Rational Bubbles

Inspired by Blanchard and Watson (1982), Cuthbertson and Nitzsche (2005) derives rational bubbles. The start point is the present value model investors use to find a stocks fundamental value, which is the discounted present value of expected future dividends. Cuthbertson and Nitzsche (2005) defines expected return in the present value model as:

$$E_tR_{t+1} = \frac{E_tV_{t+1} - V_t + E_tD_{t+1}}{V_t} \tag{4.1}$$

Where V_t is the value, or the price, of the asset at the end of time t, $D_{t+1}$is the cash flow, or the dividends, paid between time t and $t + 1$. $E_t$is the expectations operator based on information $\Omega_t$at time t or earlier, and $E(D_{t+1}|\Omega_t) \equiv E_tD_{t+1}$.

For simplicity Cuthbertson and Nitzsche (2005) assumes investors have rational expectations, and that investors are only willing to buy and hold a stock if it is expected to constantly yield the required rate of return. The required rate of return, k, which is held constant, is given by the capital asset pricing model - CAPM, introduced by Sharpe (1964), Lintner (1965) and Mossin (1966). The CAPM is an equilibrium model that addresses the relationship between risk and expected return. CAPM is used to find the required rate of return on based on the investment's level of risk, as investors must be compensated for the risk-free rate of return and the systematic risk that accompanies their investment.

$$E_tR_{t+1} = k = r_f + \beta(ER_m - r_f), \qquad k > 0 \tag{4.2}$$

The stochastic behavior of $R_{t+1} - k$ is such that no abnormal returns are made, on average. The work of Paul Samuelson (1965) and Benoit Mandelbrot (1966) laid the foundation for Eugene Fama's famous "Efficient Market Hypothesis" – EMH, assuming all security prices at any time "fully reflect" all available information (Fama, 1970). The above mentioned explained that such random walk or stochastic behavior in returns is to be expected in well-functioning competitive markets or, efficient markets, and that excess returns are a "fair game", meaning that investors cannot expect to beat the market or earn returns exceeding the market return unless they possess an informational advantage, which is given by:

$$E_t(R_{t+1} - k|\Omega_t) = 0 \tag{4.3}$$

By using equation (4.1) and (4.2) Cuthbertson and Nitzsche obtains the Euler equation which determines the movement in “value” over time:

$$V_t = \frac{E_t(V_{t+1} + D_{t+1})}{1 + k} = \delta E_t(V_{t+1} + D_{t+1}) \tag{4.4}$$

Where $\delta = 1/(1 + k)$, which is the discount factor, and $0 < \delta < 1$. Leading equation (4.4) one period ahead they arrive at:

$$V_{t+1} = \delta E_{t+1}(V_{t+2} + D_{t+2}) \tag{4.5}$$

By using the law of iterated expectations $E_t(E_{t+1}V_{t+2}) = E_t V_{t+2}$, which tells us that one’s expectations of an assets future value tomorrow, is the same as one’s expectations of that assets future value today, since agents with rational expectations cannot know how they will alter their expectations in the future (Cuthbertson & Nitzsche, 2005). By taking into consideration the expectations of equation (4.5), assuming information is only available up to time t, they get:

$$E_t V_{t+1} = \delta E_t(V_{t+2} + D_{t+2}) \tag{4.6}$$

Substituting (4.6) in (4.4), and further using successive substitution:

$$V_t = \delta[\delta E_t(V_{t+2} + D_{t+2})] + \delta(E_t D_{t+1}) \tag{4.7}$$

$$V_t = E_t[\delta D_{t+1} + \delta^2 D_{t+2} + \delta^3 D_{t+3} + \cdots + \delta^N (D_{t+N} + V_{t+N})] \tag{4.8}$$

Adding the transversality condition $\lim_{N\to\infty} E_t\delta^N[D_{t+N} + V_{t+N}] \to 0$, which rules out rational speculative bubbles, equation (4.8) becomes:

$$V_t = \sum_{i=1}^{\infty} \delta^i E_t D_{t+i} \quad (4.9)$$

Equation (4.9) is derived under constant expected returns, that the law of iterated expectations and the transversality condition holds, and we now have an expression for a stocks fundamental value V_t. If the price of an asset does not match its fundamental value, $P_t \neq V_t$, then unexploited profit opportunities exist, but when investors anticipate profiting from such "mispricing" and buy the stocks, demand increases so that the price moves towards its correct fundamental value.

If we assume all investors have homogenous expectations and that they set the assets actual market price, P_t, equal to the fundamental value, V_t, we can write equation (4.9) in price form. Written in price form, where the transversality condition ensures a unique price denoted as the fundamental value, P_t^f:

$$P_t = P_t^f = \sum_{i=1}^{\infty} \delta^i E_t D_{t+i} \quad (4.10)$$

The intuition behind the theory on rational bubbles is that a stock price may differ from its fundamental value although investors behave equally, are rational and markets are efficient, as presented in the EMH. Mathematically this means that it exists another solution which satisfies the Euler equation:

$$P_t = \sum_{i=1}^{\infty} \delta^i E_t D_{t+1} + B_t = P_t^f + B_t \quad (4.11)$$

Where B_t is the rational bubble term. Meaning that the actual market price deviate from the fundamental value by the value of the rational bubble term. Rational investors are now still willing to hold the stock and no abnormal returns are made.

By leading equation (4.11) ahead and taking the expectations at time t, using the law of iterated expectations and further substituting in the definition of P_t^f from equation (4.10) Cuthbertson and Nitzsche get:

$$\delta[E_t D_{t+1} + E_t P_{t+1}] = P_t^f + \delta E_t B_{t+1} \tag{4.12}$$

Substituting equation (4.12) into the Euler equation in price form, $P_t = \delta E_t(P_{t+1} + D_{t+1})$, they get equation (4.13):

$$P_t = P_t^f + \delta E_t B_{t+1} \tag{4.13}$$

But now (4.11) and (4.13) seemingly contradicts each other, as both, in general, cannot be solutions to the Euler equation in price form. Cuthbertson and Nitzsche then present the following approach to make these two solutions equivalents:

$$E_t B_{t+1} = B_t/\delta = (1 + k)B_t \tag{4.14}$$

Now, (4.11) and (4.13) collapse to the same expression and both satisfies the Euler equation. Equation (4.14) implies:

$$E_t B_{t+m} = B_t/\delta^m \tag{4.15}$$

Therefore, the discounted bubble term must behave as a martingale, which implies that the best forecast for all future values of the bubble depends only on its current value. This solution violates the transversality condition (for $B_t \neq 0$) but still satisfies the Euler equation and because of the arbitrary nature of B_t, the stock price from equation (4.11) is not unique (Cuthbertson & Nitzsche, 2005).

The rational bubble solution holds as long as the bubble is expected to grow at a rate such that investors earn their required rate of return, which is given by equation (4.14), $E(B_{t+1}/B_t) - 1 = k$. If not, investors will not be willing to hold the stock. Investors do not care if they are paying for fundamentals or a bubble since the bubble element of the actual market price pays the required rate of return, k.

If expected dividends are held constant and the value of the bubble at time t, is $B_t = b\ (> 0)$, which is a constant, the bubble is deterministic and grows at rate k, leading to $E_t B_{t+m} = (1+k)^m b$. Meaning that once the bubble exists, the stock price at $t+m$, with constant dividends are:

$$P_{t+m} = \frac{\delta D}{(1-\delta)} + b(1+k)^m \tag{4.16}$$

Even in a case with constant dividends, meaning constant fundamentals and thereby also implying a constant price, the existence of the bubble means that the price can grow continuously, as $(1+k) > 1$.

Investors cannot know if an increase in price comes from new fundamentals or from the growing bubble, but they do not mind paying a price over the fundamental value if the bubble element yields them the required rate of return, k, next period and is expected to persist. The bubble is a self-fulfilling expectation (Cuthbertson & Nitzsche, 2005).

5. Methodology

In this chapter we will present the methodology that underlies the various augmented Dickey-Fuller (ADF) regressions based on work of Philips et.al (2011) & Philips et.al (2015). First, we will present the method on how to detect explosive behavior, and then show how to date stamp the results. Finally, we will show how to use the dataset in its entirety before discussing implementation of the model.

The supremum augmented Dickey–Fuller (SADF), the generalized SADF (GSADF), and panel GSADF test are all univariate right-tailed tests based on the same ADF regression equation. For each time series the test applies the ADF test for a unit root against the alternative of an explosive root (right tailed). The following ADF regression is used:

$$\Delta y_t = \alpha_{r1,r2} + \beta_{r1,r2} y_{t-1} + \sum_{i=1}^{k} \delta_{r1,r2}^{i} \, \Delta y_{t-1} + \varepsilon_t \tag{5.1}$$

Δ is the first difference, y_t is the time series of interest at time t, r_1 & r_2 specify the starting and the ending point, respectively, of a subsample period of the total sample size T, $r_2 = r_1 + r_w$, where r_w is the window size of the regression, ε_t is the error term of the regression, α, β, δ are regression coefficients. The null and alternative hypothesis is:

$$H_0 : \beta_{r1,r2} = 0 \quad \rightarrow \quad (unit\ root) \tag{5.2}$$

$$H_1 : \beta_{r1,r2} > 0 \quad \rightarrow \quad (explosive\ behaviour) \tag{5.3}$$

The reason we are testing for unit root is to determine whether the time-series has a unit root or explosive behavior. If one or more of the joints in an autoregressions model (AR(p) model) has an absolute value of 1, the time series is said to have a unit root and is non-stationary. The ADF test statistics that tests H_0 is denoted as ADF_{r1}^{r2} , where:

$$ADF_{r1}^{r2} = \frac{\hat{\beta}_{r1,r2}}{se(\hat{\beta}_{r1,r2})} \tag{5.4}$$

5.2 The ADF test

In the standard ADF test, equation 5.4 is obtained by repeatedly estimate equation 5.1 on the full range of observations. In order to achieve this, we set $r_w = 1$ ($r_1 = 0$ & $r_2 = 1$). The result statistic under the null of a unit root, denoted as ADF_0^1, is given by the following equation:

$$\frac{\int_0^1 \widetilde{W} dW}{\left(\int_0^1 \widetilde{W}^2\right)^{1/2}} \tag{5.5}$$

W is a standard Brownian motion (Wiener process). $\widetilde{W}$ is a demeaned Brownian motion:

$$\widetilde{W}(r) = W(r) - \frac{1}{r}\int_0^1 W \tag{5.6}$$

The testing method used in the ADF test is suitable as long as the explosive behavior (bubbles) collapse periodically, which is not always the case. This is confirmed by earlier work of Evans (1991). Another issue with the ADF test is that it cannot date stamp the episodes of explosive behavior.

5.3 The SADF test

To cope with these challenges, Philips et.al (2011) presented another statistic which "matches the time series of the recursive test statistic against the right-tailed critical values of the asymptotic distribution of the standard Dickey–Fuller t-statistic" (Phillips et al., 2011). In the SADF test, equation 5.1 is estimated using a forward expanding window sample. The window size (r_w) is set at the smallest window size (r_0) and increased gradually to the last observation in the sample. The supremum of the estimation of equation 5.1 is called the SADF statistic and is given by:

$$SADF_{(r0)} = \sup_{r_2 \in [r_o, 1]} \{ADF_0^{r0}\} \tag{5.7}$$

With the limit distribution:

$$\sup_{r_2 \in [r_o, 1]} \frac{\int_0^{r_2} \widetilde{W} dW}{\left(\int_0^1 \widetilde{W}^2\right)^{1/2}} \tag{5.8}$$

To reject the null hypothesis of unit root, the SADF test statistics needs to exceed the right-tailed critical values. Since the SADF test is capable of detecting multiple episodes of explosive behavior, the alternative hypothesis is that we experience explosive behavior in some parts of the of the sample. However, a limitation with the SADF test turns out to be that the test is not able to give a consistent estimate of the end date of the later episodes of explosive behavior when several periods of explosive behavior are present (Vasilopoulos et al., 2020)

5.4 The GSADF test

In order to solve the time stamping issues, Philips et al. (2015) presented a new test statistic. The generalized SADF test is based on the same regression equation as the SADF test but uses a more extensive set of subsamples. Another key difference between the tests is that the GSADF test vary the endpoint of the regression r_2, as well as allowing the starting point r_1 to change. Figure 5 illustrates the different sample sequences.

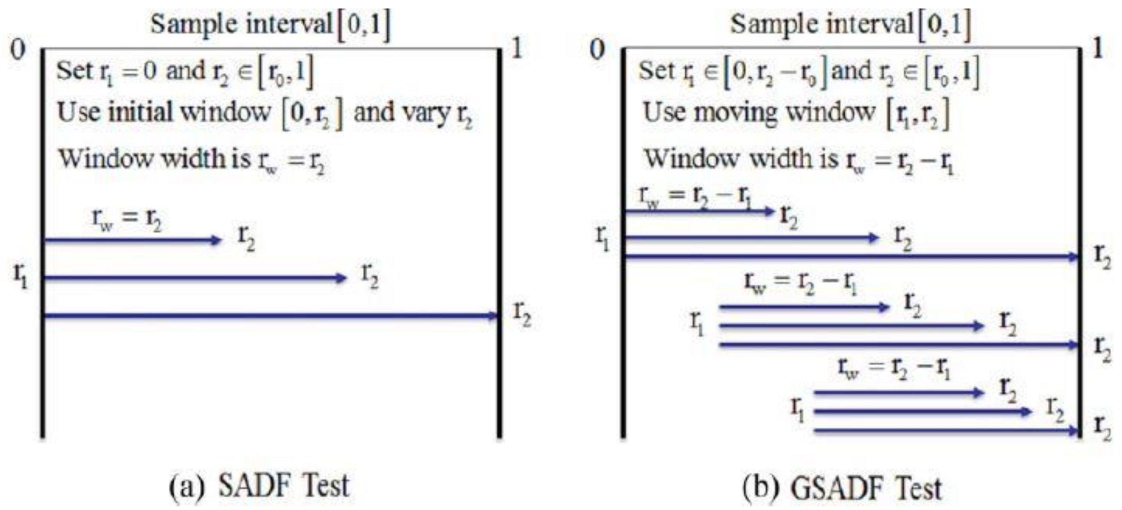


Figure 5: SADF and GSADF sample interval (Phillips et al., 2015)

The flexibility in the estimation window allows the GSADF test to better detect multiple episodes of explosive behavior, as well as producing consistent estimates of the end dates. The GSADF statistic is given by:

$$GSADF\ (r_0) = \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} \left\{ ADF_{r_1}^{r_2} \right\} \tag{5.9}$$

With the limit distribution:

$$\sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} = \left\{ \frac{\frac{1}{2} r_w [W(r_2)^2 - W(r_1)^2 - r_w] - \int_{r_1}^{r_2} W(r)\, dr [W(r_2) - W(r_1)]}{r_w^{1/2} \left\{ r_w \int_{r_1}^{r_2} W(r)^2\, dr - \left[\int_{r_1}^{r_2} W(r) dr \right]^2 \right\}^{1/2}} \right\} \tag{5.10}$$

5.5 Date stamping

If we are able to reject the null hypothesis of unit root, we can use SADF and GSADF to date stamp episodes of explosive behavior. We will use the GSADF methodology, because this method is more suitable for analyzing a given data set for bubble behavior, according to (Phillips et al., 2015). The strategy is based on the backward sup ADF test, and given by:

$$BSADF_{r_2}\,(r_0) = \underset{r_1 \in [0, r_2 - r_0]}{sup} \quad SADF_{r_1}^{r_2} \tag{5.11}$$

With the following estimation of dates:

$$\widehat{r_e} = \underset{r_2 \in [r_0, 1]}{inf} \quad \{r_2 \colon BSADF_{r_2}\,(r_0) > scv_{r_2}^{\alpha}\} \tag{5.12}$$

$$\widehat{r_f} = \underset{r_2 \in [\widehat{r_e}, 1]}{inf} \quad \{r_2 \colon BSADF_{r_2}\,(r_0) < scv_{r_2}^{\alpha}\} \tag{5.13}$$

Where r_e and r_f are the origination and termination points of a bubble, respectively. $scv_{[r_2]}^{\alpha}$ is $100(1-\alpha)\%$ critical value of SADF for $[r_2 T]$ observations.

5.6 The panel GSADF test

Since the GSADF test can only be applied to individual time series, Pavlidis et al. (2016) introduced an expansion that exploits the panel nature of the financial dataset. The extension is called the panel GSADF test and is based on a panel version of equation 5.1:

$$\Delta y_{i,t} = \alpha_{i,r1,r2} + \beta_{i,r1,r2}\, y_{i,t-1} + \sum_{i=1}^{k} \delta_{i,r1,r2}^{i}\, \Delta y_{i,t-1} + \varepsilon_{i,t} \tag{5.14}$$

Where $i = 1, \dots, N$ is the panel index, and the other variables are denoted as the same as in equation 5.1. The null and alternative hypothesis is:

$$H_0 : \beta_{i,r1,r2} = 0 \quad \rightarrow \quad (unit\ root) \tag{5.15}$$

$$H_1 : \beta_{i,r1,r2} > 0 \quad \rightarrow \quad (explosive\ behaviour) \tag{5.16}$$

The difference between equation 5.15 & 5.16 and 5.2 & 5.3 allows the panel GSADF test to discover explosive behavior is a subset of the series. In the testing procedure, a measure of overall explosive behavior is constructed by averaging the individual BSADF statistics in each time period (Vasilopoulos et al., 2020). The panel BSADF is given by:

$$panel\ BSADF_{r_2}(r_0) = \frac{1}{N}\sum_{i=1}^{N} BSADF_{i,r_2}\ (r_0) \tag{5.17}$$

With the limit distribution:

$$panel\ GSADF\ (r_0) = \sup_{r_2 \in [r_0, 1]} \ panel\ BSADF_{r_2}(r_0) \tag{5.18}$$

5.7 Implementation

To conduct the econometric tests, we have chosen to use the programming language R. Furthermore, it is required to download the data packages *exuber* and *exuberdata*. The package *exuber* is based on the function `rADF` and require input for `minw` and `lag`. `Minw` is the minimum windows size set to default ($(0{,}01+1{,}8/\sqrt{(T)})$T, where T denotes the sample size) and `lag` is set at default (0L), as recommended by Phillips et al. (2015). The output of interest is mainly the test statistics for GSADF.

Critical values for up to 600 observations are available and stored in the *exuber* package. To obtain critical values for more than 600 observations, we need the package *exuberdata*. In order to replicate the critical values, we use the command `rADF_mc_cv`. We set the number of Monte Carlo simulations to 2 000 (nrep=2000), and seed to 123. To replicate the critical values for panel data, we use a bootstrap method based on the method of Sieves, through the command `rADF_sb_cv`. We set the number of bootstraps to 500 (nboot=500).

6. Data

To answer the research question, we need to find a representation of the overall Norwegian stock market, and the green stocks. In order to select which companies are green, we need a clear definition of what green stocks are. We use the definition presented in chapter 2, "Green finance is a broad term that can refer to financial investments flowing into sustainable development projects and initiatives, environmental products, and policies that encourage the development of a more sustainable economy" (Höhne et al., 2012).

Furthermore, we have based our data collection on stocks from the Oslo Stock Exchange and Euronext Growth. We have chosen to use daily closing prices instead of weekly or monthly data, because we want to capture both longer and shorter periods (blips) of explosive behavior in the stock prices. We have chosen a period of 10 years, from 01.03.2012 - 01.03.2022, which results in 2 507 observations.

Since many of the companies that are defined as green have had IPOs in recent years, several of the companies have far fewer observations than 2 507. Therefore, it is not convenient to look at a time period longer than 10 years. We have chosen to exclude companies with less than 100 observations, because such a short period of time is not sufficient to carry out the econometric analysis. With the previous criteria in mind, we are left with 40 companies. The data is retrieved from Thomson Reuters and adjusted for dividend payments. Atlantic Sapphire and Otovo had a stock split of 10:1 on 05-01-2018 and 19-02-2021, respectively.

Table 1 displays descriptive statistics for the various green stocks, including the name, ticker, number of observations for each stock, the mean value, maximum and minimum values and the compound annual growth rate (CAGR). Since the green stocks have a wide range in number of observations, we have chosen to use CAGR as a measurement because it is considered to be one of the most accurate techniques to measure changes in returns over time. Compared to average annual growth rate (AAGR), CAGR adjust for the compound interest effect.

Table 1: Green stocks descriptive statistics

Company	Ticker	Obs	Mean	Min	Max	CAGR
Agilyx	AGLX	356	32,9	21,4	52,8	-2 %
Aker Carbone Capture	ACCA	381	18,3	4,3	34,4	122 %
Aker Clean Hydrogen	ACHA	244	7,2	3,9	13,5	-57 %
Aker Offshore Wind	AOW	381	5,6	2,2	12,5	-12 %
Andfjord Salmon	ANDF	582	44,7	25,0	70	-18 %
Arendals Fossekompani	AFK	2 206	114,3	42,5	495	18 %
Atlantic Sapphire	ASA	976	87,6	27,8	150	-20 %
Bergen Carbone Solution	BCS	220	46,5	16,1	81,8	118 %
Borregaard	BRGB	2 346	84,5	18,2	232	26 %
Bw Ideol	BWID	226	32,8	16,0	49,9	-51 %
Cadeler	CADLR	314	32,6	23,5	41	22 %
Cambi	CAMBI	266	13,8	6,4	29	-55 %
Circa Group	CIRCA	251	14,5	6,1	28,4	-47 %
Cloudberry Clean Energy	CLOUD	479	14,2	9,9	18,5	8 %
Co2 Capsol	CAPSL	249	14,2	5,0	29,5	-46 %
Desert Control	DSRT	223	22,8	12,0	40,7	82 %
Everfuel	EFUEL	335	68,6	19,0	183,4	112 %
Fjordkraft Holding	FKRFT	986	53,7	30,4	100	-6 %
Hexagon Composites	HEX	2 507	24,5	2,8	73	26 %
Horisont Energi	HRGI	274	56,6	34,9	115,7	3 %
Hynion	HYN	221	3,6	1,7	7,6	-63 %
Kalera	KALK	452	25,4	4,1	48	-59 %
Kyoto Group	KYOTO	234	29,8	16,5	53,7	-57 %
Magnora	MGN	2 425	9,9	4,6	31	5 %
Mpc Energy Solution	MPCES	278	32,3	18,9	52,4	-47 %
Nel	NEL	2 507	6,4	0,5	35	-6 %
Norsk Solar	NSOL	220	7,8	4,3	12,7	-49 %
Ocean Sun	OSUN	338	26,9	8,0	57,5	-4 %
Otovo	OTOVO	259	17,8	11,1	28	11 %
Proximar Seafood	PROXI	270	9,1	6,8	18,73	-48 %
Pryme	PRYME	257	46,5	13,1	75	-76 %
Pyrum Innovations	PYRUM	100	880,9	570,0	1200	29 %
Quantafuel	QFUEL	718	29,4	5,6	78,9	-14 %
Rec Silicon	RECSI	2 507	15,3	2,1	50	-2 %
Salmon Evolution	SALME	364	7,2	5,1	11,2	9 %
Scatec	SCATC	1 858	94,1	17,6	398	24 %
Teco 2030	TECO	348	6,3	2,1	13,6	-48 %
Tomra Systems	TOM	2 507	173,7	42,2	631	22 %
Vow Green Metals	VGM	163	4,8	2,9	8,75	-49 %
Vow Green Metals	VOW	1 976	10,5	0,5	50	35 %

The 40 green companies operate in different segments. Roughly speaking, we can divide the companies into 7 sectors: Aquaculture, Biotechnology, Carbon Capture & Storage, Waste Management & Disposal & Recycling Services, Clean Energy, Industry & Chemicals, and Energy Support & Construction & Components. As displayed in figure 6, Clean Energy is the largest represented sector, followed by the Energy Support & Construction & Components sector.

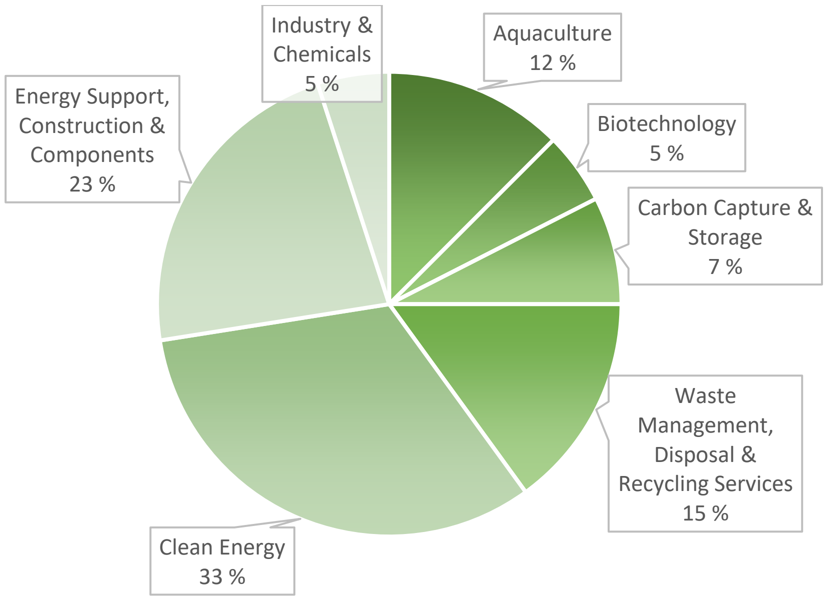


Figure 6: Green companies divided into sectors (Thomson Reuters)

The next step is to find a suitable index that represents the Norwegian stock market. The most common benchmark index for the Norwegian stock market is the Oslo Stock Exchange Benchmark Index (OSEBX). OSEBX includes the most traded and largest stocks listed on the Oslo Stock Exchange. As of 01.03.2022, OSEBX consists of 69 companies (Euronext, 2022). The index is adjusted for dividend payments.

Table 2: OSEBX descriptive statistics

Index	Ticker	Obs	Mean	Min	Max	CAGR
Oslo Stock Exchange Benchmark	OSEBX	2 507	728,2	371,8	1 237,4	11 %

For OSEBX, we have also chosen to use daily closing prices for the last 10 years, from 01.03.2012 - 01.03.2022, which gives 2,507 observations. The list of all companies on OSEBX as of 01.03.2022 can be found in the appendix.

7. Results

In this chapter we present the results from the unit root test. We start by examining the results from the unit root test of OSEBX. Then, we will examine the results of the unit root tests for the green stocks, before we consider the date stamping of the results. The next step will be to address the green stocks as a whole in the unit root test of the panel data. Finally, we will conduct a financial ratio analysis for the green stocks based on PE ratio and ROE.

7.1 OSEBX

To find out if there is a bubble developing in the green stocks, it is appropriate to start by examining if there are bubble tendencies on the Oslo Stock Exchange. This is done to find out if the bubble trends apply to the entire Oslo Stock Exchange, or just specifically the green stocks. We start by applying the unit root tests to the 10-year dataset from the OSEBX index.

Table 3: OSEBX test statistics

Stat	OSEBX	90 %	95 %	99 %
Adf	-1,68	-0,44	-0,16	0,48
Sadf	1,26	1,35	1,63	2,12
Gsadf	1,58	2,26	2,46	2,94

Table 3 displays the OSEBX test statistics for the ADF, SADF and GSADF test, as well as the belonging 90%, 95% and 99% critical values. From Table 3, it is observed that the test statistics for OSEBX do not exceed the critical values at the 95% level for GSADF, nor at the 90% level. The equivalent applies to the ADF and SADF test. Figure 7 shows test statistics for the GSADF test for OSEBX. The red line displays the 95% critical values, and the blue line shows the test statistics. The test statistics never exceed the critical values, although they were close in early 2014, and on multiple occasions in the period between 2020 and 2022.

Figure 7: GSADF test statistics OSEBX

Since OSEBX consists of a larger number of stocks within several different segments, larger movements are required before GSADF exceeds the critical values. Based on the results from the tests, it is suggested that we do not have a bubble in the Norwegian stock market as a whole today. The results also show that there have been no episodes of explosive behavior in the last ten years.

7.2 Green stocks

In this section, we test the dataset consisting of 40 different green companies for explosive behavior. We execute the ADF tests 40 times, since each stock has a different number of observations, and the ADF tests does not handle missing values. Further, we must obtain the individual critical values for the respective stocks. The critical values depend on the number of observations and will therefore vary from stock to stock.

As mentioned earlier in chapter 5, the rADF command provides three outputs, but we focus on the GSADF because this test statistic is used further in the econometric analysis to date-stamp periods of explosive behavior. The ADF and SADF were found to have decreased detection power for bubbles that burst in-sample, and these findings are consistent with other studies that used the same tests. A complete table of test statistics for ADF and SADF can be found in the appendix. Table 4 shows GSADF test statistics for each green company, with associated 90%, 95% and 99% critical values, respectively.

Table 4: Green stocks test statistics

Ticker	Gsadf	90 %	95 %	99 %	Result
ACCA	1,17	1,92	2,16	2,61	Cannot reject H0
ACHA	1,92	1,88	2,11	2,56	Rejects H0 at 10% significance level
AFK	0,32	2,23	2,44	2,93	Cannot reject H0
AGLX	1,22	1,90	2,14	2,60	Cannot reject H0
AOW	1,59	1,92	2,16	2,61	Cannot reject H0
ANDF	0,48	1,98	2,23	2,66	Cannot reject H0
ASA	2,36	2,10	2,31	2,74	Rejects H0 at 5% significance level
BCS	0,40	1,88	2,12	2,58	Cannot reject H0
BRGB	0,84	2,25	2,46	2,92	Cannot reject H0
BWID	1,75	1,86	2,11	2,56	Cannot reject H0
CADLR	0,70	1,89	2,11	2,57	Cannot reject H0
CAMBI	1,53	1,87	2,08	2,55	Cannot reject H0
CIRCA	2,46	1,85	2,09	2,54	Rejects H0 at 5% significance level
CLOUD	0,17	1,95	2,19	2,62	Cannot reject H0
CAPSL	1,00	1,89	2,11	2,56	Cannot reject H0
DSRT	-0,06	1,85	2,11	2,56	Cannot reject H0
EFUEL	2,73	1,90	2,12	2,56	Rejects H0 at 1% significance level
FKRFT	1,63	2,09	2,31	2,77	Cannot reject H0
HEX	2,43	2,26	2,46	2,94	Rejects H0 at 10% significance level
HRGI	1,92	1,89	2,11	2,61	Rejects H0 at 10% significance level
HYN	2,20	1,88	2,12	2,61	Rejects H0 at 5% significance level
KALK	1,87	1,94	2,19	2,62	Cannot reject H0
KYOTO	1,16	1,87	2,11	2,56	Cannot reject H0
MGN	1,64	2,25	2,45	2,94	Cannot reject H0
MPCES	1,17	1,89	2,11	2,61	Cannot reject H0
NEL	4,24	2,26	2,46	2,94	Rejects H0 at 1% significance level
NSOL	2,39	1,88	2,12	2,12	Rejects H0 at 5% significance level
OSUN	2,75	1,91	2,13	2,56	Rejects H0 at 1% significance level
OTOVO	2,34	1,88	2,11	2,56	Rejects H0 at 5% significance level
PROXI	3,21	1,88	2,09	2,56	Rejects H0 at 1% significance level
PRYME	2,70	1,88	2,11	2,56	Rejects H0 at 1% significance level
PYRUM	0,19	1,71	1,97	2,57	Cannot reject H0
QFUEL	1,24	2,04	2,26	2,66	Cannot reject H0
RECSI	1,43	2,26	2,46	2,94	Cannot reject H0
SALME	1,31	1,91	2,15	2,60	Cannot reject H0
SCATC	0,98	2,22	2,42	2,60	Cannot reject H0
TECO	0,80	1,90	2,13	2,57	Cannot reject H0
TOM	0,79	2,26	2,46	2,94	Cannot reject H0
VGM	1,90	1,84	2,12	2,67	Rejects H0 at 10% significance level
VOW	2,43	2,22	2,43	2,91	Rejects H0 at 5% significance level

As table 4 displays, we can reject H0 at the 5% significance level for 6 companies, and at the 1% level for 5 companies. We can also reject H0 at a 10% significance level for some companies, but according to Lehmann & Romano (2008) we have chosen to require a 95% confidence level. As a result, we experience explosive behavior in 11 of 40 green stocks in the last ten years. It is expected that there will be more cases of explosive behavior when we test single stocks versus an index, since large movements in a single stock will not affect the entire index to the same extent. Furthermore, it will be interesting to look at the results from the date-stamp to see if the episodes of explosive behavior from the various stocks overlap in time. Table 5 shows the start and end time of each episode of explosive behavior, as well as the duration.

Table 5: Episodes of explosive behavior

ASA	Start	End	Duration
1	21.12.2018	03.01.2019	4
2	04.01.2019	08.01.2019	2

CIRCA	Start	End	Duration
1	28.04.2021	03.05.2021	3
2	04.05.2021	05.05.2021	1
3	06.05.2021	07.05.2021	1
4	12.10.2021	13.10.2021	1

EFUEL	Start	End	Duration
1	07.01.2021	12.01.2021	3
2	10.02.2021	12.02.2021	2

HYN	Start	End	Duration
1	30.04.2021	03.05.2021	1
2	03.09.2021	07.09.2021	2

NEL	Start	End	Duration
1	NA	14.03.2012	13
2	23.03.2012	26.03.2012	1
3	18.07.2012	10.08.2012	17
4	14.08.2012	28.08.2012	10
5	29.08.2012	29.10.2012	43
6	26.04.2016	27.04.2016	1

NSOL	Start	End	Duration
1	06.05.2012	07.05.2021	1

OSUN	Start	End	Duration
1	08.06.2021	09.06.2021	1
2	03.01.2022	06.01.2022	3

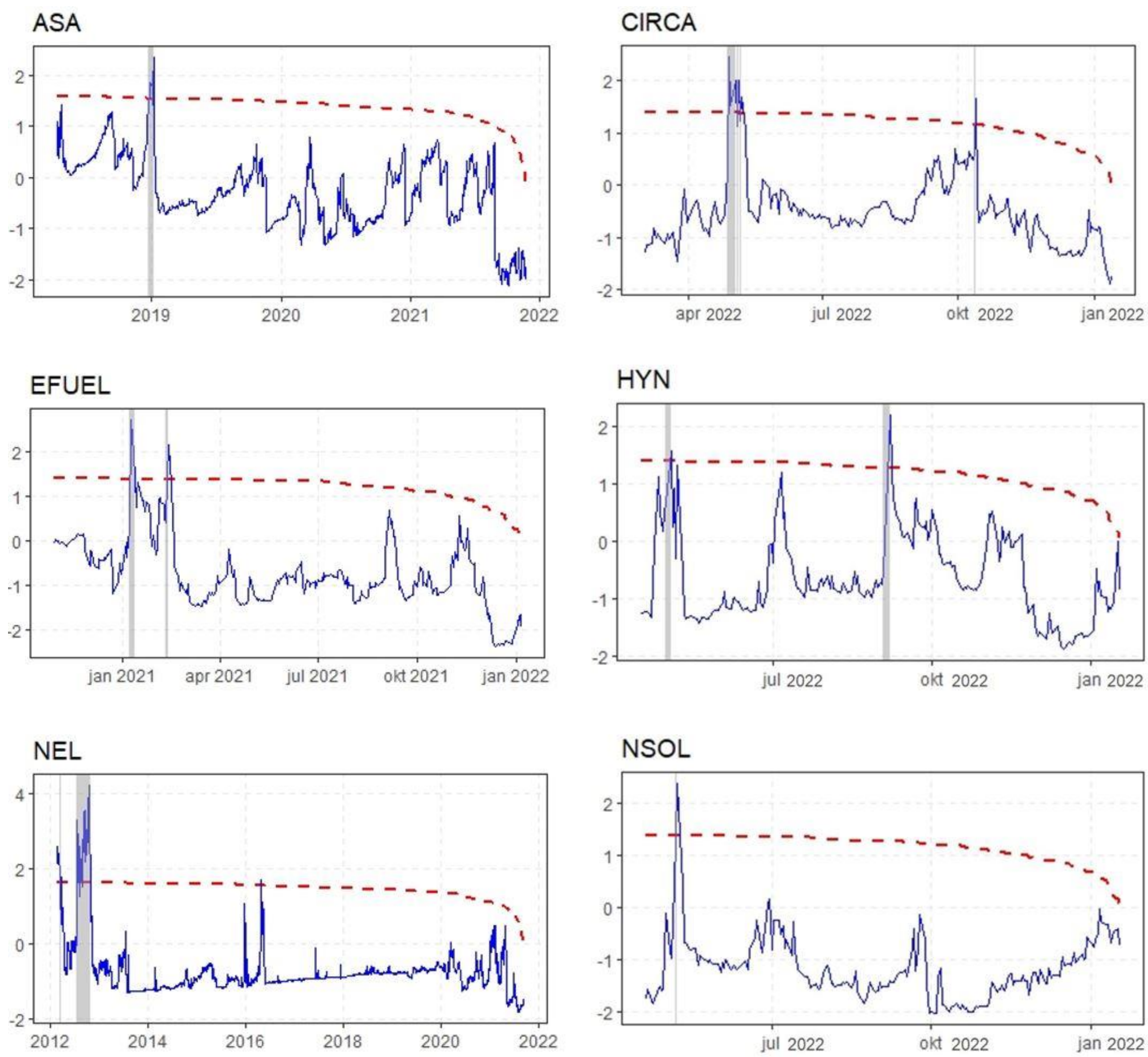
OTOVO	Start	End	Duration
1	NA	18.02.2021	1

PROXI	Start	End	Duration
1	NA	17.02.2021	11
2	18.02.2021	23.02.2021	3
3	24.02.2021	25.02.2021	1
4	08.04.2021	12.04.2021	2

PRYME	Start	End	Duration
1	28.06.2021	30.06.2021	2
2	15.12.2021	16.12.2021	1

VOW	Start	End	Duration
1	03.11.2014	17.11.2014	10
2	27.11.2014	03.12.2014	4
3	05.12.2014	08.12.2014	1

There are 29 episodes of explosive behavior. The vast majority of episodes took place in 2021, but also some episodes in 2012, 2014 and in 2019. As table 5 displays, most episodes have a relatively short duration. NEL differs from the crowd with the most episodes, as well as the longest duration. Worth noticing is that several of the stocks experienced explosive behavior early after their IPO. Regardless, there is no direct correlation between IPOs and explosive behavior. Figure 8 shows the date stamping of the episodes of explosive behavior. The red line shows the 95% critical values, and the blue line shows the test statistics. The gray areas show when GSADF exceeds the critical values, and the minimum duration.



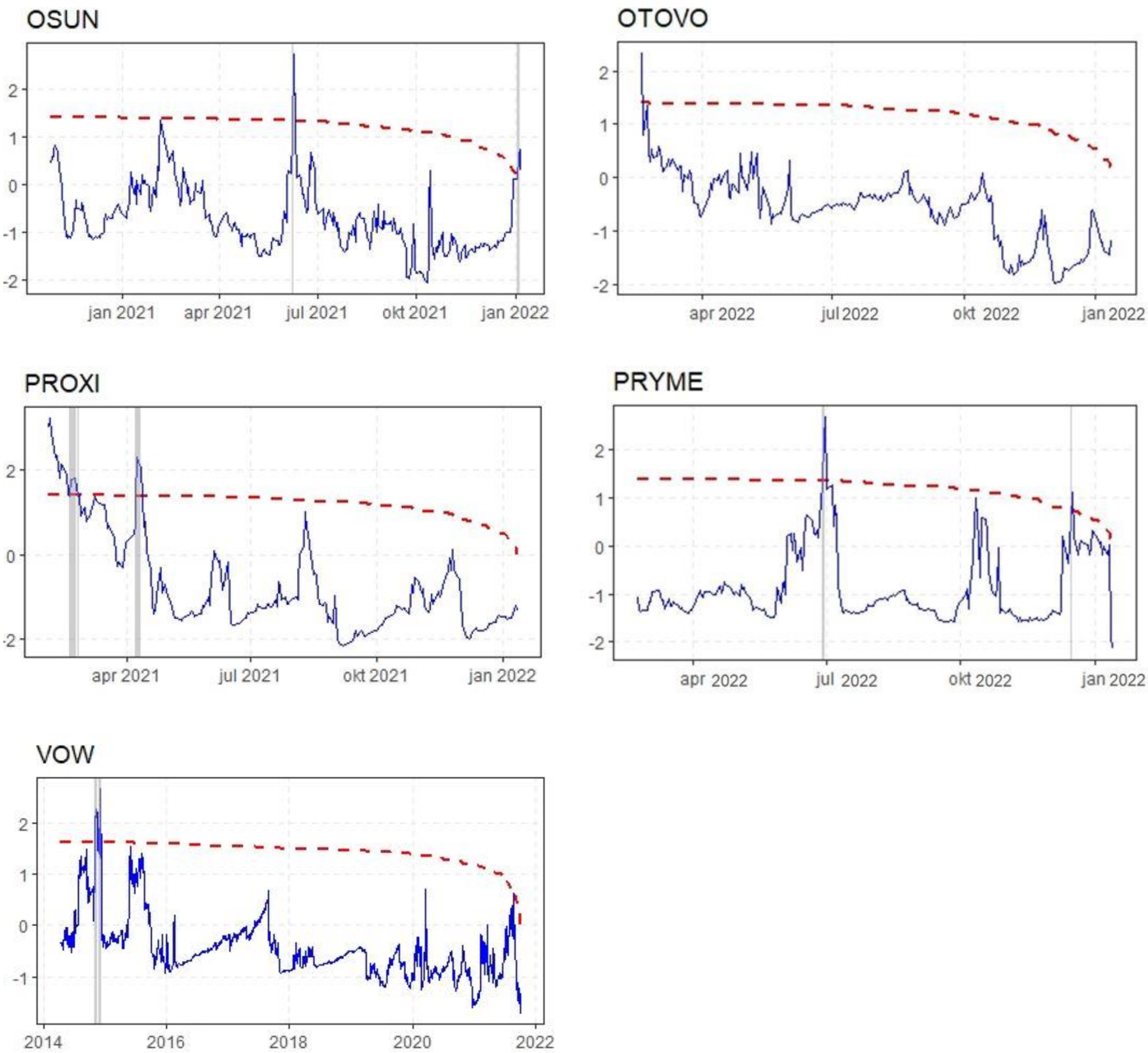


Figure 8: GSADF test statistics green stocks

To utilize the panel properties of the financial dataset, we will perform the panel GSADF test. As displayed in table 6, the test statistics do not exceed the critical values. As a result, we cannot reject the null hypothesis of unit root in the dataset in its entirety. The test statistics for the panel GSADF is -0,43, while the 95% critical values are 0,05. It is expected that we cannot reject the null hypothesis, since only 11 out of 40 stocks experienced explosive behavior. The influence of the 11 companies with explosive behavior is not strong enough to affect the dataset in its entirety.

Table 6: Green stocks panel test statistics

Test	T-stat	90 %	95 %	99 %	Result
Gsadf_panel	-0,43	0,04	0,05	0,07	Cannot reject H0

7.3 Financial ratio analysis

To complement the econometrics analysis and to provide a second angle to investigate whether there are bubbles in green stocks in the Norwegian stock market we present an analysis of some financial ratios for the green companies. Most of the companies categorized as green also classifies as growth stocks, meaning that they are young companies where spending and investment needs are high so that they can continue to grow. This may result in negative cash flows and thus negative financial ratios.

Price over earnings (PE) ratio is used to measure the relative value of a stock in relation to earnings (McWilliams, 2018). The multiple is useful for comparing different companies operating in the same segment to see how they are priced in the market in relation to each other. Return on equity (ROE) shows a company's profitability in relation to shareholders' equity. ROE also shows how efficiently a company generates profit (Arditti, 1967).

A study by Liu et al. (2016) on exuberance and collapse in the Shanghai A-share stock market states that "In general, a high PE ratio represents high valuation. If there is not a proper ROE matching the PE ratio, the Shanghai A-share stock market should, with high probability, fall" (Liu et al., 2016). The study further indicates that common characteristics of bubbles are that the market price deviates to a considerable extent from the fundamental value of the stock. A high PE ratio without a corresponding ROE can therefore be interpreted as a signal of overpricing. PE and ROE are calculated in the following manner:

$$\frac{P}{E} ratio = \frac{Market\ value\ per\ share}{Earnings\ per\ share} \tag{7.1}$$

$$ROE = \frac{Net\ income}{Shareholders\ equity} \tag{7.2}$$

The reason to study PE and ROE is because we want to examine whether the stocks are priced high in the market in relation to respective earnings. A high PE value and a low ROE may be an indication of this. Furthermore, it is worth mentioning that the respective green companies operate in different industries where the industrial median for the financial ratios varies. Factors such as capital structure and macroeconomic variables can influence the financial ratios. Therefore, we are not interested in looking at absolute values, but rather the relationship between PE and ROE. Table 7 presents the green stocks, and their respective PE and ROE value as of 01.03.2022.

Table 7: Green stocks PE & ROE 01.03.2022

Ticker	ROE	PE	Ticker	ROE	PE
ACCA	-20	-170	HYN	-53	N/A
ACHA	N/A	N/A	KALK	-20	-3
AFK	3	208	KYOTO	-129	-17
AGLX	-54,5	-16	MGN	-43	-29
AOW	N/A	N/A	MPCES	N/A	-21
ANDF	-7,7	-53	NEL	-32	-18
ASA	-24	-3	NSOL	-91	-17
BCS	-17	-62,8	OSUN	-18	-55
BRGB	18	25	OTOVO	-49	-14
BWID	-27	-4	PROXI	-73	-16
CADLR	-24	83	PRYME	-9	-8
CAMBI	6	60	PYRUM	-81	-75
CIRCA	-33	-23	QFUEL	-127	-851
CLOUD	-3	-56	RECSI	-94	-26
CAPSL	-55	-26	SALME	-4	-73
DSRT	-10	-44	SCATC	4	52
EFUEL	-13	-63	TECO	-52	-15
FKRFT	18	8	TOM	21	55
HEX	-8	-21	VGM	N/A	N/A
HRGI	N/A	N/A	VOW	77	7

PE ratio and ROE for the green companies is retrieved from Thomson Reuters. The PE ratio is the trailing twelve months PE ratio, which means that the actual earnings for the last twelve months are used. A total of six of the green stocks had one or two missing values. This may be due to the fact that the respective companies have been on the market for too short a time for there to be sufficient data basis to calculate the financial ratios. From table 7 it appears that almost every green company have negative PE and ROE. This is because many of the companies currently have negative earnings. Nevertheless, the companies may be priced high because of the market expectation of positive future cash flows.

To complement the econometric analysis, it is appropriate to investigate whether the periods of explosive behavior overlap with excessive PE ratios. As mentioned earlier, most of the episodes took place in the period from the year 2021 to the beginning of the year 2022. 11 stocks experienced explosive behavior during the 10-year period, and 7 of them in the last years: CIRCA, EFUEL, HYN, NSOL, OSUN, PROXI, and PRYME. A limitation with the task is, as mentioned, that several of the companies have negative ratios due to negative cash flows, which is the case for all the 7 stocks that experienced explosive behavior in the period 2021-2022. As a result, we cannot use the financial ratios to substantiate the econometric findings nor compare the development in ratios with the date stamp of explosive behavior.

8. Discussion

Green investing, as noted throughout this thesis, is a hot topic of conversation, as are fears about a possible bubble. As previously said, one issue is that it is difficult to spot bubbles before they burst, which is one of the reasons why asset bubbles occur. The results of the quantitative stock price analysis, macroeconomic trends, learning from historical bubbles, and a detailed examination of the stages of bubble creation can all assist in answering the thesis main research question “Is there a green bubble developing on the Oslo Stock Exchange?”

The global macroeconomic trends over the past two years does not indicate that growth stocks should outcompete the stock market as a whole. A growth stock is characterized by low or no earnings today, but exciting potential to generate significant cash flows in the future (Athanassakos, 2009). Since growth stocks have low or no earnings today, they will be highly priced in the market in relation to earnings. This can be examined by looking at the P/E multiple. Table 7 shows that most of the green companies discussed in this thesis have negative or a high P/E multiple. Several of the companies will have negative financial ratios since they have negative earnings. Based on the criteria mentioned above, it is reasonable to claim that the current green companies discussed throughout this thesis can be characterized as growth stocks.

The global stock market has been characterized by rising interest rates and rising inflation over the past two years. According to Finn Kinserdal, associate professor at the Norwegian school of economics (NHH), the valuation of companies with stable earnings and positive cash flows will not be affected by inflation. The intuition behind this is that costs, but also revenues will rise equally, resulting in equal net profit. Kinserdal further points out that companies that are priced high on the basis of high expected cash flows should decrease in value when inflation and inflation expectations rise. The reason is that the discount factor for the future cash flows also increases with increased inflation expectations, which results in a lower present value. In conclusion, Kinserdal states "ESG companies should fall in value when inflation is expected to rise and pull the entire market down" (Kinserdal, 2022).

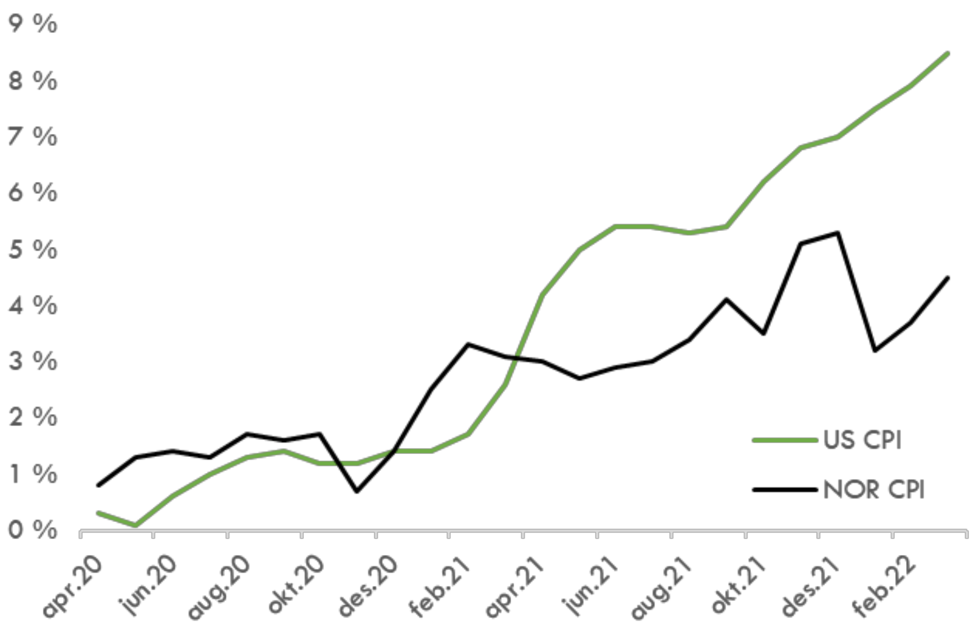


Figure 9: USA & Norway CPI April 2020-2022 (Thomson Reuters)

The Consumer Price Index (CPI) shows the development in consumer prices for goods and services and is a standardized tool for measuring inflation. Figure 9 displays the development in CPI in Norway and in the USA over the last two years. The development indicates that the price of growth stocks should be reduced. From another perspective, actual inflation is just one of the factors affecting inflation expectations. Figure 10 displays the relationship between inflation expectations, actual inflation, and monetary policy. Inflation expectations are not only affected by actual inflation, but also expectations and monetary policy.

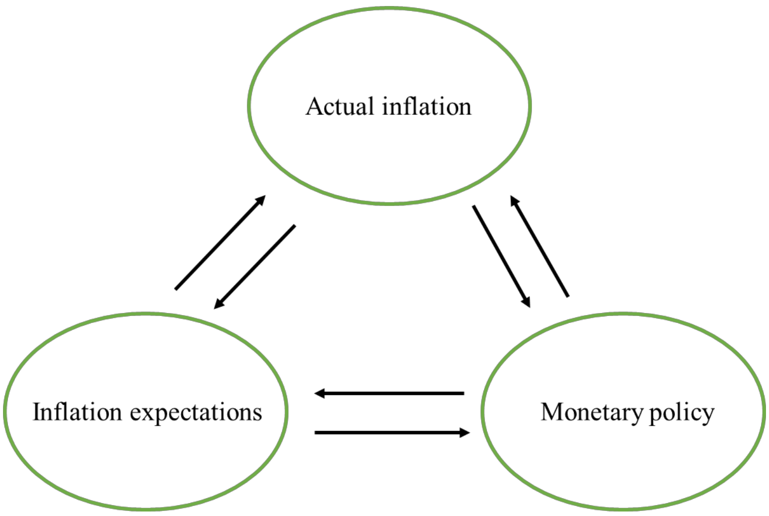


Figure 10: Inflation relationship (Norges Bank, 2017)

Interest rates are another macroeconomic factor that has an impact on stock prices. Rising interest rates lead to an increase in the required rate of return, which in turn leads to an increased discount factor and lower present value. An empirical study of stock market sensitivity to interest rates and inflation, equity duration, and determinants of interest rate sensitivity concludes, among other things that, "the evidence strongly suggests that high growth stocks are more sensitive to interest rates than low growth stocks" (Tessaromatis, 2003). Figure 11 shows the yield for the ten-year treasury bond in Norway and USA (a common measure of risk-free interest rates). The development is more or less identical in both markets, and shows that interest rates have risen sharply in the last two years.

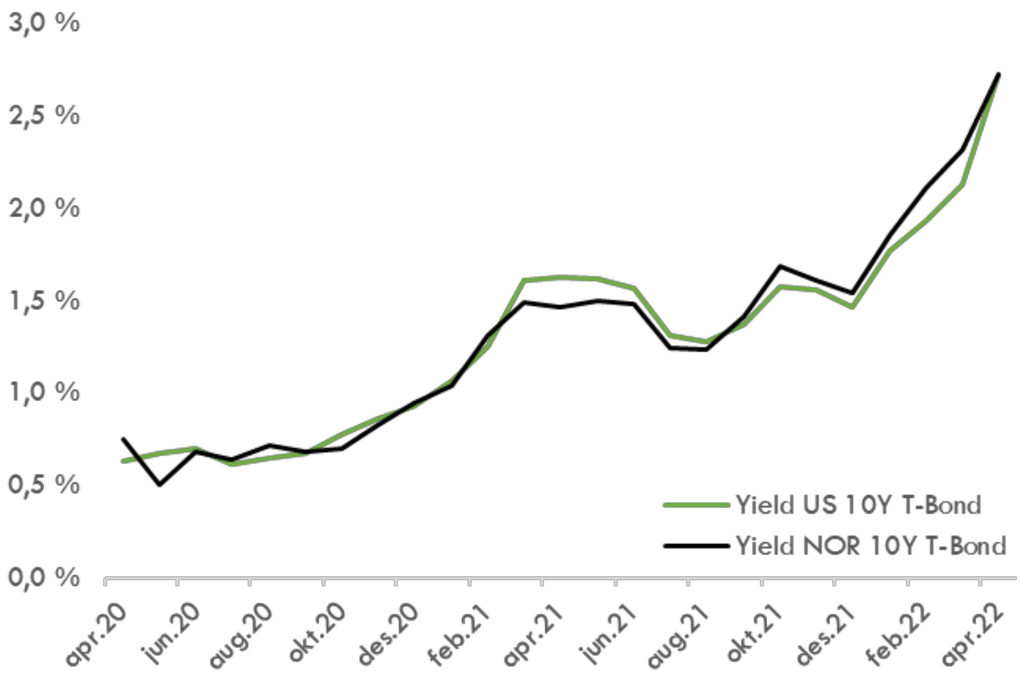


Figure 11: Yield USA & Norway 10-Year Treasury Bond (Thomson Reuters)

Based on the macroeconomic factors discussed above, it suggests that stock prices of the green companies should have been declining in the last two years. Figure 2 shows that the development has been the exact opposite. To find answers to why this is happening, we can consider behavioral finance theory. A plausible reason for the discrepancy between fundamental value and stock price can be explained by the grater fool theory. Investors ignore the fundamental valuations and other data and are willing to buy such overvalued assets because they believe there will always be a buyer - a greater fool - willing to pay more (Kindleberger & Aliber, 2005).

Another explanation for irrational behavior among investors is that there is asymmetric information among investors. Under information asymmetry, bubbles can emerge without everyone knowing, in contrast to the case of information symmetry where everyone knows there is a bubble going on (Brunnermeier, 2001). Everyone knows an asset is overvalued, but everyone cannot know that everyone else also knows this. Allen, Morris and Postlewaite (1993) argue that it is this lack of higher-order knowledge that makes it possible for finite bubbles to exist. This, on the other hand, contradicts the EMH, which claims that stocks are always traded at the equilibrium price.

Considering the ADF regressions, the results indicate something incompatible with what the macroeconomic trends suggest. The results from the Dickey-Fuller tests indicate that there is no bubble on the OSEBX index. The test values do not exceed the critical values for ADF, SADF and GSADF statistics at the 95% level, nor at the 90% level. That implies that there are no episodes of explosive behavior, even though the stock market had a record year in 2021 after recovering from the decline caused by the covid-19 pandemic. Ultimately, there is no evidence of a bubble in the Norwegian stock market today.

Several of the green stocks are exhibiting bubble-like characteristics that can develop into a bubble. Altogether, the Dickey-Fuller tests resulted in explosive behavior in 11 of 40 green stocks in the last ten years. It is expected that we will have more cases of explosive behavior when we test single stocks versus an index, since large movements in a single stock will not affect the entire index to the same extent. In total, there were 29 episodes of explosive behavior, and the vast majority of episodes took place in 2021. Developments in interest rates, inflation, and stock prices in the period 2020-2022 along with the episodes of explosive behavior in 2021 indicate that there may be bubble tendencies in some of the green stocks.

The history of past asset bubbles provides a useful reference point. With few quantitative models to choose from when identifying a bubble, history can assist in detecting commonalities. In the late 1990s, internet stocks with innovative technology became the subject of speculation and began their rapid ascent, even though many had negative earnings and had never reported any profits. The political interest in innovative technology and the redirection of government expenditures escalated. The focus on sustainability and the green transition is now pervasive in both the public and business sector. In addition, political arrangements are being made for the green transition. The development ahead of the Dot-Com bubble and the development in the green transition share similar features. Figure 12 shows global investment in green energy transition. In the last ten years, annual investment globally has almost tripled, and it is expected that green investments will increase in the future (World Economic Forum, 2021).

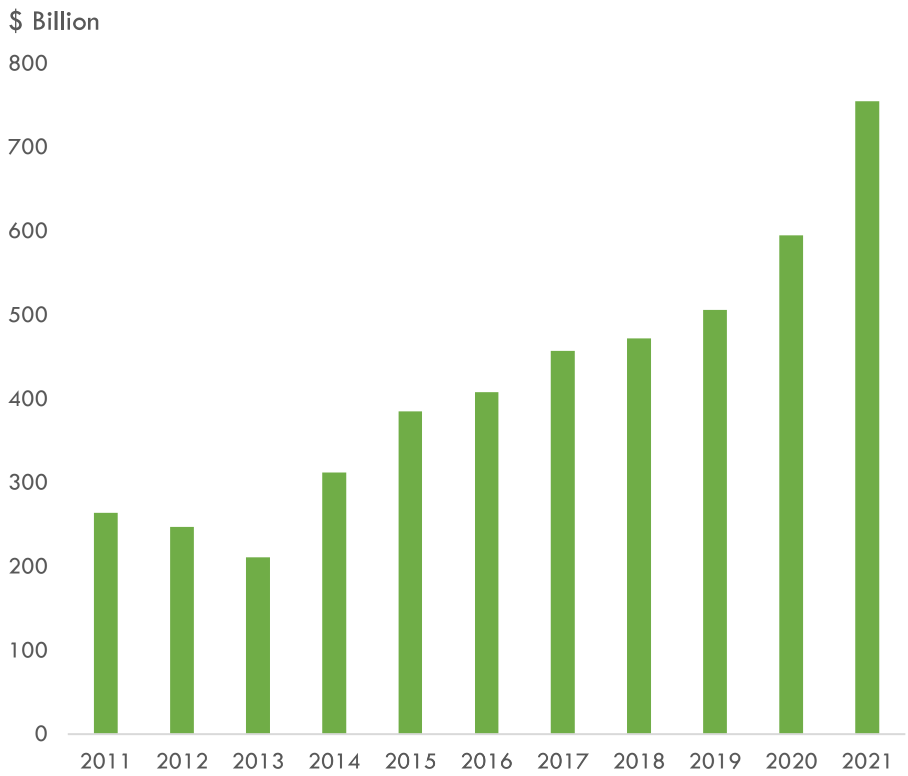


Figure 12: Global investment in green energy transition (Bloomberg, 2022)

The first step in the Minsky model is displacement. As presented in chapter 4, displacement occurs as a result of an exogenous shock on the macroeconomic system that leads to an economic expansion, for example exceptionally low interest rates. Low interest rates were the case prior to the financial crisis in 2008 and were also the instance in 2021 when the stock market recovered from the covid-19 shock. Following the displacement-phase comes the boom-phase. This phase contains an expansion of bank credit, making the total money supply larger. The media coverage is also growing, and investors become afraid of missing out on huge profits and prices gain a momentum. As popularity and demand increase, companies rush to get listed on the stock exchange. This was the case in 2020 and 2021 when a record number of green companies were listed on Euronext growth and the Oslo stock exchange.

Followed by a price-boom comes the third step in the Minsky model, euphoria. This phase is characterized by prices rising to record levels, attracting more investors. The valuations of the companies exceed the fundamental value by the multiple and excessive gearing is used to speculate in the assets. In this phase, investors might believe they can resell the asset at an even higher price, luring them to believe the upside is limitless, consistent with the greater fool theory mentioned earlier. The vast majority of the green companies have a negative PE multiple, and those who have a positive one has high values. This indicates that investors are willing to pay a lot for companies with low or no earnings, in the hope of selling them at a profit, or that the companies will generate positive cash flows in the future.

9. Conclusion

With the green transition in progress, ESG-friendly investment, and especially green investment, is becoming increasingly popular. 2020 and 2021 were record years in terms of IPOs for green companies. The media is full of headlines with well-known investors who have made a lot of money on green investment. Although the global stock market was affected to a substantial extent by the covid-19 pandemic, the Norwegian stock market recovered in 2021, delivering record numbers. The green companies did even better, even though the macroeconomic conditions were not conducive for growth.

In 2020, the market has been characterized by instability related to the covid-19 pandemic. Interest rates and inflation reached bottom levels in the first quarter of 2020, but accelerated upwards in 2021, and are heading for record levels today. The situation should indicate that growth stocks should not increase in value. Considering figure 2, the development has been the opposite. The green companies on the Oslo Stock Exchange delivered record numbers. If we study figure 2 further, one can observe several common features with the Minsky model.

The results from the Dickey-Fuller tests on the OSEBX index dictate that there is no bubble in the Norwegian stock market today. Of the green stocks, 11 out of 40 experienced explosive behavior over the past ten years. Most of the events took place in 2021, which agrees with the development in stock prices in 2020 and 2021. There are signs of a bubble forming in the green stocks, but it has no effect on the market in its entirety. Finally, we tested the green stocks with a panel Dickey-Fuller test to utilize the panel properties of the financial dataset. The results indicate that there is no bubble in the green stocks on the Oslo Stock Exchange altogether today. If there is one thing history has taught us, that it is difficult to detect assets bubbles before they burst, which is one of the reasons why asset bubbles occur in the first place.

The main limitations of this task are related to the sample selection. Several of the green companies, especially on the Euronext growth index, were listed recently and were excluded from the analysis due to few observations. Other limitations associated with the task are linked to the Dickey-Fuller model. The model used throughout this thesis is relatively new and struggle to discover bubbles before they reach apex.

Further research of interest is to conduct the analysis again at a later date in order to include the new listed companies that were excluded from this thesis. In addition, it will be of interest to see how the green stocks prices develop in terms of inflation, interest rates and the war situation in Ukraine. It might also be interesting to further research the leverage ratio of the green growth firms and investigate whether these companies fall victim to the underinvestment problem, where growth firms become so levered that equity holders will not partake in positive NPV projects because it doesn't increase equity value, even though it increases the overall firm value. Further development of the Dickey-Fuller model that can account for macroeconomic factors and behavioral finance will be of great interest for further research in the field.

References

Allen, F., Morris, S., & Postlewaite, A. (1993). Finite Bubbles with Short Sales Constraints and Asymmetric Information. *Journal of Economic Theory, Vol. 61*, pp. 206-229.

Arditti, F. D. (1967, March). Risk and the Required Return on Equity. *The Journal of Financ*, pp. 19-36.

Athanassakos, G. (2009, March 23). Value versus growth stock returns and the value premium: The Canadian experience 1985–2005. *Canadian Jurnal Of Administrative Sciences* , pp. 109-121.

Bailey, R. E. (2005). *The Economics of Financial Markets.* New York: Cambridge University Press.

Bøe, E., & Nilsen, A. A. (2022, March 23). *E24*. Retrieved from E24: https://e24.no/boers-og-finans/i/Rrp43d/ulltveit-moe-om-roekkes-kjempegevinst-mitt-tap

Blanchard, O. J., & Watson, M. W. (1982). Bubbles, Rational Expectations, and Financial Markets. *National Bureau of Economic Research, Working Paper Series*. https://doi.org/10.3386/w0945

Bloomberg. (2022|, January). *Energy Transition Investment Trends 2022.* https://assets.bbhub.io/professional/sites/24/Energy-Transition-Investment-Trends-Exec-Summary-2022.pdf

Brunnermeier, M. K. (2001). *Asset Pricing under Asymmetric Information.* Oxford: Oxford University Press.

Cuthbertson, K., & Nitzsche, D. (2005). *Quantitative Financial Economics: Stocks, Bonds and Foreign Exchange.* Chichester, West Sussex: John Wiley & Sons, Ltd.

Diba, B. T., & Grossman, H. I. (1988). The Theory of Rational Bubbles in Stock Prices. *The Economic Journal, Vol. 98, No. 392*, pp. 746-754.

Euronext. (2022, April). *Euronext*. Retrieved from Euronext: https://live.euronext.com/nb/ipo-showcase

Euronext. (2022, March). *Euronext*. Retrieved from Statistics: https://live.euronext.com/en/resources/statistics

Fama, E. (1970, May). Efficient Capital Markets: A Review of Theory and Empirical Work. *The Journal of Finance, Vol. 25, No. 2*, pp. 383-417.

Garber, P. M. (1990). Famous First Bubbles. *The Journal of Economic Perspectives, Vol. 4, No. 2*, pp. 35-54.

Grytten, O. (2021, November 5). NHH-professor frykter grønn børsboble. (S. Lorch-Falch, & J. B. Sættem, Intervjuere)

Haigh, A. (2021, June 4). *Bloomberg*. Retrieved from Bloomberg: https://www.bloombergquint.com/business/assets-soar-at-esg-fund-pioneer-in-australia-on-seismic-shift

Höhne, N., Khosla, S., Fekete, H., & Gilbert, A. (2012, June 14). *International Development Finance Club.* Retrieved from International Development Finance Club: https://www.idfc.org/wp-content/uploads/2019/03/idfc_green_finance_mapping_report_2012_06-14-12.pdf

Hovland, K. M. (2017, April 4). *E24*. Retrieved from E24: https://e24.no/norsk-oekonomi/i/ddA2mq/strengere-tiltak-mot-forbrukslaan

International Monetary Fund. (2008, October). *IMF.* Retrieved from IMF: https://www.imf.org/~/media/Websites/IMF/imported-flagship-issues/external/pubs/ft/weo/2008/02/pdf/_textpdf.ashx

Keynes, J. M. (1936). *The General Theory of Employment, Interest, and Money.* New York: Harcourt Brace & Co.

Kindleberger, C. P. (1978). *Manias, Panics, and Crashes.* London: The Macmillan Press.

Kindleberger, C. P., & Aliber, R. (2005). *Manias, Panics and Crashes: A History of Financial Crises.* London: Palgrave Macmillan.

Kinserdal, F. (2022, Fabruary 10). *NHH*. Retrieved from NHH: https://www.nhh.no/nhh-bulletin/artikkelarkiv/2022/februar/pavirker-inflasjonen-aksjemarkedet/

Lehmann, E. L., & Romano, J. P. (2008). *Testing statistical hypotheses.* New York: Springer.

Linton, O. (2019). *Financial Econometrics.* Cambridge: Cambridge University Press.

Liu, Z., Han, D., & Wang, S. (2016). Testing Bubbles: Exuberance and collapse in the Shanghai A-share stock market. I *China's New Sources of Economic Growth: Vol. 1: Reform, Resources and Climate Change* (pp. 247-260). ANU Press.

McWilliams, J. D. (2018, December 31). Prices, Earnings and P-E Ratios. *Financial Analysts Journal*, pp. 137-142.

Mendelbrot, B. (1966, January). Forecasts of Future Prices, Unbiased Markets, and Martingale Models. *Journal of Business (39)*, pp. 242-55.

Minsky, H. P. (1982). The Financial-Instability Hypothesis: Capitalist Processes and the Behavior of the Economy. In C. P. Kindleberger, & J.-P. Laffargue, *Financial Crises: Theory, History, and Policy* (pp. 13-39). Cambridge: Cambridge University Press.

Minsky, H. P. (1986). *Stabilizing an Unstable Economy.* Yale: Yale University Press.

Nilsen, J. B., & Lang-Ree, A. (2021, August 9). *E24*. Retrieved from E24: https://e24.no/boers-og-finans/i/rWQ8qR/nordmenn-stroemmer-til-groenne-aksjer-nesten-ubegrenset-hva-vi-kan-faa-inn

Norges Bank. (2017). *Norges Bank.* Retrieved from Norges Bank: https://www.norges-bank.no/contentassets/0c8589f5ea0e43cea0c7b9f88b285983/staff_memo_12_2017.pdf?v=12/21/2017150702&ft=.pdf

Phillips, P. C., Shi, S., & Yu, J. (2015, November). Testing for multiple bubbles: Historical episodes of exuberance and collapse in the S&P 500. *International Economic Review* , pp. 1043-1078.

Phillips, P. C., Wu, Y., & Jun, Y. (2011, February 24). Explosive behavior in the 1990s NASDAQ: when did exuberanse escalate asset values? *International economic review*, pp. 201-226.

Regjeringen. (2021, January 4). *Regjeringen.no*. Retrieved from Regjeringen.no: • https://www.regjeringen.no/no/tema/okonomi-og-budsjett/finansmarkedene/boliglansforskriften-1.-januar-202031.-desember-2020/id2679449/

Samuelson, P. (1965). Proof That Properly Anticipated Prices Fluctuate Randomly. *Industrial Management Review (6)*, pp. 41-90.

Scheinkman, J. A. (2014). *Speculation, Trading, and Bubbles.* New York: Columbia University Press.

Shiller, R. J. (1984). Stock Prices and Social Dynamics. *Brookings Papers on Economic Activity*, pp. 457-510.

Shiller, R. J. (2000). *Irrational Exuberance.* Princeton, New Jersey: Princeton University Press.

Shiller, R. J. (2015). *Irrational Exuberance.* Princeton: Princeton University Press.

Skaug, K. (2021, July 7). *Aksjenorge*. Retrieved from Aksjenorge: https://aksjenorge.no/wp-content/uploads/2021/07/Grafpakke-AksjeNorge-2-kvartal-2021_fin.pdf

Stiglitz, J. E. (1990). Symposium on Bubbles. *Journal of Economic Perspectives, Vol. 4, No. 2*, pp. 13-18.

Tessaromatis, N. (2003, May 26). *SSRN.* Retrieved from SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=392589

Thaler, R. H. (2016). Behavioral Economics: Past, Present, and Future. *American Economic Review, 106(7)*, pp. 1577–1600.

Tirole, J. (1982). On the Possibility of Speculation Under Rational Expectations. *Econometrica (50)*, pp. 1163–82.

Vasilopoulos, K., Pavlidis, E., & Martínez-García, E. (2020). *Lancaster University Management School.* Retrieved from The Department of Economics: https://eprints.lancs.ac.uk/id/eprint/143989/1/LancasterWP2020_007.pdf

World Economic Forum. (2021). *World Economic Forum.* Retrieved from World Economic Forum: https://reports.weforum.org/green-investing-2013/green-investment-current-flows-and-future-needs/?doing_wp_cron=1651054860.8330979347229003906250

Appendix

Table A1: Companies on OSEBX 01.03.2022

Companies on OSEBX		
ABG Sunndal Collier	Equinor	Orkla
Adventia	Europirs	PCI Biotech Holding
AF Gruppen	Fjordkraft Holding	Pexip Holding
Aker	Flex Lng	Photocure
Aker BP	Frontline	Rec Silicon
Aker Horizons	Gaming Innovation	Salmar
Aker Solutions	Gjensidige Forsikring	Sats
Arcticzymes Techno	Golden Ocean Group	Scatec
Atea	Hexagon Composites	Schibsted Ser. A
Avance Gas Holding	Kahoot!	Schibsted Ser. B
B2Holding	Kid	Sparebank 1 SR-BK
Bakkafrost	Kitron	Stolt-Nielsen
Bergenbio	Kongsberg Automotive	Storebrand
Bonheur	Kongsberg Gruppen	Subsea 7
Borregaard	Lerøy Seafood GP	Telenor
Bouvet	Mowi	TGS
Bw Lpg	Mpc Container Ships	Tomra Systems
Carasent	Multiconsult	Ultimovacs
Crayon Group Holding	Nel	Veidekke
Dnb Bank	Nordic Manovector	Vow
Dno	Nordic Semiconductor	Wallenius Wilhelms
Elkem	Norsk Hydro	Xxl
Entra	Norwegian Air Shuttle	Yara International

Table A2: Green stocks test statistics for ADF & SADF

Ticker	Adf	90 %	95 %	99 %	Sadf	90 %	95 %	99 %
ACCA	-0,52	-0,43	-0,13	0,56	1,17	1,14	1,44	2,06
ACHA	1,40	-0,44	-0,11	0,58	1,46	1,11	1,39	1,96
AFK	-3,90	-0,40	-0,06	0,56	-0,92	1,35	1,63	2,12
AGLX	-2,09	-0,40	-0,10	0,65	-0,30	1,14	1,41	2,04
AOW	-1,94	-0,43	-0,13	0,57	0,83	1,14	1,44	2,06
ANDF	-1,89	-0,41	-0,06	0,61	-0,24	1,24	1,53	2,07
ASA	-1,42	-0,41	-0,02	0,69	0,65	1,30	1,58	2,10
BCS	-1,42	-0,41	-0,07	0,58	-0,27	1,10	1,39	1,95
BRGB	-1,64	-0,38	-0,05	0,57	0,37	1,35	1,62	2,12
BWID	-1,51	-0,42	-0,05	0,56	-0,26	1,10	1,39	1,96
CADLR	-1,73	-0,43	-0,03	0,68	-0,38	1,12	1,41	1,99
CAMBI	-2,00	-0,45	-0,12	0,60	1,04	1,11	1,40	1,99
CIRCA	-1,55	-0,46	-0,15	0,59	1,37	1,10	1,39	1,95
CLOUD	-2,91	-0,42	0,02	0,83	-0,31	1,19	1,50	2,01
CAPSL	-1,02	-0,47	-0,14	0,55	-0,18	1,11	1,39	1,96
DSRT	-0,81	-0,42	-0,09	0,58	-0,29	1,10	1,39	1,95
EFUEL	-1,22	-0,37	-0,04	0,66	2,66	1,12	1,41	1,99
FKRFT	-1,02	-0,41	-0,06	0,54	0,58	1,30	1,57	2,10
HEX	-1,49	-0,44	-0,14	0,43	0,85	1,35	1,63	2,12
HRGI	-2,17	-0,46	-0,14	0,56	-0,69	1,35	1,40	1,99
HYN	-1,96	-0,40	-0,06	0,66	1,25	1,10	1,39	1,95
KALK	-1,72	-0,41	0,01	0,73	1,68	1,18	1,46	2,04
KYOTO	-0,85	-0,39	-0,07	0,61	0,48	1,10	1,40	1,96
MGN	-2,04	-0,46	-0,06	0,50	0,60	1,35	1,62	2,12
MPCES	-0,13	-0,49	-0,18	0,54	1,10	1,12	1,41	1,99
NEL	-1,53	-0,44	-0,16	0,48	0,25	1,35	1,63	2,12
NSOL	-2,27	-0,41	-0,07	0,58	-0,01	1,10	1,39	1,95
OSUN	-1,47	-0,42	-0,03	0,68	2,14	1,13	1,41	1,99
OTOVO	-0,59	-0,44	-0,14	0,55	-0,55	1,11	1,40	1,95
PROXI	2,89	-0,44	-0,11	0,54	3,12	1,11	1,40	1,99
PRYME	-1,59	-0,44	-0,12	0,59	-1,00	1,11	1,40	1,95
PYRUM	-0,64	-0,41	-0,08	0,65	-0,01	0,99	1,29	1,92
QFUEL	-1,15	-0,42	-0,06	0,63	0,62	1,27	1,54	2,01
RECSI	-1,36	-0,44	-0,16	0,48	0,85	1,35	1,63	1,12
SALME	-1,79	-0,43	-0,07	0,55	-0,59	1,15	1,42	2,04
SCATC	-0,93	-0,41	0,03	0,72	0,86	1,35	1,63	2,12
TECO	-1,59	-0,43	-0,08	0,60	0,58	1,14	1,41	2,04
TOM	-1,46	-0,44	-0,16	0,48	-0,14	1,35	1,63	2,12
VGM	-1,68	-0,36	0,04	0,76	1,56	1,10	1,37	1,93
VOW	-1,29	-0,41	-0,08	0,55	0,15	1,35	1,63	1,12