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Exploring bubble tendencies in the lithium-ion battery market

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Master's Thesis in Financial Economics

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Abstract

We applied structural time series econometrics and correlation analysis to key macroeconomic and sector-specific indicators to detect potential bubbles in the lithium-ion battery market in the United States and Europe. Anchored in economic theories such as the financial instability hypothesis, hegemonic stability theory, real business cycles, the AD-AS framework, and financial bubble theory, the analysis seeks to provide clarity in a sector marked by an emerging stage. In the absence of a publicly traded Lithium-Ion Battery (LIB) index, the thesis introduces the Battery Company Index (BCI) created by the writers of this thesis.

The BCI is an aggregate of LIB firms publicly listed on stock exchanges in Europe, the US, and globally. This index serves as a new instrument to indicate the pulse of the market and to benchmark financial health against regional monetary fluxes, credit movement, production outputs, and asset price variances. Research conducted between 2016 and 2023 reveals potential bubble patterns, with the years 2020 and 2021 standing out as particularly noteworthy, especially for the US. It posits that the unique market conditions, amplified by subsidies and monetary stimulus, may have fostered a situation for speculative behaviour. The analysis of the BCI and corresponding macroeconomic indicators captures these dynamics, suggesting financial instability within the sectors in this period. In conclusion, we find speculative behaviours within the stock market segments, confirming a broad complex economic bubble.

The interplay of various factors like the emergent nature of the LIB market, creates a difficult market environment, making definite statements on the presence of bubbles challenging, especially for estimating fundamental value. However, we look at the findings of this thesis as a preliminary contribution to academic discussions regarding potential financial bubbles within the LIB sector.

Acknowledgment

This master's thesis represents the end of our educational voyage through the Master of Science in Business and Administration, with a major in Financial Economics, at the Norwegian School of Economics. The start of our exploration stemmed from an interest in finance, technology, innovation, renewable energy, and the profound insights gained from the course *Crashes and Crises*. The course, led by Professor Ola Honningdal Grytten in the autumns of 2022 and 2023, gave us a comprehensive understanding of the construction, identification, progression, and resolution of economic crises, as well as their various stages.

Crafting this thesis proved both demanding and time-intensive, yet it was overwhelmingly enriching and inspiring. The opportunity to explore a subject that captivates our interests and contributes to the forward march towards sustainable development and finance has been exceptionally enlightening.

The last four months have been notably informative, equipping us with a newfound knowledge in a significant scholarly field. We are immensely grateful to our supervisor, Professor Grytten, for his advice and substantial support throughout the thesis development.

Our sincerest thanks also go to our families, partners, and friends for their support and patience during this academically intensive term.

Bergen, December 2023.

Julia S. Olsen ------------------------------------ Josefine Sundberg ------------------------------------

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Abbreviations

AD	Aggregate Demand
AS	Aggregate Supply
BCI	Battery Company Index
DPA	Defense Production Act
ECB	European Central Bank
EEA	European Economic Area
EU	European Union
EUR	Euro
EV	Electric Vehicle
GDIP	Green Deal Industrial Plan
GDP	Gross Domestic Product
GWh	Gigawatt per hour
HP	Hodrick-Prescott
IEA	International Energy Agency
IMF	International Monetary Fund
IPCEI	Important Project of Common European Interest
IPI	Industrial Production Index
IPO	Initial Public Offering
IRA	Inflation Reduction Act
ITC	Investment Tax Credit
LFP	Lithium Ferro Phosphate
LIB	Lithium-ion battery
mt	Metric tons
Na-ion	Natrium-ion
NMC	Nickel Manganese Cobalt
NZIA	Net-Zero Industry Act
PTC	Production Tax Credit
R&D	Research and Development
RD&D	Research Development and Demonstration
TCTF	Temporary Crisis and Transition Framework
TWh	Terawatt per hour
UN	United Nations
US	United States
USD	United States Dollar

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1. Introduction

1.1 Motivation and Purpose

The world is facing a global climate crisis. Actors have various suggestions for solving the problem, primarily divided into two views: significantly reduce energy consumption or develop clean technology to establish a carbon-neutral economy. The United Nations' Paris Agreement of 2015 escalated the emergence of clean technologies – one of them being lithium-ion batteries (LIBs), a vital component in electric vehicles (EVs), portable electronics, and battery energy storage systems for renewable energy production and distribution. At the midpoint of the Paris Agreement, there remains a 30 percent reduction in greenhouse gas emissions to be achieved by 2030 (UN Environment Programme, 2023). This implies investment opportunities of roughly USD 4.5 trillion per year (IEA, 2023c).

The economy has recently experienced several global shifts. The COVID-19 and Russia-Ukraine war, in addition to the increased Chinese dominance in the global market, have put protectionism on the political agenda. The subsidy race between the United States (hereafter the US) and Europe will hopefully accelerate the energy transition. History, however, has shown that protectionism and domestic (re-)industrialisation can lead to international imbalances in supply and demand and bubble tendencies (Grytten, 2023). The world is turning into solving the climate crisis domestically even though it is a global problem. In the context of a dynamic economic environment characterised by ongoing and evolving conditions, the innovation of clean technology has prompted us to inquire into the historical and contemporary impact on LIB prices.

This year, the financial market has witnessed multiple bank collapses in contrast to the two previous years. The bank runs were primarily driven by sharp increases in interest rates, which heightened the risk of loan defaults. This was coupled with shrinking bank reserves due to the decline in bond prices realised before maturity, incurring losses. The bankruptcy of Silicon Valley Bank has underscored the potential risks associated with extending significant loans to volatile businesses, such as technology companies (IMF, 2023a). Moreover, Goldman Sachs' downgrading of the battery company, Freyr, this summer, intensified the motivation to explore bubble tendencies in the battery sector (Spetalen & Waalen, 2023).

Our motivation for exploring the LIB market stems from our interdisciplinary engagement in the fields of finance, technology, and energy transition. As far as we know, there is no research using crisis theory and structural time series analysis to detect financial bubbles in the market for LIBs. The purpose of this research is to provide new insights into the use of crisis theory and structural time series analysis on an evolving market. Primary research naturally carries numerous limitations but is something we consider to be important in comprehending novel financial aspects and growing industries. We hope that this study will serve as an inspiration to others seeking further insights into this topic and encourage further research as time series data extends for longer trends.

1.2 Research question

This study will delve into the market of LIB companies, with a specific emphasis on the United States and Europe. This examination aims to facilitate a comparative analysis of two Western economies as they navigate their respective paths towards energy transition. The master's thesis will address the following research question:

Can one find signs of financial bubbles in the US and European lithium-ion battery market?

1.3 Limitation

This thesis is grounded in economic-historical theory and methodologies, focusing on a sector-specific theme. Consequently, this study will centre its analysis on economic-historical perspectives, excluding considerations of social-cultural or social science factors. The scope of this examination will be restricted to the European and US markets. This decision is partly informed by data availability and validity, as well as the intention to facilitate a comparative analysis of two Western regions characterised by well-defined economic and political landscapes. The focus will be on publicly traded LIB manufacturers, spanning from the production of battery material compounds to battery module packs (as detailed in Section 3.2.2). LIBs play a pivotal role in ensuring a stable supply of renewable energy, rendering them indicative of the overall outlook for the energy transition.

For a LIB company to be classified as either European or US, it must be publicly listed within the respective region. Stock exchange time series data commences in 2016, while economic indicators with longer time series dating back to 2000 will also be analysed.

1.4 Outline

The master's thesis is outlined as follows:

Chapter 2 introduces relevant economic theory and literature. Its objective is to acquaint the reader with theoretical frameworks and concepts that will underpin the subsequent analysis. Within this chapter, the following frameworks are presented: Minsky's financial instability hypothesis, Kindleberger's hegemonic stability theory, real business cycle theory, the AD-AS framework, and financial bubble theory.

Chapter 3 delivers pertinent background information to equip the reader with the requisite knowledge for a deeper comprehension of potential drivers within the LIB industry. This chapter, firstly, delves into the energy transition landscape concerning global climate objectives, geopolitical trends, and subsidy regimes in both the US and Europe. Secondly, it elucidates LIBs and the dynamics of their industry, encompassing the value chain, chemical technology, market participants, historical performance, and future market projections.

Chapter 4 provides an in-depth exposition of the study's methodology and data, with a particular emphasis on addressing limitations, assumptions, and the rationale behind chosen approaches.

The findings of the analysis conducted in this thesis are carefully delineated across Chapters 5, 6, and 7. Chapter 5 is dedicated to a detailed exhibition of the study's outcomes relating to money stock and credit indicators. Subsequently, Chapter 6 delves into an analysis of LIB production indicators. Finally, Chapter 7 shifts the focus to the LIB stock markets, offering a critical assessment and in-depth understanding of the market dynamics within this domain.

Chapter 8 offers a critical discussion of the existence of financial bubble tendencies in the LIB market in the US and Europe, along with recommendations for further research.

Lastly, Chapter 9 encompasses the presentation of the analysis conclusions and their ramifications.

2. Theoretical framework

This section of the thesis presents the theoretical framework that will further anchor the response to the research question. It clarifies several key economic theories and models, including the financial instability hypothesis, the concept of the power of hegemonies, the real business cycle theory, the AD-AS framework, and the bubble theory.

2.1 The financial instability hypothesis

The financial instability hypothesis was developed by Hyman Minsky to study whether a capitalist economy is fundamentally unstable (Grytten & Hunnes, 2016, p. 87). By conducting empirical studies on historical crises, he concludes his research with inherent financial instability being a fact (Minsky, 1982, p. 18). Minsky argues that the composition of hedge finance, speculative finance, and Ponzi finance determines the endogenous fragility of the financial system (Minsky, 1982, p. 29). Hedge finance represent the preferred finance framework within an economy due to its capacity to effectively manage risk differentiation, and ensure the fulfilment of future financial obligations, including debt and other economic commitments. In contrast, speculative and Ponzi finance represents situations where excessive speculation on future economic expansion or reliance on external investments to pay for existing economic debt and commitments prevail. It is noteworthy that as the prevalence of speculative and Ponzi finance practices increases, the potential for negative economic outcomes, including the financial crisis, escalates parallelly (Koilo & Grytten, 2019, p. 63).

The share of each financing behaviour, in addition to what Minsky calls “the big theorem”, forms the core message of Minsky’s hypothesis. The big theorem claims there is a continuous risk for financial bubbles and crises, thereby emphasising the need for active regulation to facilitate adequate incentive structures to pursue financial stability. Proactive measurements and regulation in a continuously moving market is a difficult task as financial innovation fundamentally will lie ahead of regulation regimes (Knoop, 2015, pp. 151-152). According to the historian Youssef Cassis (2011, p. 105), it is ambiguous whether a crisis empirically leads to more regulation or de-regulation, even if there often is a strong desire for more.

It is important for authorities to pursue financial stability to maintain trust in the financial system (Grytten & Hunnes, 2016, p. 90). The Central Bank of Norway describes financial stability as a robust financial system able to respond to displacements in the economy so that the system can sufficiently provide financing, proceed payments, and re-allocate risk (Norges Bank, 2023). The historians Knutsen and Ecklund (2000) simply defines financial stability as the “absence of crises”. Grytten (2021) defines financial stability as financial markets and institutions providing capital and liquidity at a sustainable level. After the financial crisis in 2007-2010, authorities have put more importance on the system risk of the global financial system, so-called “macroprudential” to pursue financial stability (NOU, 2011, p. 202).

2.1.1 Critisism

The Minskian model of financial instability is criticised by Kindleberger (2005, p. 33) pointing out that one model is not sufficient in explaining all crises, as each crisis is unique. Furthermore, Kindleberger (2005, p. 34) argues that the model has lost its relevance due to structural changes in the business world, especially regarding the rise of modern and cross-national cooperations. Palley (2010) points out the weakness of the exclusive focus on financial markets, with speculation and excess optimism as the main drivers of financial instability. New Marxists and structural Keynesians argue that crises originate from more profound issues within the real economy, emphasising on the importance of the relationship between wages and productivity growth as explanatory factors. Critics also disagree with the Minsky model’s interpretation of increased (decreased) leverage during economic expansions (contractions), as the ‘paradox of debt’[1] reveals that debt ratios often move in opposite directions (Ryoo, 2012, p. 2).

The Minsky framework is a viable starting point in detecting bubble creation. However, we find it necessary to support our research with several theoretical frameworks as the Minsky financial instability hypothesis is considered narrow in exploring new fields of bubble research. In the lack of real economic drivers and international perspectives in the Minsky model, Kindleberger’s hegemonic stability theory will be undertaken in the following.

[1] “The paradox of debt refers to the phenomenon in which individual firms’ attempt to reduce their indebtedness by cutting investment spending can lead to increasing indebtedness as the consequent reduction in aggregate demand and profits makes firms rely more on debt finance.” (Ryoo, The paradox of debt and Minsky's financial instability hypothesis, 2012, p. 2)

2.2 Hegemonic stability theory

Charles Kindleberger (1910-2003) is one of the most known crisis economists, studying the effect of international and domestic organs' interference on bubble creation and financial crisis (Altman, 2003). Kindleberger places significant importance on the dispersion from financial markets to the real economy. He argues that a 'hegemony', also referred to as a 'lender of last resort', is responsible for ensuring financial stability in the economy. A 'hegemony' can be defined as an organ with the capacity and autonomy to influence the market significantly in a direction regarding financial stability, demand volume, supply volume and liquidity (Grytten & Hunnes, 2016, p. 41). With its power to implement financial measures, it should be able to counteract crisis build-up (read: bubbles), reduce crisis dissemination and ensure crisis management (Kindleberger, 1987, pp. 288-291).

Kindleberger claims that a hegemony has sentimental effect on the financial market as a monetary insurer. Furthermore, a hegemony may have the ability to grow confidence in severe market conditions without a large increase in the volume of money once investors conclude that credit will be more available (Kindleberger & Aliber, 2005, p. 46).

Hegemony can be a domestic or international influencer. The latter is necessary when a country is unable to recover from a crisis on its own. International financial or political authorities such as the US, G20, European Union, European Central Bank, and International Monetary Fund are examples of hegemonies established to provide financial stability in the globalised world of trade (Grytten & Hunnes, 2016, p. 41).

2.2.1 Criticism

Regulation and intervention of financial systems to maintain financial stability do not come without scrutiny. Critics of the 'lender of last resort's' role of ensuring liquidity argue that speculation is encouraged when the knowledge of such credit is available (Kindleberger & Aliber, 2005, p. 47). The moral hazard dilemma arises when investors, driven by a strong belief in the likelihood of government subsidies for potential losses, may pursue unusually high returns. The dilemma provides a compelling case for non-intervention, prompting the question of whether financial crises or a 'lender of last resort' is the fairest method of value allocation, with both aiming to mitigate the likelihood and severity of future crises (Kindleberger & Aliber, 2005, p. 241). Most monetarists believe that if the money stock increases at a constant rate, there is no need for a ‘lender of last resort’ since they believe the money supply has a direct effect on prices and inflation (Kindleberger & Aliber, 2005, p. 275).

Kindleberger answers his critics that only a well-functioning hegemony reduces the probability and effect of a boom-bust economy (Grytten & Hunnes, 2016, p. 42). “The general rule that the state should always intervene or that the state should never intervene are both wrong” (Kindleberger & Aliber, 2005, p. 23). He argues that the concern of globalisation and increased inflows from foreign investors increase the risk of financial instability and that hegemony both domestically and internationally has a crucial role in providing the public good of financial stability (Kindleberger & Aliber, 2005). The issue of value allocation is examined by the strategies available to hegemony in terms of rewarding and penalising various actors. He also delves into the significance of adaptive expectations in guiding market participants on actions to restore confidence during economic downturns and to proactively avert the formation of financial bubbles (Kindleberger & Aliber, 2005).

2.3 Real business cycle theory

In *Measuring Business Cycles*, Burns and Mitchell define business cycles as recurring variations in the aggregate economic activities of nations, about phases of expansion, recession, contraction, and revival that occur almost simultaneously across economic sectors. These cycles, typically lasting one to twelve years, exhibit indivisibility into smaller, similar cycles (Burns & Mitchell, 1946).

Crucially, these cycles express the change between economic expansion, characterised by increased activity, and contraction, marked by reduced activity. These fluctuations involve the synchronised movement of economic indicators, with real Gross Domestic Product (hereafter: GDP) at the forefront. However, a comprehensive understanding of business cycles imposes the consideration of multiple aggregate measures, including inflation, unemployment, interest rates, trade dynamics, and housing prices (Grytten & Hunnes, 2016).

Economists have debated the origins of business cycles, with Keynes (1936) emphasising demand side fluctuations, while Kydland and Prescott (1982) focused on real shocks, like pandemics, impacting the supply side of the economy. Certainly, Kydland’s and Prescott's *Time to Build and Aggregate Fluctuations* introduces an essential perspective on the role of shocks in an economy.

Their work emphasises that business cycles are not solely driven by variations in demand, as suggested by traditional Keynesian theories, but also by real shocks that impact the supply side of the economy. These real shocks can be disruptive events or changes in technology and productivity that affect the production process and, subsequently, real economic fluctuations.

The key insight from this research is that ‘time-to-build’-considerations are crucial for understanding the effects of these real shocks (1982). The concept of ‘time to build’ refers to the fact that certain economic activities, such as winemaking, constructing ships or developing new technologies, require a substantial amount of time to be completed before they can contribute to the GDP. During this time, investments are made in the development and construction of these goods. The investments are integral to the production process but are not immediately reflected in the GDP until the final product is finished.

Real shocks, such as technological innovations or supply disruptions (e.g., a pandemic or a sudden increase in resource costs), can significantly impact the production and ‘time-to-build’-aspects of the economy (Altug, 1989). When a positive shock, like a technological advancement, occurs, it can lead to increased productivity and shorter ‘time-to-build’-periods. In opposition, negative shocks, such as supply disruptions or crises, can disrupt production and extend the ‘time-to-build’-periods.

Kydland’s and Prescott's work underscores the importance of considering these ‘time-to-build’-dynamics when analysing the effects of real shocks on an economy (Altug, 1989). By doing so, they provide a more comprehensive framework for understanding how changes in technology, investments, and supply side disturbances can influence aggregate economic fluctuations. In this context, their insights help to explain the complexities of business cycles beyond the Keynesian demand side perspectives and highlight the significance of supply side factors and their impact on an economy's dynamics.

2.3.1 Criticism

In his (2019) book *Advanced Macroeconomics, 5th edition* Paul Romer levelled substantial criticism against Kydland’s and Prescott's 1982 aggregate fluctuations model, highlighting several key points of criticism:

One of the primary critiques offered by Romer is the “lack of realism” in the model. Romer points to their paper, which demonstrated that the inability of policymakers to commit to a low-inflation policy could lead to excessive inflation even in the absence of an important long run trade-off. He contends that this model's fundamental assumption, where policymakers cannot credibly commit to low inflation, is at odds with real-world policymaking dynamics.

Another point Romer makes is that in a situation of low inflation, policymakers will pursue expansionary policies to boost output temporarily above its normal level. However, he highlights a critical flaw in this logic and calls it ‘policy ineffectiveness’. He argues that because the public is aware of policymakers’ incentive to pursue expansionary policies, they would not genuinely expect low inflation. Consequently, Romer posits that this leads to a situation where policymakers’ discretionary actions result in inflation without any corresponding increase in output. This, in his view, underscores a fundamental flaw in the model’s representation of real-world economic dynamics.

2.4 AD-AS

The AD-AS (Aggregate Demand - Aggregate Supply) model is a fundamental tool in economics, providing an overarching framework that encompasses various economic factors in one illustrative diagram (Jones, 2014).

2.4.1 Aggregate Demand

The Aggregate Demand (AD) curve, as described by Jones (2014), serves as a crucial instrument for the central bank to determine short run output in relation to the inflation rate. This is best understood through the IS curve, expressed by equation 1:

$$\boldsymbol{IS}: \tilde{\boldsymbol{Y}}_t = \bar{\boldsymbol{a}} - \bar{\boldsymbol{b}}(\boldsymbol{R}_t - \bar{\boldsymbol{r}}) \qquad \textbf{(1)}$$

Where $\tilde{Y}_t$ represents output, $\bar{a}$ and $\bar{b}$ are coefficients, R_t is the interest rate set by the central bank, and $\bar{r}$ is the equilibrium interest rate.

Furthermore, the AD curve also consists of the Policy Rule, and is stated by equation 2:

$$\boldsymbol{PR}: \boldsymbol{R}_t - \bar{\boldsymbol{r}} = \bar{\boldsymbol{m}}(\boldsymbol{\pi}_t - \bar{\boldsymbol{\pi}}) \qquad \textbf{(2)}$$

Where π_t represents the observable inflation, $\bar{\pi}$ is the target inflation rate set by the government, and $\bar{m}$ measures the aggressiveness of monetary policy in responding to inflation changes.

From these equations, the AD curve can be defined through equation 3:

$$\boldsymbol{AD\ curve}: \tilde{\boldsymbol{Y}}_t = \bar{\boldsymbol{a}} - \bar{\boldsymbol{b}}\bar{\boldsymbol{m}}(\boldsymbol{\pi}_t - \bar{\boldsymbol{\pi}}) \qquad \textbf{(3)}$$

The AD curve represents the total quantity of goods and services demanded at different price levels within an economy. It typically slopes downward, indicating that as prices decrease, there is a greater willingness amongst individuals and businesses to increase their consumption. This leads to an increase in the real GDP. Changes in the AD curve can be attributed to shifts in consumer spending, government spending, investments, and net exports.

If the inflation rate (π_t) surpasses its target level ($\bar{\pi}$), the central bank responds by raising the interest rate ($\bar{r}$) with the objective of reducing short run output ($\tilde{Y}_t$) (Jones, 2014). Consequently, changes in π_t represent movements along the AD curve. Other factors in the equation include $\bar{a}$, which scales how external shocks impact the economy through aggregate demand, and $\bar{m}$, which measures the effectiveness of monetary policy in controlling inflation. These elements, in turn, influence the slope of the AD curve.

For instance, a change in inflation results in a movement along the AD curve, as it essentially maps out the relationship between output and the inflation rate. In response to increasing inflation, the monetary policy rule dictates that the central bank should raise interest rates, ultimately reducing short run output.

In summary, fluctuations in inflation prompt movements along the AD curve, while shocks to aggregate demand and variations in the central bank's inflation target led to shifts in the AD curve.

2.4.2 Aggregate Supply

The Aggregate Supply (AS) curve shows distinct characteristics in the short run and the long run. In the short run, it summarises the planned supply that firms expect to stock in the immediate future, dependent upon inflation and various other factors (Jones, 2014).

According to Jones (2014), the AS curve is an equation employed by firms within the economy, denoted as equation 4:

$$\boldsymbol{AS\ curve}: \boldsymbol{\pi}_t = \boldsymbol{\pi}_{t-1} + \bar{\boldsymbol{v}}\tilde{\boldsymbol{Y}}_t + \bar{\boldsymbol{o}} \qquad \textbf{(4)}$$

One noteworthy attribute of the AS curve is the intercept, representing the point on the graph where short run output equals zero. This intercept, denoted as π_{t-1}, implies that as inflation rates evolve over time, the AS curve undergoes shifts, a central feature within the model. Moreover, this curve may also be influenced by inflation shocks, for instance when $\bar{o}$ assumes a positive value for a specific period. Here, π_{t-1} signifies the expected inflation derived from the previous period. In the absence of inflation shocks and when output reaches its potential, firms anticipate the continuity of the present inflation rate. These adjustments explain the dynamic nature of the AS curve.

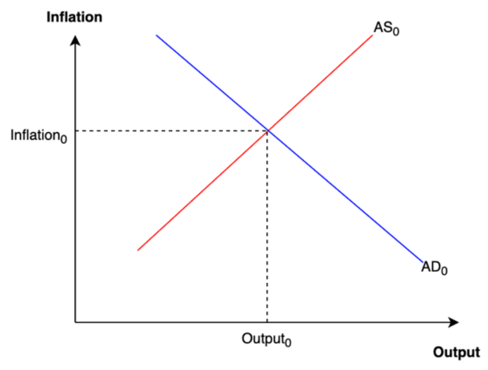
By keeping π_{t-1} constant, as it is already determined when period t commences, the Phillips curve establishes a connection between the current inflation rate, π_t, and short run output. Notably, this relationship exhibits an upward-sloping trajectory, a characteristic that justifies labelling it as an AS curve.

The initial assumption of the expected inflation rate for the forthcoming period mirrors the previous period's inflation rate. This assumption holds in the absence of inflation shocks and when output operates at its full potential. The interpretation of π_{t-1} as an indicator of expected inflation plays a key role in the subsequent developments.

2.4.3 The application of the model

To account for both the AD and AS in an economy, one could use the AD-AS framework, which combines equations 3 and 4. This helps us to illustrate the output and price level in an economy. Dutt and Skott (2005) argue that the strength of the framework is the emphasis on both supply and demand, and that macroeconomic results change based on the interaction among different markets. In Figure 2.1, the AD-AS framework is presented graphically:

Figure 2.1: AD-AS framework (Jones, 2014)

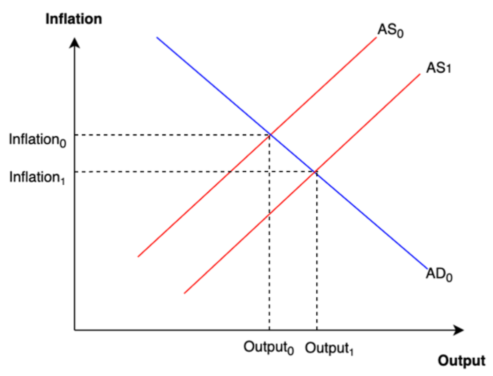


2.4.4 Subsidy shock

One can consider two different types of shocks imposed by subsidies, shocks to the AS and the AD curve. This section will illustrate what happens in the case of the implementation of increased and decreased subsidies.

One of the measures the Biden administration has imposed is the Inflation Reduction Act of 2022 (see Section 3.1.3). The act imposes long term energy tax credits on companies which produce or support renewable energy development. This act can be viewed as a positive supply shock. In accordance with the AD-AS framework, Figure 2.2 illustrates this positive shift:

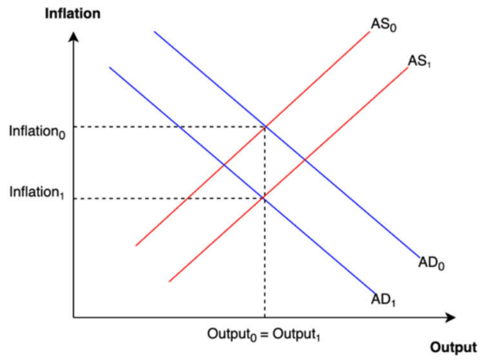
Figure 2.2: Positive AS shift (Jones, 2014)



The AS curve will shift to the right, and in the short term, it will reduce inflation and increase GDP.

Another feature of the AD-AS framework is the case of negative shocks. Previously, consumers of EVs could get tax reductions when they bought a new EV, but for example in Norway after the 1st of January 2023, the Norwegian Tax Administration imposed a tax on bought cars with a value above NOK 500,000 (Skatteetaten, 2022)

Figure 2.3: Negative AD shift (Jones, 2014)



2.4.5 Criticism

The AD-AS framework has faced significant criticism from various sources, including David Colander (1995). This criticism centres around several key issues like lack of consistency, inappropriate disequilibrium adjustments and obscured pedagogical tools.

One of the fundamental criticisms, as discussed by David Colander in *The Stories We Tell,* is that the AD-AS model lacks logical consistency. Its parts are derived from various economic models, which often reflect different and inconsistent views of the economy (Colander, 1995).

The AD-AS model is often taught with a disequilibrium adjustment story where short run aggregate adjustment is driven by price level flexibility. However, this story is inconsistent with both observed economic realities and the adjustment story accepted by most macroeconomists (Colander, 1995).

Overall, these criticisms call for a reconsideration of the AD-AS framework and suggest the need for alternative approaches to improve its pedagogical value and its alignment with observed economic phenomena.

2.5 Financial bubble theory

Several economists have tried to define the phenomenon of a financial bubble. Yet, there is no agreement on a uniform definition in the literature. In the process of answering the research question of this thesis, the section will be used as an anchoring point throughout the analysis.

Inspired by Ola H. Grytten (2016, p. 76), financial bubbles can be defined as frequently traded assets to prices deviating significantly from the long term market equilibrium. The deviation can be either positive or negative depending on the relationship between the two variables (Grytten, 2023). Even though negative bubbles are less studied empirically, and as a result less written about in literature, it is important not to neglect the meaning of the concept (Goetzmann & Kim, 2017).

The mathematical notation of a bubble, quantifying the bubble value as the deviation from the fundamental value, is written as follows (Grytten & Hunnes, 2016, p. 83):

$$\textbf{Bubble test: } \boldsymbol{b_t = p_t - \sum_{j=1}^{\infty} \left(\frac{1}{1+r}\right)^j E_t(d_{t+j})} \tag{5}$$

The market price of the asset is known as p_t, and $\sum_{j=1}^{\infty} \left(\frac{1}{1+r}\right)^j E_t(d_{t+j})$ is the asset's value calculated as a discounted sum of future expected returns. A bubble exists if $b_t \neq 0$, as the equation will not be balanced on the right-hand side. The market price, p_t, is still the rational short term equilibrium price while deviating from the long term equilibrium price (Grytten & Hunnes, 2016, p. 83).

Academics have varying views on how broadly the term financial bubble should be understood. Grytten (2023) argues that a financial bubble can be either euphoric or non-euphoric. In this thesis, this broader boundary definition of 'financial bubble' is to be examined.

2.5.1 Euphoric and non-euphoric bubble

Bubbles can be classified into two distinct categories determined by the explanatory variables causing the bubble. A non-euphoric bubble can possibly be defined as temporal equilibrium which represents overpricing or overheating compared to long term equilibrium (Grytten, 2023). This implies that a non-euphoric bubble may arise due to factors explained by the laws of supply and demand resulting in a short term equilibrium in which market participants may act upon. The observed overpricing must be significantly higher than the established trend, exceeding normal boom values. The temporal equilibrium can be explained by changes in fundamental factors such as oil prices or population growth rate (Grytten & Hunnes, 2016, p. 77). Empirically, non-euphoric bubbles are characterised by more pronounced deviations from long term trends compared to bubbles caused by euphoria (Grytten, 2023).

A euphoric bubble is characterised by expectations of further growth in asset prices despite market participants having knowledge of mismatches in real economic conditions (Grytten, 2023). In the literature, a euphoric bubble is also referred to as a speculative, self-fulfilling, or rational bubble, where a definition of the latter is defined by Gürkaynak:

> *"Equity prices contain a rational bubble if investors are willing to pay more for the stock than they know is justified by the value of the discounted dividend stream because they expect to be able to sell it at an even higher price in the future, making the current high price an equilibrium price. Importantly, the pricing of the equity is still rational, and there are no arbitrage opportunities when there are rational bubbles"* (Gürkaynak, 2008, p. 166).

Gürkaynak argues that the asset pricing itself is rational as investors' expectations are directly reflected in asset prices. Grytten (2016, p. 78) highlights the importance of psychology and 'behavioural finance' as explanatory variables of price fluctuations as well as economic factors. He argues that detecting bubbles is difficult as investors have different expectations, both rational and irrational. This is substantiated by Keynes (1936) who writes about irrational behaviour as the main driver of the economy in his book *The General Theory of Employment, Interest and Money*. Keynes writes that the characteristics of human nature and the spontaneous urge to action rather than inaction – understood as 'animal spirits' – can explain a large proportion of the positive activities in the economy. Keynes argues that quantitative methods such as weighted averages of benefits multiplied with associated probabilities will only explain a small part of the price fluctuations in the economy (Keynes, 1936).

Akerlof and Shiller (2009, p. vii) have in newer times studied the term 'animal spirits'. They argue that 'animal spirits' almost drive the whole economy. This statement challenges traditional economic views, suggesting irrational factors for bubble formation potentially provide higher explanatory power (Ülkü, Ali, Saydumarov, & Ikizlerli, 2023). Grytten (2016, p. 77) argues that the reason euphoric bubbles are hard to detect is due to market participants trying to find economic reasons for mispricing even though the cause cannot be justified by economic explanatory variables.

2.5.2 Bubble creation

Despite the various definitions of a financial bubble, there is a common description of *how* a financial bubble can arise. The prominent history economists, Minsky and Kindleberger, agree that positive bubbles are likely to develop in times with over-optimistic expectations and when financial markets lack sustainable balance resulting in credit to over-expand (Grytten, 2021, p. 180). Grytten (2023) agrees that bubbles most often occur due to monetary or credit expansions.

Money surplus is often used to expand production capacity by investing in technology, capital, or labour. Increased production capacity leads to increased GDP given that consumers on the demand side follow the development. This process describes long term growth in the real economy and does not cause a bubble itself (Solow, 1956).

In saturating markets, where demand for consumption exceeds production capacity, the money surplus is often placed in asset investments, such as stocks, bonds, and real estate (Grytten & Hunnes, 2014, p. 42). Expectations of further growth in asset prices influence bubbles to grow until markets turn due to negative shifts in future price expectations (Grytten, 2021, p. 181). Creditors' willingness to lend money to investors will increase if the bubble's return increases (Grytten & Hunnes, 2016, p. 78).

A negative financial bubble is, according to Goetzmann and Kim (2017), not well explained by macroeconomic or institutional factors. Therefore, fundamental indicators, such as monetary contraction, are not sufficient in detecting negative bubbles. However, Goetzmann and Kim (2017) emphasise behavioural theories justifying the emergence of negative bubbles. They conclude that negative bubbles arise due to temporary, severe negative sentiment in the stock market. The statement is consistent with Ülkü et al. (2023) which explains negative bubbles naturally are driven by overreaction and panic.

2.5.3 The bubble's destiny

The natural characteristic of a bubble is to grow bigger until it bursts. Financial bubbles are associated with the same attribute. Acknowledged bubble theory suggests that a positive bubble either ends with a price correction or a financial crash (Grytten & Hunnes, 2016). A possible definition of a financial crash is when asset prices fall rapidly, significantly beyond a normal correction in the market (Grytten, 2023). The crash includes panic, leading to a more pronounced downturn below the fundamental value. If the negative value is significantly below the long term trend, a negative bubble has risen because of the burst of a positive bubble.

A bursting bubble can have substantial consequences as investors often lose great amounts of money. In addition, bubbles bursting tends to correlate with bank crises (Grytten, 2021). The correlation is much explained by the credit relationship between investors and banks. When a positive bubble bursts, the return on investments declines as asset prices falls, and so the demand for credit decreases. Investors experiencing huge losses in credit-funded investments struggle with meeting financial obligations. Increased number of defaults and the realisation of malinvestments destroy the fundamental relationship between market participants as both sides try to hedge themselves from further losses. Financial institutions' fear of huge losses drives the credit supply further down (Grytten, 2021).

Inspired by Kindleberger, the seven-step dynamic model for financial crisis by Grytten & Hunnes (2016) argues that not all positive bubbles burst, and that wise use of hegemony can hinder the bubble from bursting. Kindleberger underscores that a well-functioning hegemony serves as a remedy to mitigate the impact of a negative bubble (Kindleberger & Aliber, 2005).

3. Background

In this chapter, we will provide an overview of the energy transition and the LIB industry to provide the reader with the requisite background information.

3.1 Energy transition

3.1.1 Climate goals

In 2015, the United Nations' Paris Agreement solidified a global commitment to environmental action, setting the goal of capping global warming to below two degrees Celsius, with aspirations to limit the rise to 1.5 degrees Celsius. Nations agreed to intensify efforts through Nationally Determined Contributions every five years, with the EU pledging to become climate-neutral by 2050 and aiming for a 55 percent emission reduction by 2030 (European Parliment, 2021). Concurrently, the US, having re-joined the Agreement in 2021, focuses on conserving 30 percent of its natural areas by 2030 and aiding global ecosystem preservation (National Geographic, 2021).

Simultaneously, the energy transition is underway, shifting from fossil fuels to zero-carbon solutions, crucial for realising the Paris Agreement's 2050 targets. Trends indicate a decline in fossil energy demand, with local coal use dropping and EV adoption rising, reflecting broader technological and environmental influences on the global energy landscape (IEA, 2023d). This transition, driven by economic, technological, and ecological factors, is integral to achieving sustainable climate objectives (Solomon & Krishna, 2011).

3.1.2 Geopolitics of 'de-risking'

The de-industrialisation of developed countries from the 1990s has resulted in cost-efficient trade as well as increased supply chain and geopolitical risk. This includes outsourcing of knowledge, technology, labour, and capital to developing and emerging countries (StudySmarter, 2023). Globalisation has fallen below its peak in the early millennials, meaning a reduction in international trade and foreign direct investments. Due to lack of capital and industrial knowledge in the manufacturing sectors, developed countries are worse positioned for the industries of the future, such as battery production (Prasad, 2023).

The world has recently experienced several eye-opening events leading to increased focus on the risks regarding globalisation and dependence on foreign countries. The Russian invasion in Ukraine resulted in a sudden deficiency of energy sources for countries heavily dependent on Russian oil and natural gas, such as Germany (EPRS Strategic Foresight and Capabilities Unit, 2023). During COVID-19, companies around the world experienced critical supply chain shocks resulting in a growing focus on self-sufficiency (Shih, 2020). Furthermore, escalating tension between the US and China, challenges free trade and information sharing, negatively affecting technological and economic development. The events demonstrate the vulnerabilities of being dependent on one or few sources, even if it is the optimal solution for cost minimisation. The increased emphasis by governments on geopolitical risk has advanced the discourse on enhancing supply chain resilience through 'de-risking' (EPRS Strategic Foresight and Capabilities Unit, 2023).

Both the US and the EU have introduced regulatory frameworks and measures to 're-shore' or 'friend-shore' production lines (Demertzis, 2023). 'Re-shoring' refers to the opposite process of international outsourcing by increasing domestic production. 'Friend-shoring' refers to the fragmentation of the global market by relocating business partners to countries with somewhat equal geopolitical views to reduce country and supply chain risk (Prasad, 2023). Governments and international organisations' implementation of 'strategic autonomy' in critical materials and important industries for clean technology, has little emphasis on the loss in economic efficiency. Nonetheless, both the US and EU find de-risking necessary for business stability and continuity (Demertzis, 2023). Recent geopolitical trends and measures have already influenced business decisions and profitability of several industrial sectors, such as LIB companies.

3.1.3 Subsidy programs

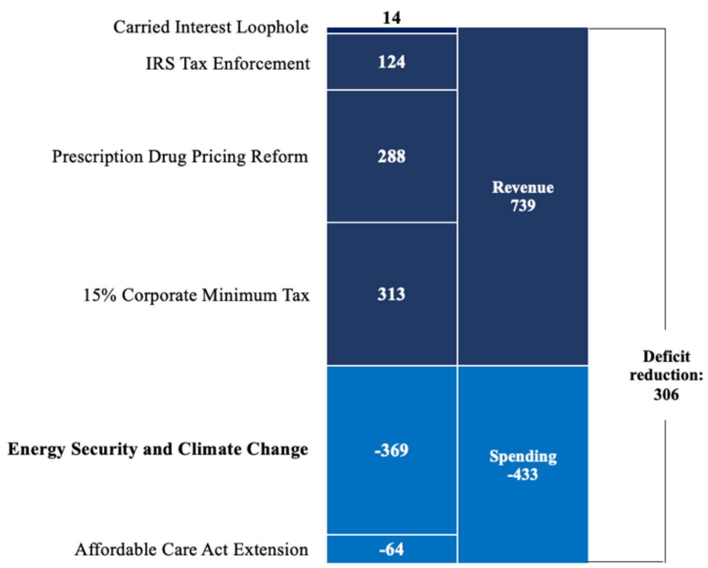
The US and EU have introduced subsidy programs to stimulate battery manufacturing among other clean technology sectors in alignment with their energy transition objectives and de-risking strategy. The subsequent section will provide an overview of the pertinent regulatory frameworks, with particular emphasis on battery manufacturing.

The United States

In the US, there are primarily four policies aimed at stimulating domestic manufacturing: the *Inflation Reduction Act*, the *Bipartisan Infrastructure Law*, the *CHIPS and Science Act*, and the *Defense Production Act*.

The *Inflation Reduction Act* (IRA) was signed by the Biden administration on the 16th of August 2022 (The White House, 2023b). Illustrated in Figure 3.1, the Democrats enforced the law aiming for inflation reduction through governmental budget deficit reduction of an estimated USD 306 billion (Senate Democrats, 2023).

Figure 3.1: IRA budget (Senate Democrats, 2023)



The largest share of the revenue side of the IRA budget derives from the prescription drug pricing reform in addition to the introduction of a minimum corporate income tax of 15 percent on the largest corporations. Moreover, the IRA aims to decrease the budget deficit by increasing efficiency and enforcement in IRS administration, as well as limitations on carried interest. The expenditure side of the budget is primarily subsidies and tax breaks on clean technology, amounting to USD 369 billion over a decade. The budget's revenue and spending estimates have sparked extensive discussion, with numerous analyses suggesting that the deficit reduction is likely to be significantly less than initially budgeted (Storm, 2022). Additionally, non-partisan analysts have predicted that the IRA will exert no substantial influence on the inflation rate, whether in the short term or long term (Storm, 2022).

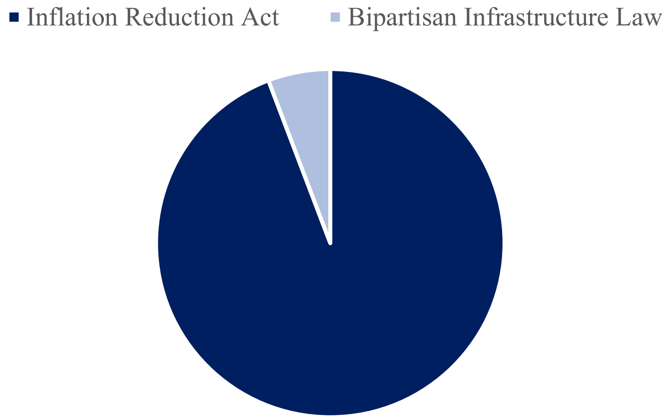
Despite the ambiguous and uncertain effects on inflation, stakeholders agree that IRA will thrive with increased private investments and the production of clean technology in the US (Erraia, Śpiewanowski, & Wahl, 2023). Battery producers are estimated to receive roughly USD 150 billion between 2023 and 2032 making them among the largest direct subsidy recipients of the IRA (Erraia, Śpiewanowski, & Wahl, 2023). Battery producers have the choice between production tax credits (PTC) or investment tax credits (ITC), where the company production scale determines the most beneficial scheme (see Appendix 1 for more detailed information).

The *Infrastructure Investment and Jobs Act*, commonly known as the *Bipartisan Infrastructure Law*, was signed by President Joe Biden on the 15th of November 2021 (U.S. Department of Transportation, 2023). The law aims to repair and improve infrastructure to climate change and cybersecurity risks. The total funding amounts to USD 550 billion over five years, with direct subsidies to battery manufacturers only being designated later. On the 19th of October 2022, it was announced that USD 2.8 billion would be allocated to battery manufacturing and processing companies. Additionally, USD 7 billion was allocated to incentivise US battery manufacturers to incorporate domestic critical minerals and components into their production processes, thereby supporting the nation in achieving its climate objective. Pairing recipients from the two funding sources, battery manufacturers are provided subsidies amounting to USD 9.2 billion in total (The White House, 2023a).

The *CHIPS and Science Act* was signed by the Biden-Harris administration on the 7th of August 2022, and aims to reduce dependence on China by strengthening supply chains, lowering costs, and creating jobs in the semiconductor industry (The White House, 2022b). The law does not directly affect the battery industry but supports the trend of increased subsidisation supporting the domestic industry.

The US *Defense Production Act* (DPA) goes back to 1950 and has historically been enforced to secure war materials firstly in the Korean War era. The law has over time widened its scope towards non-war material security in terms of any creation of crises. The DPA was recently enforced during the COVID-19 crisis in terms of critical medical production and distribution (Busby, Holland, Morgan Bazilian, & Orszag, 2023). In March 2022, President Biden further expanded the DPA's purpose, using the law as an important tool towards clean energy transition in the US. Under the force of the DPA, Biden designated five critical minerals associated with large-capacity battery production (lithium, nickel, cobalt, graphite, and manganese). The designation of the critical minerals did not provide direct funding but gave the Department of Defense the mandate to conduct feasibility studies on mining reserve locations. More than USD 200 million is invested through the Department of Defense. Moreover, it has been issued debt under the *Department of Energy Loan Program Office* of USD 102 million to Syrah Resources in Vidalia, Louisiana. The loan is granted to produce the first domestic battery-grade natural graphite active anode material, which is as of 2022 100 percent imported from China (The White House, 2022a).

Figure 3.2: US Direct subsidy split by law in percent (Erraia, Śpiewanowski, & Wahl, 2023) and (The White House, 2023a)



From Figure 3.2 it is clear that the IRA is the most prominent subsidy program aiming for mass deployment in the battery industry.[2] The *Bipartisan Infrastructure Law* and the *Defense Production Act* substantiate the US geopolitics of de-risking. Compared to the subsidy programs presented in Figure 3.2, these laws have a diminished impact on the conditions of the battery market.

Europe

The subsidy programs provided in Europe are mostly driven by cross-national cooperation through the European Commission. The European subsidy environment is complex consisting

[2] The subsidies are nominal values not discounted over the designated granting period due to uncertain distribution estimates. In discounted terms, the IRA share is lower than shown in the figure as the subsidies are spread over a longer period.

of plans, acts, and funds supporting the UN's goal of climate neutrality by 2050. The most relevant programs for battery actors will be presented in the following.

The European subsidy programs for batteries started in 2014 through the *Important Projects of Common European Interest* (IPCEI) concerning infrastructure and strategically important value chains in the European Economic Area (EEA). Since its adoption, two of six grants have been approved for battery projects. The first battery initiative, *IPCEI on Batteries*, was approved in 2019 with a budget of EUR 3.2 billion (European Commission, 2019). The second battery initiative, *IPCEI European Battery Innovation* or *EuBatIn*, was approved in 2021 with an associated budget of EUR 2.9 billion (European Battery Alliance, 2021). The grants provided are not financed by the EU but by participating countries.

Horizon Europe BATT4U is the flagship of the EU's battery ambition. The goal is to increase energy density, power density, charging speed, lifetime, and safety of batteries. Furthermore, the initiative aims to drive battery prices and demand down through more sustainable use of raw materials, production, and recycling of batteries. The budget designated from 2021 to 2026 is EUR 925 million and supports research development innovation only (Erraia, Śpiewanowski, & Wahl, 2023, p. 19).

The President of the European Commission, Ursula von der Leyen, presented the *Green Deal Industrial Plan* (GDIP) in February 2023 as a response to the IRA in the US. Europe already had a roadmap towards the goal of becoming the first climate-neutral continent by 2050, through the *European Green Deal* enforced in 2019 (European Commission, 2023d). However, the European Commission acknowledged the risk of EU companies moving to the US due to significantly higher economic benefits under IRA and enabled a plan for faster decarbonisation through the new GDIP (European Commission, 2023a).

On 16th of March 2023, the Commission presented the *Net Zero Industry Act* (NZIA) as an extension of the GDIP. The law aims to secure at least 40 percent of the EU's clean technology needs to be domestically produced by 2030. The NZIA does not provide new funding sources to the EU battery industry. However, it enables faster growth in the EU battery market as the law ensures the development and implementation of education and training to reskill and upskill the labour force required for the carbon neutral technology industry. Additionally, the NZIA aims to simplify the application process and reduce the administrative burden of setting up projects (European Commission, 2023b).

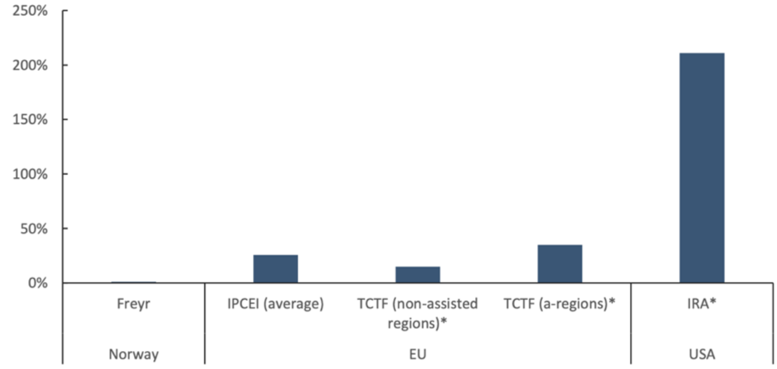
The *Temporary Crisis and Transition Framework* (TCTF), first adopted on the 23rd of March 2022, was amended on the 9th of March 2023 in line with the GDIP and the NZIA. The framework was enforced because of the Russia-Ukraine war to increase effectiveness and provide higher support to certain individual companies in the race towards net zero. The TCTF is effective until the 31st of December 2025 and provides tax breaks, loans, and guarantees to facilitate European energy supply. The amendment as of 2023 applies to the EEA countries (European Commission, 2023c).

In addition to the above, there are programs that are not battery-specific. The *Innovation Fund* provides funding to pilot projects and large-scale production demonstrating emission reduction. The budget estimate is EUR 38 billion for the 2020-2030 period but depends on the income from the auctioning of emission allowances in the *European Emission Trading System* (ETS). *InvestEU* is a scheme providing up to 60 percent debt financing and loan guarantees for the pilot phase and mass deployment. Furthermore, *Regional Aid* is provided to mass production projects in disadvantaged areas of Europe. Lastly, Europe has the *European Critical Raw Material Act* for economic and national security reasons, similar to the US (Erraia, Śpiewanowski, & Wahl, 2023).

Brief comparison

Figure 3.3 illustrates the estimated differences in state-aid intensity in battery deployment under various subsidy regimes. The starred bars are estimates from the Norwegian consultancy, Menon Economics. Under IRA, the US provide an estimated state-aid intensity of over 200 percent. This is substantially higher than key European regimes.

Figure 3.3: Actual and estimated state-aid intensity under various regimes in Norway, the EU and the US (Erraia, Śpiewanowski, & Wahl, 2023).



*Estimated values of state-aid intensity by Menon Economics.

Even with the new subsidy regimes in Europe, Menon Economics (2023) is almost certain that the IRA will affect the battery landscape in Europe. Significant numbers of new large-scale battery factories in the US have already been announced, as well as projects moving from Europe to the US. Increased investments in battery production in the US mean relatively higher battery prices in Europe (Erraia, Śpiewanowski, & Wahl, 2023).

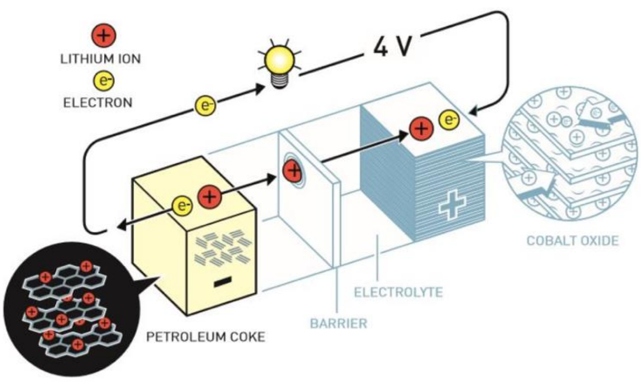
3.2 The battery industry

The energy transition encompasses a comprehensive value chain, from critical mineral extraction to the production of clean energy-storing technologies, notably batteries. LIBs are dominant in the EV industry and are the fastest-growing electricity storage technology globally, with lithium being indispensable for electrification (IEA, 2023d). In the following section, we will provide a detailed examination of the LIB industry, delving into its historical evolution, intricate value chain, current market status, and outlook.

3.2.1 The evolution of battery technology and chemistry

The architecture of LIBs, as seen in Figure 3.4 is founded on rechargeable cells comprising anodes, typically made of graphite, cathodes of lithium metal oxide, and an electrolyte that facilitates lithium ions' mobility (Dempsey, Campbell, & Davies, 2023). In operation, the batteries rely on a chemical reaction, facilitating the movement of lithium ions from the anode to the cathode through the electrolyte, generating electric current through an external circuit (Argonne National Laboratory, 2023). These components, along with a separator to prevent electrical contact while permitting ion exchange, are typically encased in cylindrical modules and, within EVs, configured into expansive battery packs.

Figure 3.4: The first commercially viable LIB (Gustafsson, von Heijne, Ramström, Chemistry, & Fernholm, 2019)



The trajectory of LIB technology, from its origin in Whittingham's 1970s research to its current state, has been shaped by the energy crisis and environmental consciousness. Whittingham's Nobels-recognised work laid the foundation for rechargeable lithium batteries, prevailing early setbacks such as lithium dendrite growth through innovative material substitutions and safety enhancements. Goodenough's subsequent upscaling of cathode potential via metal oxides and Yoshino's integration of petroleum coke anodes furthered the development (Gustafsson, von Heijne, Ramström, Chemistry, & Fernholm, 2019), culminating in the commercialisation by Japanese giants like Sony and Panasonic (Panasonic, 2023).

Today's LIBs, while still unrivalled in capacity and voltage, are evolving into two main streams: NMCs, prevalent in Western markets for their high energy and rapid charging, and LFPs, favoured in China for safety, cost, and longevity. The cathode compositions fundamentally differentiate these technologies: NMC batteries comprise lithium, nickel, manganese, and cobalt, while LFP batteries utilise lithium iron phosphate (Dempsey, Campbell, & Davies, 2023). Table 3.1 outlines the significant contrasts between the two.

Table 3.1: Main differences between NMC and LFP LIBs (Dempsey, Campbell, & Davies, 2023)

	NMC	LFP
Average cost (USD/kWh)	130-180	90-120
Energy density (kWh/kg)	230-325	120-180
Battery lifetime (charging cycles)	500-2,000	3,000<

3.2.2 Value chain

The battery value chain is multifaceted and segmented primarily into *upstream, midstream,* and *downstream* (Dempsey, Campbell, & Davies, 2023). The *upstream* involves the extraction of raw materials from mines located across the globe. The lithium is mostly mined in regions like Australia and Latin America, particularly the "lithium triangle" encompassing Argentina, Bolivia, and Chile (IEA, 2023d). These raw materials are then refined into battery-grade chemicals like sulphate, carbonate, and hydroxide (Palandrani, 2020). The supply chain, however, is challenged by the concentration of major producers, with China refining over 70 percent of the mined lithium (Bernhart, 2023)

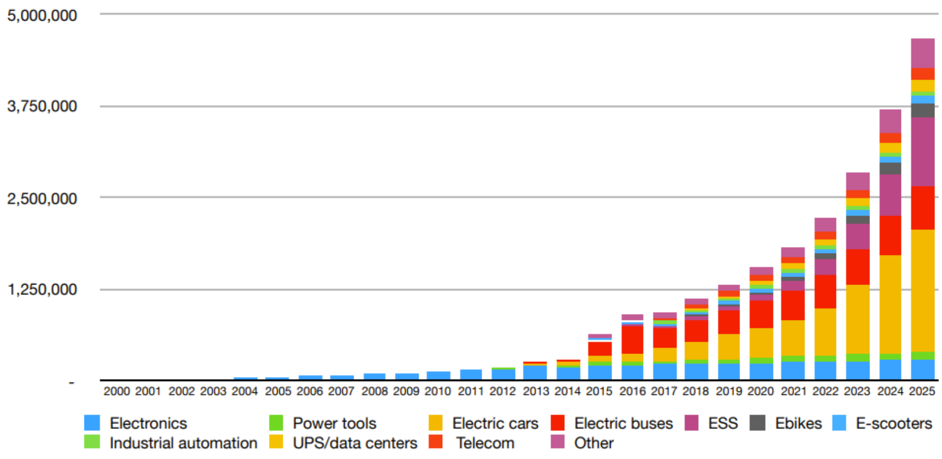
In the *midstream* phase, the supply chain encompasses chemical companies as key actors, like Panasonic, CATL and LG Chem (Palandrani, 2020). These companies transform the refined compounds to craft electrochemically active materials, like lithium-ion metal oxide, which are crucial for both cathode and anode production. Efforts towards supply chain diversification are afoot, with the EU increasing its regional extraction capacity (IEA, 2023d). Also, the *midstream sector* includes battery cell manufacturers. These manufacturers are central in assembling battery cells, bringing together various constituent parts, like the anode, cathode, separators, electrolyte, and casing materials.

Downstream, the landscape bifurcates into companies producing battery cells, which are then assembled into modules. These modules are then dispatched to end-users like Tesla and BMW, Daimler, and Volkswagen (Palandrani, 2020). The batteries find utility in a wide spectrum of applications, ranging from EVs to handheld devices (Dempsey, Campbell, & Davies, 2023).

3.2.3 End markets, size, and outlook

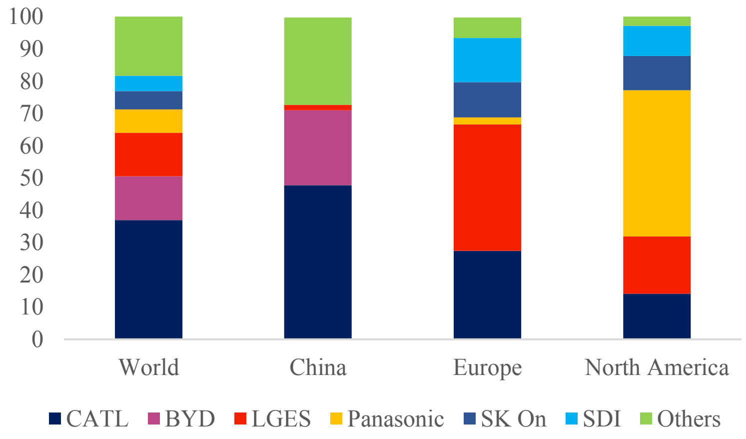
The growing LIB market is significantly propelled by the electrification of the transportation sector, reshaping end markets and influencing market size and prospects. The demand for LIBs is poised to ascend to 6,000 GWh by 2030, a testament to their diversification beyond consumer electronics to power a surplus of devices and EVs (Degan, 2023). Since 2010, there has been a remarkable 500 percent increase in the annual deployed capacity of LIBs. The automotive industry is experiencing robust growth, lifted by technological advancements and growing EV adoption (Melin, 2018). In Figure 3.5, we can see this transformation from 2000, and the forecasted development until 2025:

Figure 3.5: LIBs placed on the global market (cell level, tonnes) (Melin, 2018)



Regional and manufacturing discrepancies define the market landscape, with NMC battery producers prevailing in the US and Europe, while LFP manufacturers like CATL and BYD gain market share, as clear by CATL's prominence in Europe and North America (Bernstein, 2023). This trend aligns with geopolitical strategies and subsidy regimes, highlighting a protectionist tilt. (Bernstein, 2023). This is further displayed in Figure 3.6.

Figure 3.6: Market shares as percent of sales (Campbell, Dempsey, & Davies, 2023)

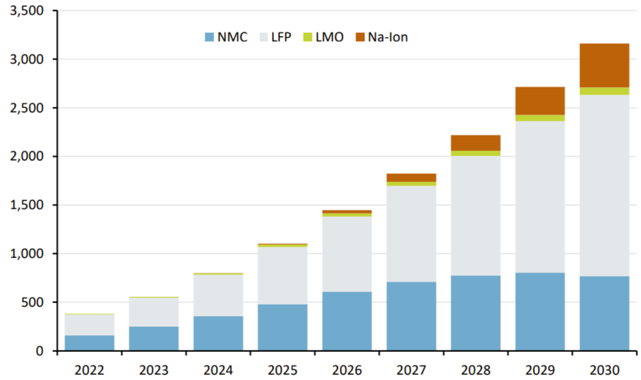


McKinsey's 'Battery 2030'-report anticipates that the global demand for batteries is on an upward trajectory. McKinsey's Battery Insight team projects an annual growth rate exceeding 30 percent within the LIB supply chain, from extraction to recycling, with market valuation potentially surpassing USD 400 billion by 2030 and a market size of 4.7 TWh (Fleischmann, et al., 2023).

Such forecasts reveal an upsurge in LIB consumption, from 700 GWh in 2022, to approximately 4.7 TWh by 2030, predominantly fuelled by EV applications. This vigorous expansion is attributed to regulatory shifts towards sustainability, escalating consumer appetite for environmentally conscious technologies, and automotive manufacturers' commitments to phasing out combustion engines in pursuit of stringent emission goals (Fleischmann, et al., 2023).

Looking ahead, Rystad Energy forecasts a realignment in market shares between leading LIB types, with LFP batteries gaining predominance over NMC counterparts. Additionally, Rystad Energy acknowledges the potential emergence of novel battery technologies by 2026 (Rystad Energy, 2023). Figure 3.7 illustrates the anticipated annual demand for batteries by chemistry. Looking ahead, Rystad Energy forecasts a realignment in market shares between leading LIB types, with LFP batteries gaining predominance over NMC counterparts. Additionally, they acknowledge the potential emergence of novel battery technologies by 2026 (Rystad Energy, 2023). Figure 3.7 illustrates the anticipated annual demand for batteries by chemistry.

Figure 3.7: Annual battery demand by chemistry (GWh) (Rystad Energy, 2023)



4. Methodology and data

This chapter presents the approach to assess bubble tendencies in the LIB market. Recognising the crucial role of a well-structured methodology in enabling a comprehensive analysis, a discussion of potential risks, anticipated limitations, and measures taken to address challenges in the study is provided. The objective is to provide the reader with model specifications and the data collection procedure used in the empirical analysis in Chapters 5, 6, and 7.

4.1 Model specifications

4.1.1 Hodrick-Prescott Filter

The Hodrick-Prescott (hereafter: HP) filter, established in 1981, is a fundamental tool in economic analysis. It is notably utilised for dissecting time series data, particularly in identifying deviations from trends (Hodrick & Prescott, 1981). The filter's mechanics have universal applications, dividing series into smooth (long term trend g_t and seasonal s_t components) and volatile (stochastic or business cycle c_t) parts, plus irregularities i_t (Weron & Zator, 2015).

$$\boldsymbol{x_t = g_t + c_t + s_t + i_t} \quad \textbf{(6)}$$

When analysing stochastic time series, the seasonality and irregularities may be included in the cyclical component. Therefore, according to Koilo and Grytten (2019), the HP filter is instrumental in structural time series analysis breaking down seasonally adjusted and stochastic time series (x_t), into its trend (g_t) and cyclical (c_t) components.

$$\boldsymbol{x_t = g_t + c_t} \quad \textbf{(7)}$$

The objective of the HP filter is to minimise the variance of the cycle component c_t while accommodating second difference variations in the trend component g_t. The equation is as follows (Koilo & Grytten, 2019):

$$\boldsymbol{HP_t = \min_{g_\tau} (\sum_{t=1}^{T} (x_t - g_t)^2 + \lambda \sum_{t=2}^{T-1} [(g_{t+1} - g_t) - (g_t - g)]^2)} \quad \textbf{(8)}$$

Here, the first sum represents the punishment for deviating from the original series, and the second sum punishes the roughness of the smoothed series (Koilo & Grytten, 2019). As outlined in *Postwar US Business Cycles: An Empirical Investigation* by Hodrick and Prescott (1981), the λ parameter controls the smoothness of the g_t. A high λ value implies greater smoothing, leading to a trend with limited fluctuations and minor cycles. The selection of λ is subject but crucial, with recommended values of $\lambda = 100$ for annual data, $\lambda = 1{,}600$ for quarterly data, and $\lambda = 14{,}400$ for monthly data (Koilo & Grytten, 2019). There are no uniform λ values for daily observations. Grytten (2023) suggests using a dynamic approach, choosing several smoothing parameters. The impact of variations in the λ parameter on cyclical values serves as an indicator in detecting euphoric bubble tendencies (Grytten, 2023).

To calculate the percentage deviations from trend, the estimated trend component is subtracted from the matching observable components:

$$\boldsymbol{c_t = x_t - g_t} \quad \textbf{(9)}$$

In cases with extreme deviations, relative gaps can be calculated using logarithmic values:

$$\boldsymbol{log\,(c_t) = log\,(x_t) - log\,(g_t)} \quad \textbf{(10)}$$

The filter is a two-sided filter, meaning it considers historical, current, and future data points when determining the trend, a method often likened to 'a random walk without drift' This attribute is valuable for analysing the impact of past events on current market dynamics. However, it has its limitations:

- Endpoint Problem: The filter's behaviour at the endpoints of the time series can pose challenges, potentially generating artificial cycles that do not align with the observed data (Grytten & Hunnes, 2016).
- Lambda Parameter (Smoothing): The choice of the lambda (λ) parameter introduces a smoothing effect, influencing the trade-off between minimising changes in trend growth and minimising cyclical part variance. The selection of an appropriate λ value can be somewhat subjective, but Hodrick and Prescott argue that one should apply $\lambda = 100$ for annual data, $\lambda = 1{,}600$ for quarterly data and $\lambda = 14{,}400$ for monthly data (1981).

- Prolonged Cycles: The HP filter assumes that expansion and contraction phases in economic cycles have equal durations, which may not always reflect reality, as downturns can be sudden and shorter than upturns.
- Equal Weighting of Economic Phases: It assigns equal weight to upturns and downturns, which might not be ideal in situations where one phase significantly outweighs the other in terms of economic importance.
- Real-Time Challenges: The filter's reliance on past data can pose challenges when analysing real-time data, as it may not provide timely insights into the latest developments.

In practice, the effects of applying different λ values can be illustrated through sample fits of the HP filter to various data sets. For mid-term modelling and datasets with shorter lead times, the appropriate λ value may differ, necessitating comparative analysis with other models.

In summary, the Hodrick-Prescott filter, while indispensable in economic research for differentiating between trend and cyclical components, requires careful consideration of its limitations, particularly in endpoint behaviour and λ parameter selection. The filter’s adaptability across various datasets underscores its value yet emphasises the need for nuanced application.

4.1.2 Coefficient of correlation

The coefficient of correlation is explained as the covariance divided by the standard deviations of two datasets. The Greek letter, *rho* (ρ), is the notation of the correlation coefficient and is expressed mathematically in equation 11.

$$\boldsymbol{\rho = cov(x, y) = \frac{\sigma_{xy}}{\sigma_x \sigma_y} = \frac{\sum_{i=1}^{N}(x_i - \mu_x)(y_i - \mu_y)}{\sqrt{\sum_{i=1}^{N}(x_i - \mu_x)^2} + \sqrt{\sum_{i=1}^{N}(y_i - \mu_y)\char`^2}}} \tag{11}$$

The advantage of the correlation parameter is the interpretation due to its upper and lower limit of $-1 \leq \rho \leq 1$. A correlation coefficient equal to +1 means there is a perfectly positive linear relationship between variables x and y. A perfectly negative linear relationship exists with a correlation coefficient of -1. The state of no linear relationship exists with a coefficient of correlation equal to 0. All outstanding interpretations are evaluated in relation to the three values and will be categorised in Table 4.1 (Calkins, 2005).

Table 4.1: Indication of correlation level (Calkins, 2005)

Range	Classification
0.9 - 1.0	Very high
0.7 - 0.9	High
0.5 - 0.7	Moderate
0.0 - 0.5	Low

The linear relationship assumption should be approached cautiously, as it may result in other relationships going unnoticed. The correlation coefficient cannot determine the direction of causality. Moreover, the presence of measured or unmeasured variables, often referred to as the 'confounding effects', may also influence the perception of the results (Janse, et al., 2021).

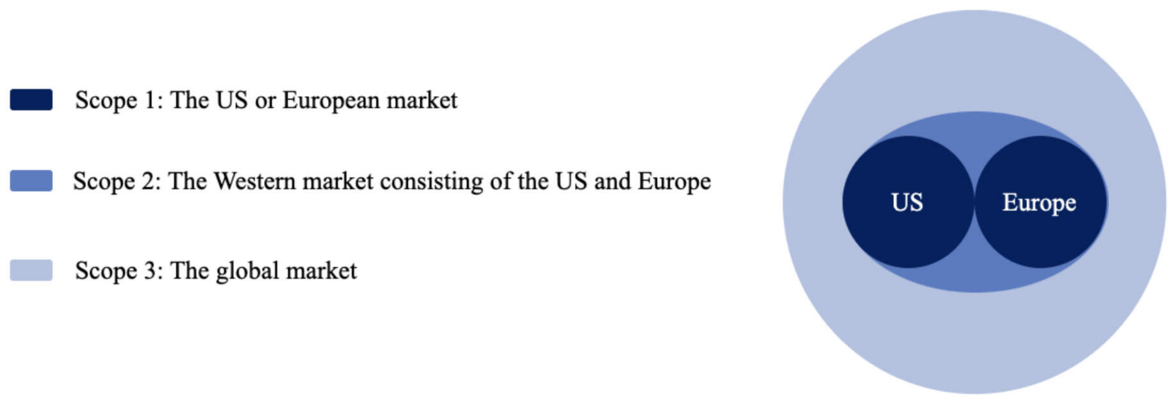
4.1.3 Media trends

According to Calverley (2011) & Buckley (2011), another way of identifying bubbles is increased media coverage. Looking at the coefficient of correlation between asset prices and media trends determines the validation of this methodology.

4.2 Research design

4.2.1 Segregation of data

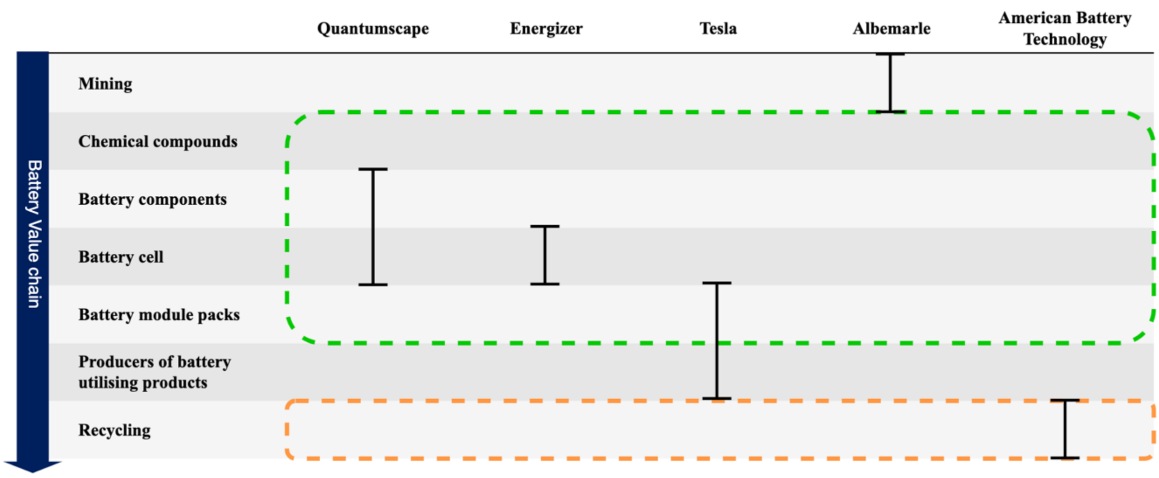
Figure 4.1: Region scope



The research question confines the thesis to the US and European markets. Predominantly, the data is focused on the two regions, both separately and aggregated. Global market data is collected for comparative analysis purposes, resulting in three distinct scopes, as illustrated in Figure 4.1. Scope 1 pertains individually to either the US or the European market. Scope 2 encompasses the Western market, aggregating data from both the US and European markets. Finally, Scope 3 addresses the global market, supplying context for the US and European data.

Furthermore, the thesis is confined to LIB manufacturers, as depicted in Figure 4.2 highlighting the value chain scope. The green area, encompassing the production of chemical compounds, battery components, cells, and module packs, constitutes the research focus. The inclusion of recycling companies, represented by the orange area, is contingent upon the company's inclusion in the green area. If the condition is not met, as exemplified by American Battery Technology, the company is excluded from the analysis. This method ensures that mining companies like Albemarle and EV producers such as Tesla do not influence the perception of the LIB manufacturing sector. This approach is applied in Scope 1 and 2 and not in Scope 3 due to the number of observations.

Figure 4.2: Value chain scope (Campbell, Dempsey, & Davies, 2023)



4.2.2 Data

In this thesis, a diverse array of data sources has been used to explore the research question. The principal data encompassing companies' stocks and stock exchanges were acquired from Refinitiv Workspace (2023). Concurrently, country-specific data was gathered from Eurostat, the European Commission, Statista, and the Federal Reserve, among others. The most central time series data, central to this research, particularly examines the potential bubble tendencies within the LIB market. For a robust HP filtration and application of a correlation analysis, it is generally recommended to have a substantial number of data points. The adequacy of data points can depend on the frequency of the data (daily, monthly, quarterly) and the specific context of the study.

Table 4.2: Quantitative data overview

Data	Description	Time period	Source
Money stock	Development in the Money Stock of both the US and the European Union	Jan 2016 - Sep 2023	Federal Reserve and the Eurostat
Governmental RD&D spending	Development in governmental RD&D spending on Energy Efficiency and other power and storage technologies in the US and Europe	2000-2022	International Energy Agency
Gross Public/Federal Debt	Development in gross public or federal debt in the US and the EU	2000-2023	Federal Reserve and Eurostat
Consumer credit	Development in US and European consumer credit	Jan 2016 - Sep 2023	Federal Reserve and European Central Bank
Company-specific data	Company specific data like common stock, gross debt, and leverage	2016-2022	Refinitiv Workspace and the company's financial reports
Shares outstanding	Aggregated number of shares outstanding in the sector over time	01.01.2016-29.09.2023	Refinitiv Workspace
Output	Real Gross Domestic Product	2016-2023	U.S Bureau of Economic Analysis, European Commission
Production	US and EU20 Industrial Production Index (IPI) battery sector	2000-2022	Federal Reserve and European Central Bank
Battery prices	LIB cell and packs real values as of 2022 USD	2016-2023	Statista
Mineral prices	Global benchmarks determined by the largest import market on lithium, nickel, cobalt, and manganese prices in nominal values converted to real values	2016-2022	International Monetary Fund

Data	Description	Time period	Source
Deflator	Implicit price deflator used to convert mineral prices to real values (USD 2022 = 100)	2016-2022	Federal Reserve
Stock index	This encompasses daily returns weighted by the market capitalisation of each stock within the index	2016-2023	Refinitiv Workspace
IPO evolution	The number of Initial Public Listings in the LIB industry per year	1969-2023	Refinitiv Workspace
Market concentration	The cumulative number of listed LIB companies per year	1969-2023	Refinitiv Workspace
Demand	Global demand per region for LIBs	2016-2022	International Energy Agency
Media interest	This tracks the frequency of buzz words related to our research appearing in the media	2016-2023[3]	Nexis Uni
Consumer interest	This tracks the frequency of google searches of words related to our research	Jan 2004-Sep 2023	Google Trends

4.2.3 Lithium-ion Battery Company Indices (BCI)

Addressing the absence of a publicly available lithium-ion battery index pertinent to the scopes of this thesis, we undertook the initiative to establish our self-created index, designated as the Battery Company Index (BCI). Using Refinitiv Workspace's comprehensive company overview, we selectively filtered for LIB manufacturing companies, focusing predominantly on those within the European and US markets.

Daily stock prices, ranging from the 4th of January 2016 to the 29th of September 2023, were used to calculate the daily indexed value. The BCI mirrors the methodology of larger global indices, like the S&P 500, where the total return of the index (I_t) at time (t) is a function of the weighted market capitalisation $\left(w_{n,t}\right)$ multiplied by the company's return $(r_{n,t})$, as presented in equation 11:

$$\boldsymbol{I_t = \sum_{\substack{n=1 \\ t=1}}^{N} \left(w_{n,t} * r_{n,t}\right)} \qquad \textbf{(11)}$$

[3] The 2023 data point is an estimate based on Q1 and Q2 data from 2023.

Each company's contribution to the index is weighted by its market capitalisation, ensuring a proportional representation in the index. Also, each index is based on listed LIB companies following the regional and value chain criteria outlined in Section 4.2.1. The tables below illustrate the five largest companies as of 29th September 2023 exerting the most influence in the created stock market indices.

Table 4.3: Largest companies BCI West

West		
Ticker	**Full Name**	**Weights**
QS	Quantumscape Corp	27.29%
ENR	Energizer Holdings, Inc.	19.04%
ENVX.O	Enovix Corp	16.70%
VAR1.DE	Varta AG	6.73%
SES	Scandinavian Enviro Systems AB	6.63%

Table 4.4: Largest companies in the BCI US and Europe

US			Europe		
Ticker	**Full Name**	**Weights**	**Ticker**	**Full Name**	**Weights**
QS	Quantumscape Corp	31.57%	VAR1.DE	Varta AG	49.66%
ENR	Energizer Holdings, Inc.	22.03%	LECN.S	LecLanche SA	21.44%
ENVX.O	Enovix Corp	19.33%	FORSEE.PA	Forsee Power Société	14.48%
SES	Scandinavian Enviro Systems AB	7.67%	SERK.MI	Seri Industrial SpA	12.10%
FREY.K	Frery Battery	6.57%	GELN.L	Alelion Energy	1.99%

It is crucial to acknowledge that certain companies, due to their larger market capitalisation, exert a considerable influence on the index. For instance, in September 2023, Varta AG constituted approximately 50 percent of the BCI West compared to the other 19 companies. This weighting mechanism was deliberately chosen to account for market fluctuations and integrate new Initial Public Offerings (hereafter: IPO) effectively.

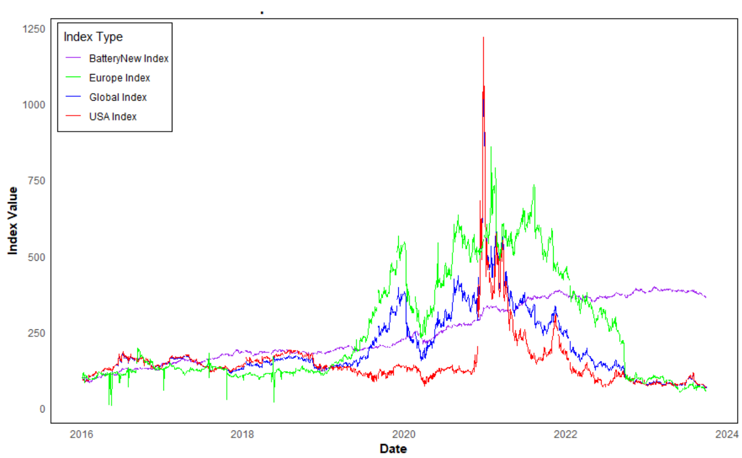
To capture the global nature of the LIB market, another index was created to encompass 50 companies worldwide. This expansion was crucial to address the research question in a global context. A considerable number of these companies are listed on Chinese and South Korean stock exchanges. In BCI International, Korean firms such as LG Energy Solution have a substantial 47.55 percent weight, highlighting the dominance of Asian companies in the global market.

Table 4.5: Largest companies BCI International

Ticker	Full Name	Weights
373220.KS	LG Energy Solution, Ltd.	47.55%
006400.KS	Samsung SDI Co., Ltd.	15.18%
300014.SZ	EVE Energy Co., Ltd.	7.34%
603659.SS	Shanghai Putailai New Energy Technology Co., Ltd.	4.73%
2074	Gotion High Tech Co., Ltd.	3.26%

Figure 4.3 illustrates the evolution of the BCIs. The left plot displays the progression of the BCI in the US, European and Western stock markets. The right plot depicts the global development.

Figure 4.3: Evolution in the BCIs West, US, Europe and International



Alongside the self-created BCIs, the study employs additional equity indices that share similarities in region and/or sector for comparative analysis. Descriptive statistics are presented in Table 4.6.

Table 4.6: Descriptive statistics BCIs and similar indices

Index	Mean	Median	Min	Max	Standard deviation	Beta
BCI Western	195.44	158.25	66.78	1,144.37	112.24	0.04
BCI USA	152.72	133.39	68.39	1,219.00	93.57	0.01
BCI Europe	252.67	142.96	10.13	859.92	181.08	0.11
BCI Global	248.56	209.63	85.03	398.10	96.58	0.11
S&P Global Clean Energy	1,154.28	1,027.56	392.63	3,911.68	712.68	-0.09
EuroStoxx 50	2,705.12	2,893.08	615.90	5,464.43	1,153.59	0.73
FTSE UK 100	4,801.45	5,288.41	986.90	8,014.31	1,967.76	1.50
Nasdaq 100	3,008.53	1,627.10	107.16	16,573.34	3,729.99	3.36
Nasdaq Clean Edge Green Technology	328.58	246.92	104.61	1,152.37	225.21	0.18
S&P 500	597.66	101.62	4.40	4,796.56	953.68	1.00

4.2.4 Media data collection

The media data, collected from Nexis Uni, only includes the US media houses. Additionally, intraday observations exceeding 10,000 mentions cannot be collected from the database as it indicates + 10,000. This instance only happened on the 8th of July 2022 when collecting intraday data for “Electric vehicle” mentions. As the actual figures might be higher than reported, this could also affect the correlation coefficients. Despite these limitations, the focus on US media is maintained due to its significant global reach and influence.

4.2.5 Qualitative data

Moreover, qualitative data from diverse sources have been collected to achieve a more nuanced picture of the LIB industry determinants. While a significant portion of the quantitative data pertains to the overall economy, intentionally including qualitative data aims to offer more sector-specific insights. These qualitative sources will supplement the results in Chapters 5, 6, and 7 and contribute to the discussion of bubble tendencies in Chapter 8.

The White House website is a key source for understanding the regulatory landscape for US LIB manufacturers. This data is essential for analysing shifts in industry profitability and access to capital in the US. The European Commission's press corner provides crucial qualitative data about the market dynamics in the European LIB industry, encompassing governmental battery production policies. Financial times is a liberal British newspaper, primarily covering financial and political matters. In recent times, the newspaper has published numerous articles about the battery industry addressing trends and challenges. *The battery revolution-series* has been a core resource for the qualitative data used (Davies, et al., 2023).

Supplementary qualitative sources, listed in the References, contribute to a deeper understanding of the sector, aiding in the assessment of the significance of each finding within a broader context.

4.2.6 Research quality

The robustness of this research depends on the quality and reliability of the data collection and analysis methods. Reliability is achieved when outcomes can be consistently replicated under similar methodologies (Golafshani, 2003). All the data sources used in this thesis, are collected from publicly available financial databases, like Refinitiv Workspace, allowing for the findings to be verified and reproduced independently.

Validity in research ensures that the measures and analyses conducted accurately reflect the intended study purpose (Creswell & Miller, 2000). To ensure the validity of the findings, the evaluation of both internal and external aspects of the data has been conducted. The study does not pursue causality, but instead, it uses time series data to contextualise economic phenomena and answer our research question effectively.

In this thesis, the data applied is assumed to be correct, reliable, and valid as it is collected from public sources, can easily be replicated, and validated.

4.2.7 Limitations

The methodology adopted for data collection in this thesis is accompanied by several inherent limitations, necessitating a nuanced interpretation of the findings. A primary concern is the heterogeneity in the analysis of the companies in both BCI International and West, each listed on distinct stock exchanges across various countries. This diversity essentially introduces a variation in the number of trading days, thereby affecting comparability. For instance, while the 4^{th} of July is a public holiday for US stock exchanges, it is considered a regular trading day in European markets. This discrepancy in trading days across different stock exchanges could potentially lead to biased interpretations of market behaviour and performance.

Further complexity arises from the dynamic nature of the BCIs, particularly due to the inclusion of new companies. This integration often results in fluctuations in the index's weighting over specific intervals, reflecting the ever-evolving composition of the index. This aspect is crucial for understanding the variable nature of the BCIs and their impact on trend analysis over time.

In terms of data collection time frames, there exists a notable disparity. While stock market data is updated in real-time, company-specific information is typically available on a quarterly or semi-annual basis. Ideally, a larger dataset including monthly, or daily updates would provide a more detailed insight, but such data was not accessible. This limitation in data frequency could potentially affect the robustness and granularity of the analysis.

Additionally, the method for aggregating data points into less frequent intervals varies. Our study used average values, but other data sources might employ different methods, such as using the last or first date of the quarter or month. This inconsistency in methodologies could result in discrepancies when comparing data across different periods, thus affecting the accuracy of temporal comparisons.

The LIB industry presents its unique set of challenges. The industry is characterised by confidential agreements on LIB prices, which significantly hinders the collection of comprehensive and correct price data. Consequently, our study had to rely on a price index to approximate these values, which may not fully capture the nuances of the actual market price.

The scope of data collection for Europe also varies due to differing methodologies used by various data sources in defining the European region or the European Union. In our study, the BCI includes companies within the EU, except for some London-listed companies, post-Brexit. This decision to focus primarily on EU-based companies post-Brexit introduces a geographical limitation, especially considering the significant economic and political changes following Brexit in 2020. These changes have notably impacted GDP time series and data collected from sources like the ECB or Eurostat, which have adjusted their definitions of the EU from EU28 (28 countries) to EU27 (27 countries) post-Brexit.

Lastly, the nascent state of the LIB market introduces another significant limitation. The lack of long term time series data in this evolving market hinders comprehensive trend analysis. This paucity of data is particularly problematic when employing analytical tools like the HP filter with real-time data, as the filter's efficacy is contingent on the availability of extensive historical data.

In summary, the limitations outlined in this section underscore the importance of a careful and contextual interpretation of the data and findings of this study. They also highlight the need for ongoing research and data collection to enhance the accuracy and reliability of future analyses in these dynamic and evolving sectors.

5. Leverage

This chapter presents the results derived from structural times series analysis considering money stock and credit indicators, including M2, governmental RD&D spending, common stock, gross federal debt, gross sector debt, and leverage. Additionally, GDP serves as a comparative indicator in the M2 analysis.

5.1 Money stock

5.1.1 M2 and GDP

In this section, the primary emphasis is placed on the analysis of M2. However, to elucidate potential indications of economic overheating, a comparative examination of the relational progression between M2 and GDP is conducted. This approach is supported by the rationale that a disproportionate increase in money relative to value added might signal a potential surplus of monetary circulation. Money supply includes cash, checking deposits, and easily convertible near money, indicating the amount of money in circulation within an economy (Federal Reserve Bank of St. Louis, 2023). GDP is used as a measure of economic activity and growth, including the overall net production of a country.

Figure 5.1 illustrates the trends in M2 and GDP for the US and the EU from 2000 to 2022. The figure indicates that there are periods where their growth rates diverge or converge, with notable changes occurring around the years 2008 and 2020, particularly in the US, where M2 escalates steeply relative to GDP in 2020. After 2020, the period marked a shift and substantial rise in M2, coinciding with the onset of the Covid-19 pandemic. Both the US and Europe show decreasing trends in M2 after 2022, which is the first observed decrease in M2 at least since 2000.

Figure 5.1: Development of M2 and GDP in the US and Europe

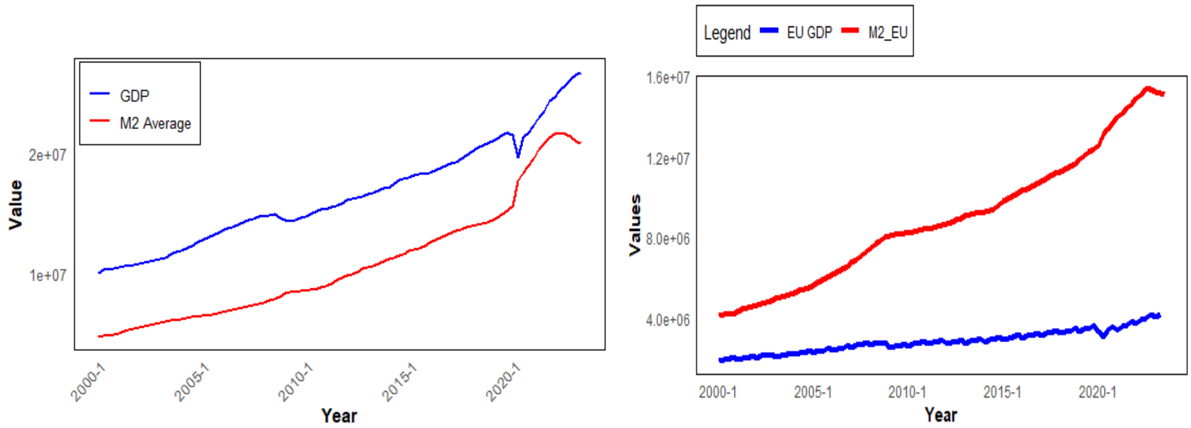


Table 5.1 presents deviations from the trend for both M2 and GDP, reporting peaks and troughs for both observed regions for the periods 2000 to 2022. It shows that both regions experienced significant fluctuations during this period. For the US, there was a notable peak in M2 in 2021 and a significant trough in 2020. The EU's peak and trough in M2 were less extreme, both occurring in 2020. Regarding GDP, the US's peak and trough were observed in 2022 and 2020, respectively, while the EU experienced its most substantial GDP deviation in 2008 and a significant drop in 2020.

Table 5.1: Summary M2 and GDP – cycle values as percentage deviation from trend

Indicator	**Data Range**	**Lambda**	**US**		**EU**	
			Peak	**Trough**	**Peak**	**Trough**
M2	2000-2022	14,400	5% (2021)	-8% (2020)	3% (2008)	-3% (2020)
GDP	2000-2022	1,600	2% (2022)	-11% (2020)	8% (2008)	-13% (2020)

5.1.2 Governmental RD&D spending

Governmental research development and deployment (RD&D) investments in energy efficiency, power, and storage technologies, including LIBs, contribute to the financial influx into the clean energy sector. Although the ideal dataset would solely focus on the LIB domain, the available analysis employs broader sector data.

Table 5.2 reveals noteworthy fluctuations in public RD&D spending. The US emerges with the most pronounced variance within the dataset, exhibiting an especially high peak value in 2009 of 154 percent. It is noteworthy that peaks and troughs in the US and Europe do not coincide.

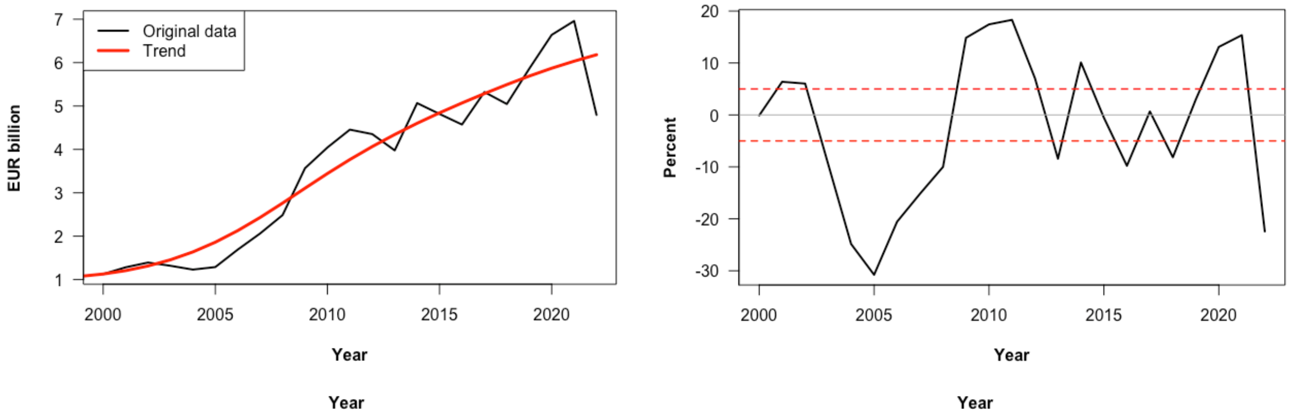
Table 5.2: Summary governmental RD&D spending on energy efficiency, power, and storage technologies – cycle values as percentage deviation from trend

Indicator	Data Range	Lambda	US		Europe	
			Peak	**Trough**	**Peak**	**Trough**
Governmental RD&D spending	2000-2022	100	154% (2009)	-38% (2006)	18% (2011)	-31% (2005)

The time series analysis depicted in Figure 5.2 delineates a threefold in US RD&D spending from 2000 to 2022, surging from USD one to three billion. Two notable intervals are characterised by negative cyclical values spanning from 2003 to 2008 and from 2011 to 2017. The cyclicality of values lacks a discernible pattern, with cycle durations fluctuating between approximately three years (2008 to 2011) and six years (2011 to 2017).

In the European context, the average cyclical fluctuations (volume of ten percent) are comparatively less pronounced than those observed in the US (volume of 18 percent). Nonetheless, RD&D spending has increased significantly, escalating from approximately EUR one to nearly seven billion between 2000 and 2020. Notably, in the final two years of this period, European RD&D spending experienced a marked decline, falling notably below the long term trend. Conclusive assertions regarding consistent cyclical durations are precluded.

Figure 5.2: HP filter of governmental RD&D spending on energy efficiency and other power and storage technologies in Europe (IEA, 2023b)



5.1.3 Common stock

Issued and paid common stock is contingent upon the combined factors of share quantity and per-share pricing. Fluctuations in common stock values serve as indicators of the prevailing business cycles within the LIB industry. The notable deviations from the established trend are shown in Table 5.3, portraying variations across all regions. In 2021, peak values are simultaneously evident in both the US and globally, while trough values similarly manifest in Europe and globally during 2016.

Table 5.3: Summary common stock – cycle values as percentage deviation from trend

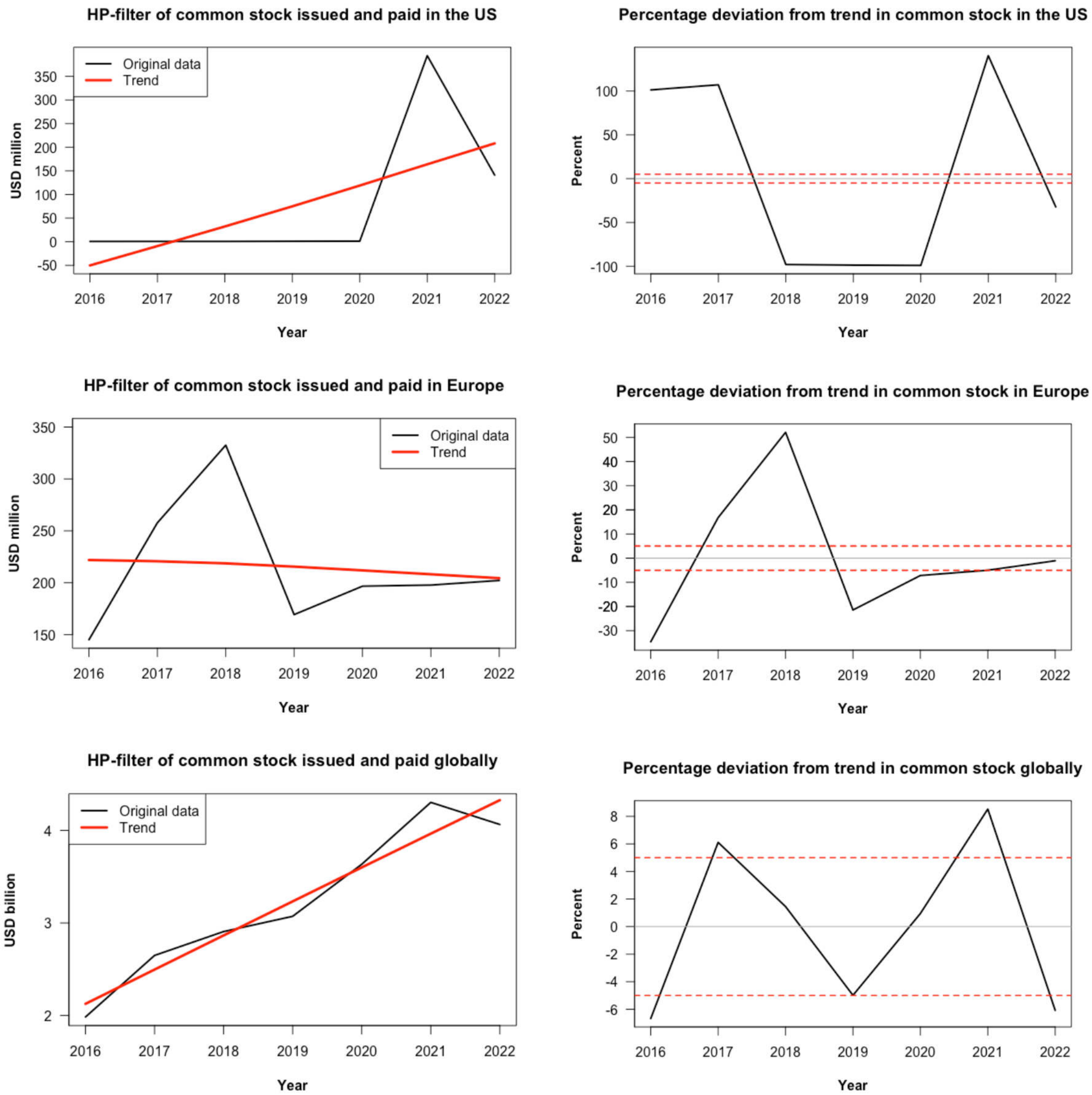
Indicator	Data Range	Lambda	US		Europe		Global	
			Peak	Trough	Peak	Trough	Peak	Trough
Common stock	2016-2022	100	140% (2021)	-107% (2017)	52% (2018)	-35% (2016)	9% (2021)	-7% (2016)

Graphical analysis is depicted in Figure 5.3, revealing an upward-sloping long term trend of common stock in the US. Notably, from 2020 to 2021, the US witnessed a significant upswing in the cumulative value of common stock within the LIB industry. Examining the flat development in common stock prior to 2020, provides a basis for inferring that the positive long term trend stems from the observations in 2021 and 2022. The pinnacle in 2021 is succeeded by a corrective downturn surpassing -50 percent.

In the European context, the long term trajectory in common stock exhibits relative stability, marked by cycle values that are comparatively modest in comparison to the US market. Despite this, the European market experienced a conspicuous peak in common stock during 2018, exceeding 50 percent from the established trend. After a deviation of approximately -20 percent in 2019, the cycle values demonstrate a tendency to converge towards zero.

The global LIB market has witnessed a steeper positive development in common stock relative to the US. When excluding the endpoint values in the global cycle analysis, significant positive cycle values are observed in 2017 and 2021, amounting to approximately six and eight percent, respectively.

Figure 5.3: HP filter and percentage cycle values of common stock in the US, Europe and globally (Refinitiv Workspace, 2023)



5.2 Credit

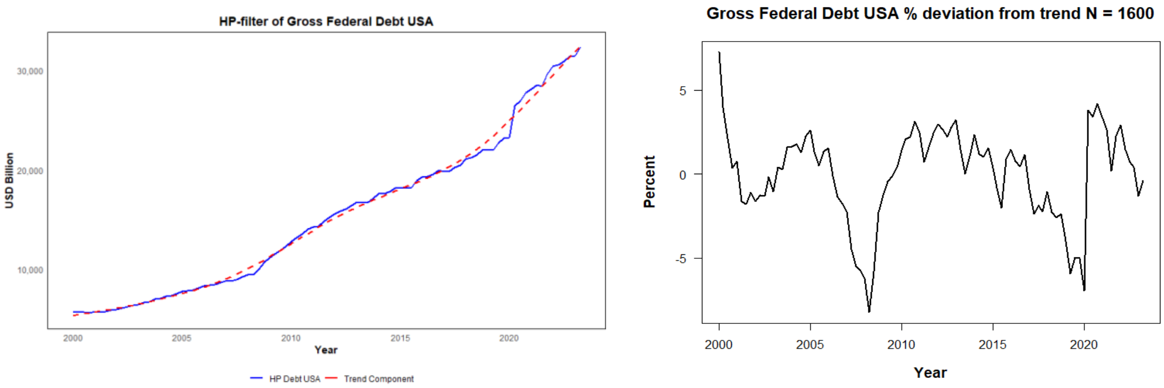
5.2.1 Gross public debt

This section delves into the trends of gross public debt in the US and the EU from 2000 to 2022.

Table 5.4: Summary Gross Public Debt – cycle values as percentage deviation from trend

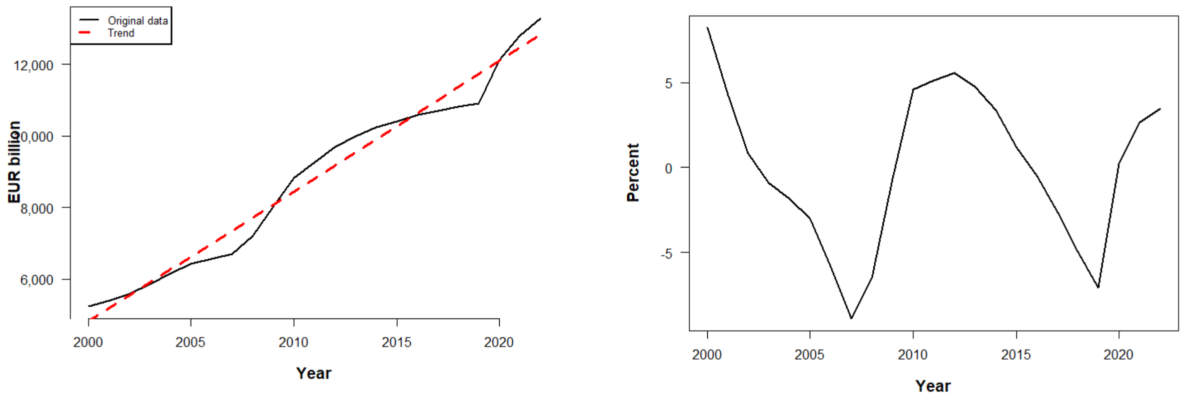
Indicator	**Data Range**	**Lambda**	**US**		**Europe**	
			Peak	**Trough**	**Peak**	**Trough**
Gross public debt	2000-2022	1,600	7% (2020)	-8% (2008)	8% (2012)	-9% (2008)

Figure 5.4: HP filtration and percentage cycle values of Gross Federal Debt in the US (Federal Reserve Bank of St. Louis, 2023)



According to data from the Federal Reserve Bank of St. Louis (2023), as depicted in Figure 5.4 and summarised in Table 5.4, indicates that the US gross federal debt has experienced significant cyclical deviations. The year 2020 saw a peak in the gross federal debt, reflecting an increase in debt during that period. On the other hand, 2008 marked a trough, suggesting a decrease in debt levels at that time.

Figure 5.5: HP filtration and percentage cycle values of Gross Federal Debt in the EU (European Central Bank, 2023)



The analysis of the EU's gross debt is based on data from the European Central Bank data (2023) and presented in Figure 5.5 and Table 5.4. This approach is due to the lack of uniformly denominated data from all EU countries. The EU's gross debt trajectory, especially after 2010, showed notable fluctuations. A peak in the debt level was observed in 2012, while during the financial crisis of 2008, the gross debt experienced a significant decrease, marking a trough.

In summary, the observed variability in the debt levels relative to long term trends in both the US and EU provides objective measures of how fiscal policies have fluctuated in response to economic conditions.

5.2.2 Gross sector debt

The gross debt of each company, collected from Refinitiv Workspace (2023), includes both operational and financial book values of debt, reflecting the overall level of liabilities in the company. To evaluate the financing structure on the company level it would be convenient to analyse the market value of net debt by extracting operational debt including and by using market values of the companies' financial assets and liabilities. In our analysis, the gross debt indicator should be interpreted as the overall credit obligations of the company.

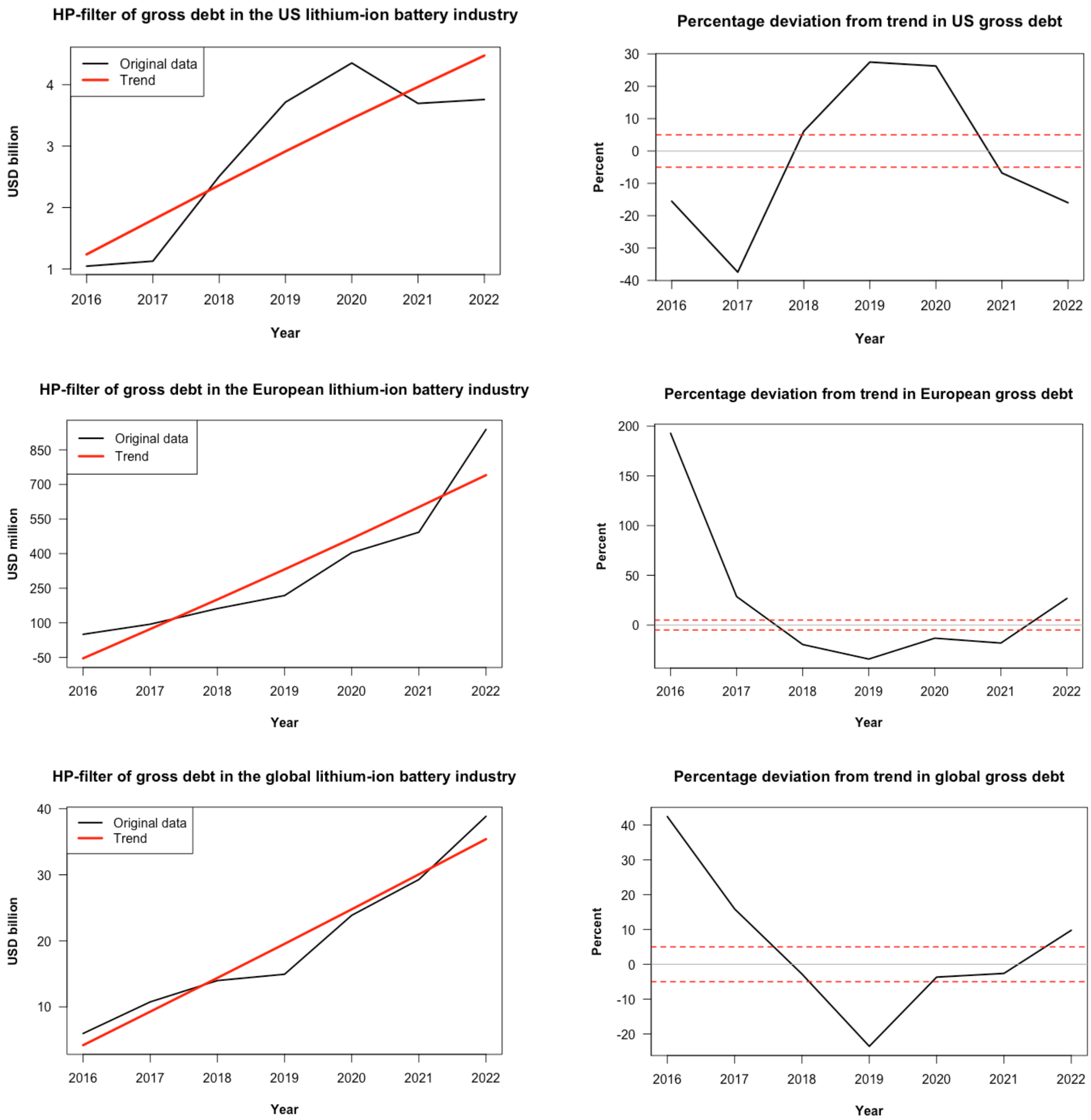
Table 5.5 provides an overview of the peak and trough cycle values of the total gross debt in the LIB sector in the respective regions. Europe exhibited the most extreme maximum value of 193 percent in 2016, occurring concurrently with the global market. However, endpoint values must be interpreted with caution. It is noteworthy that the peak observed in the US in 2019 coincides with the trough years in the European and global markets.

Table 5.5: Summary sector gross debt – cycle values as percentage deviation from the trend

Indicator	Data Range	Lambda	US		Europe		Global	
			Peak	**Trough**	**Peak**	**Trough**	**Peak**	**Trough**
Sector gross debt	2016-2022	100	28% (2019)	-37% (2017)	193% (2016)	-34% (2019)	42% (2016)	-24% (2019)

Based on the structural analysis of trend and cycle values in Figure 5.**6**, it is evident that the European market exhibits a closer adherence to the global trajectory, manifesting a convex shape. In contrast, the US market adheres to a concave curve.

Figure 5.6: HP filter and percentage cycle values of sector gross debt in the US, Europe and globally (Refinitiv Workspace, 2023)



5.2.3 Leverage

To examine the LIB market's proclivity towards a specific capital structure over time and its impact of leverage on bubble formation, the subsequent analysis delves into the development of leverage cycles.

The leverage ratio describes the relationship between debt and equity. A higher leverage ratio implies a greater reliance on debt. To scrutinise the leverage cycle in the LIB industry, the median leverage values are examined over time. The results are presented in Table 5.6 revealing the highest discrepancy in the US market and notable peaks across all markets in 2018. The trough values exhibit a slightly broader distribution between 2019 and 2021.

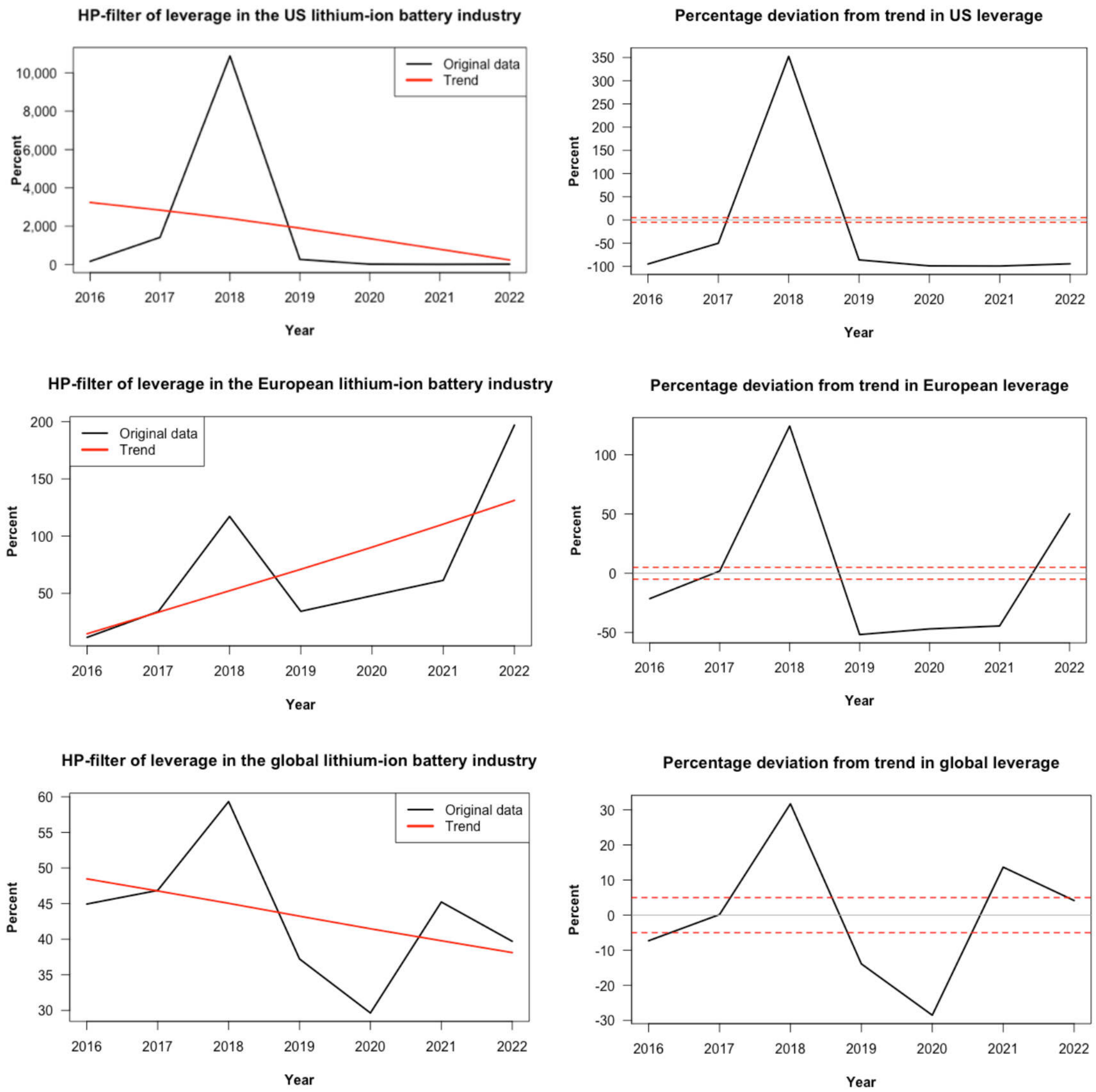
Table 5.6: Summary sector leverage – cycle values as percentage deviation from trend

Indicator	Data Range	Lambda	US		Europe		Global	
			Peak	**Trough**	**Peak**	**Trough**	**Peak**	**Trough**
Sector leverage	2016-2022	100	353% (2018)	-99% (2021)	124% (2018)	-52% (2019)	32% (2018)	-29% (2020)

As depicted in Figure 5.7, the leverage ratio displays a declining trend in the US and global markets, whereas it demonstrates an ascending trend in the European market. Supplementary to the peak noted in Europe in 2018, the leverage ratio witnessed a significant increase in 2022, reaching 50 percent above the long term trend, indicating an elevated proportion of debt in relation to equity. Within the global LIB market, the leverage ratio experienced a substantial descent below the long term trend in 2020, followed by an ascent of the long term trend in 2021, occurring one year prior to the local maximum observed in Europe.

Distinct cycle patterns are not evident in the US and Europe. In the global market, the analysed data range suggests a two-year cycle duration, illustrated by a boom cycle from 2017 to 2019 and a bust cycle from 2019 to 2021. Nevertheless, the limited time frame precludes definitive conclusions regarding cycle duration. Moreover, the stagnation observed in the leverage cycle post-2021 raises questions about the initial hypothesis. Given substantial fluctuations and an indistinct cycle pattern in leverage cycles, establishing a normative leverage level from this analysis remains inconclusive.

Figure 5.7: HP filter and percentage cycle values of sector leverage in the US, Europe and globally (Refinitiv Workspace, 2023)



6. Production

6.1 Industrial production index battery sector

The Industrial Production Index (IPI) for the battery sector serves as an indicator of production output in the battery market. Given that a bubble economy is characterised by stagnant production output alongside a persistent increase in asset prices significantly above sustainable trajectory, the IPI for the battery sector emerges as a critical indicator. It encompasses all types of batteries diluting the specificity of the indicator but still provides interesting findings related to production output in the LIB market. Commencing at a baseline of 100 in January 2000, the index tracks the evolution of value added until the end of June 2023.

Table 6.1: Summary industrial production index battery sector – cycle values as a percentage deviation from trend

Indicator	**Data Range**	**Lambda**	**US**		**Europe**	
			Peak	**Trough**	**Peak**	**Trough**
Industrial production index battery sector	Jan 2000-Jun 2023	14,400	15% (Sep 2000)	-28% (Apr 2020)	27% (Jun 2021)	-47% (Apr 2020)

Table 6.1 shows that the European market exhibits more volatile production cycles compared to the US market. Both regions experienced troughs in battery production in April 2020. The peak in the US was identified in September 2000, registering a 15 percent deviation from the established trend. While acknowledging the caution required in interpreting endpoints, the monthly frequency of the data suggests that the production output in September 2000 may indeed represent the actual peak within the analysed data range. In Europe, the peak is evident in June 2021, slightly over a year following the trough.

Figure 6.1 depicts stagnations in US sectoral economic growth between 2000 and 2004, and between 2015 to 2020. The production has experienced an approximate ten percent decline in the analysed period. The percentage cycle values exhibit a discernible pattern characterised by relatively similar peak and trough values over time, apart from the substantially lower trough value observed in April 2020.

Figure 6.1: HP filter and percentage cycle values of the IPI in the US (Refinitiv Workspace, 2023)

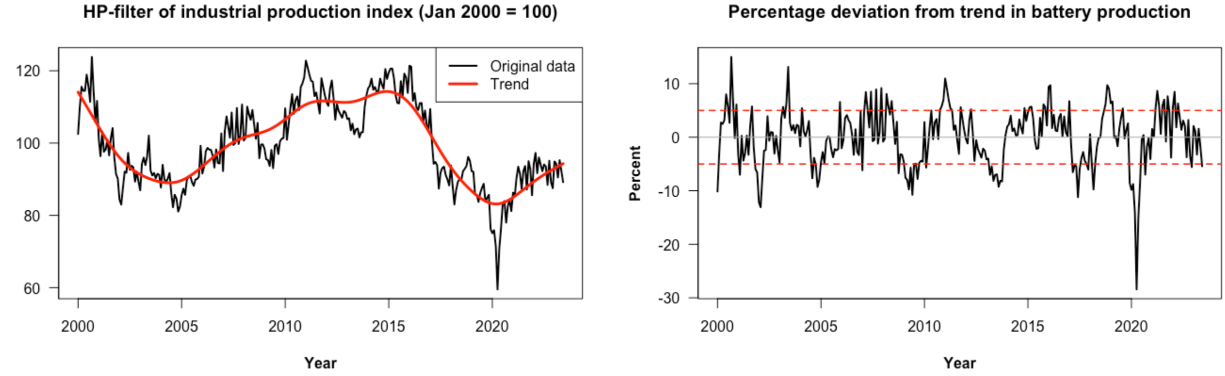
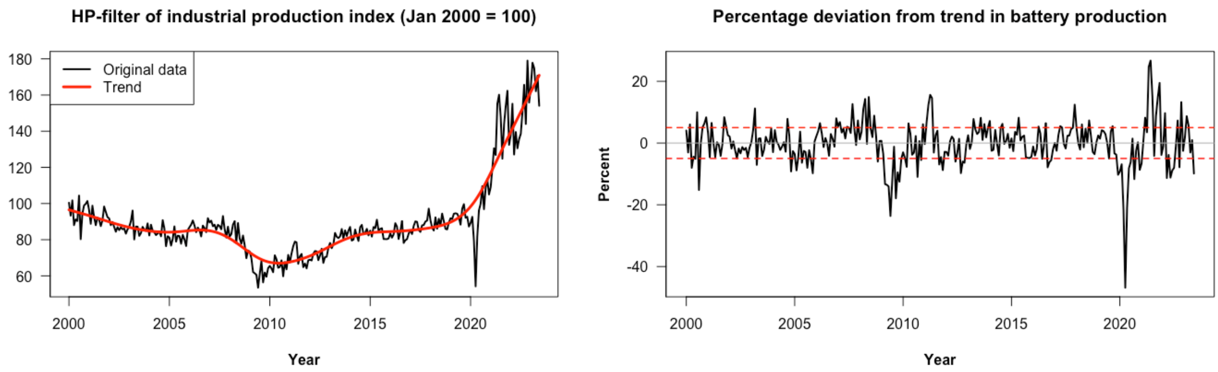


Figure 6.2 illustrates a noteworthy reduction in European production output, amounting to nearly 40 percent from 2000 to 2010, succeeded by a substantial increase of approximately 120 percent from the trough in 2010 to June 2023. The absolute cycle values tend to increase over time, supported by the observed peak and trough values in 2021 (27 percent) and 2020 (-47 percent), respectively.

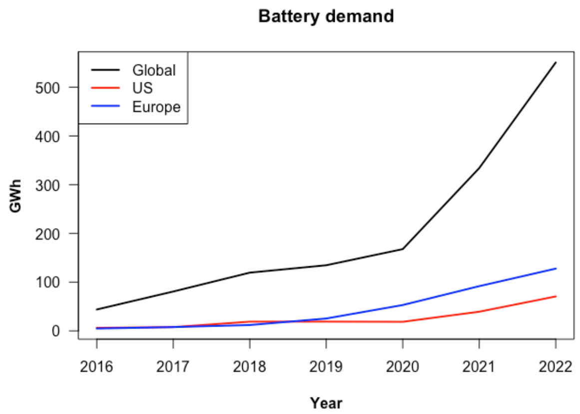
Figure 6.2: HP filter and percentage cycle values of the IPI in Europe (Refinitiv Workspace, 2023)



6.2 Demand

Figure 6.3 illustrates the scale of the global LIB market compared to the US and European markets. All markets witnessed a noteworthy surge in demand after 2022.

Figure 6.3: Evolution in battery demand in the US, Europe and globally (IEA, 2023a)



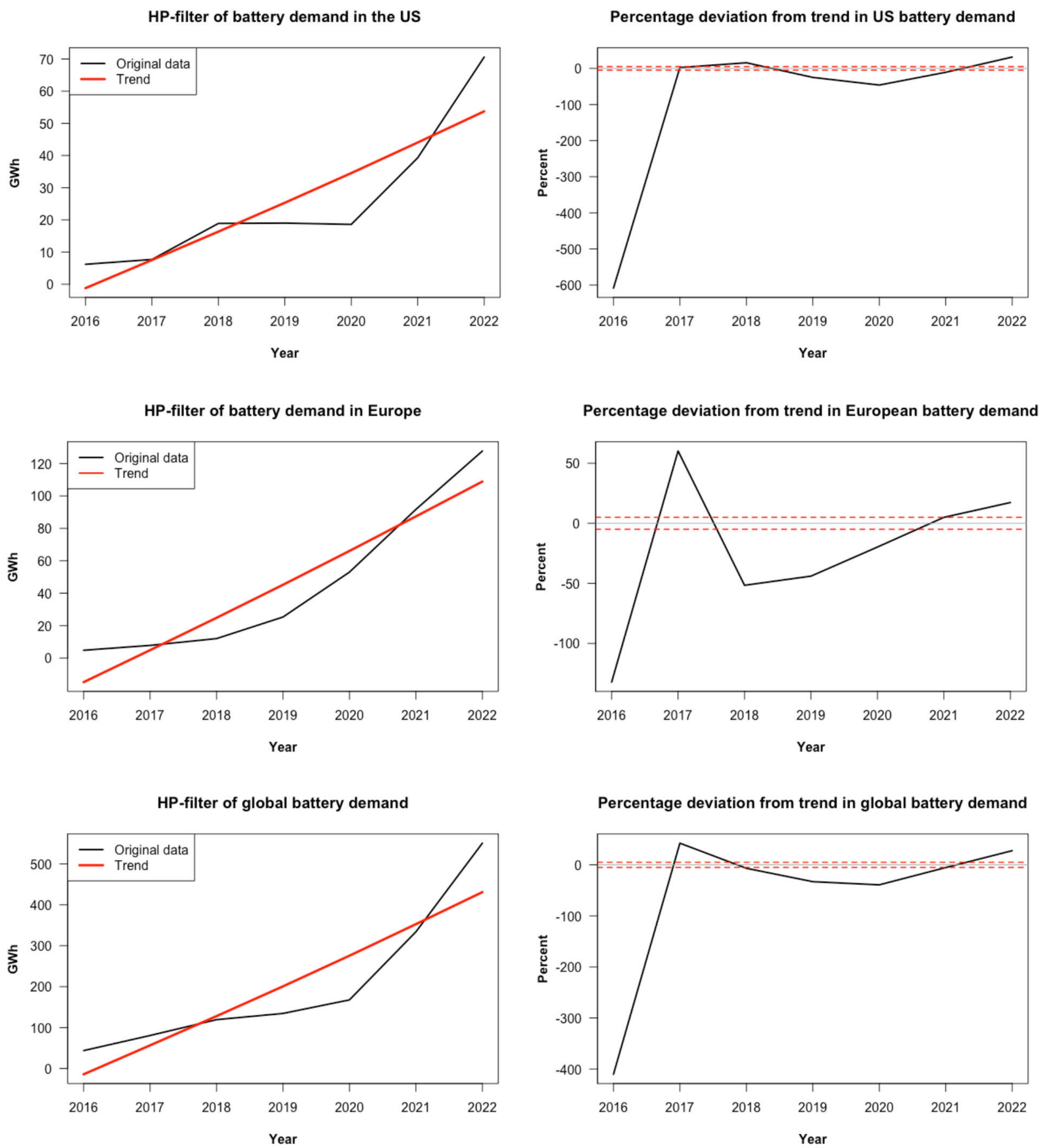
As indicated in Figure 6.3, trough cycle values were observed across all regions in 2016. Both the European and global markets witnessed the peak deviation from the trend in 2017, whereas the US market recorded a lower peak in 2022. As 2016 and 2022 represent the initial and final observations in the dataset, findings related to these years are susceptible to endpoint bias, thereby diminishing validity.

Table 6.2: Summary market concentration – cycle values as percentage deviation from trend

Indicator	Data Range	Lambda	US		Europe		Global	
			Peak	Trough	Peak	Trough	Peak	Trough
Demand	2016-2022	100	31% (2022)	-609% (2016)	60% (2017)	-132% (2016)	42% (2017)	-410% (2016)

The results in Figure 6.4 indicate a demand level approximately 50 percent below the long term trend from 2018 to 2020 in the European and global markets, and from 2019 to 2020 in the US market. Both the global and US markets underwent a noticeable escalating growth rate after 2020, while the European market has seen a more gradual acceleration in demand growth.

Figure 6.4: HP filter and percentage cycle values of shares outstanding (IEA, 2023a)



6.3 Asset prices

6.3.1 Lithium-ion battery prices

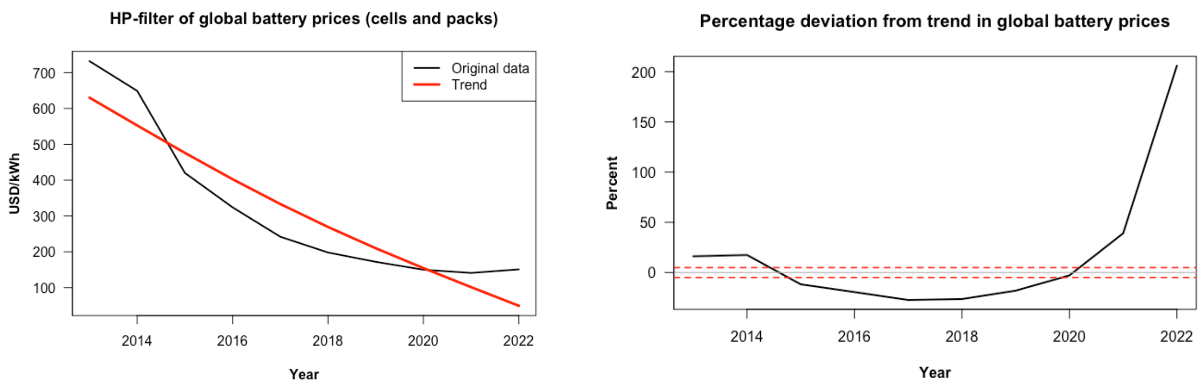
The global price of LIB, including both cells and packs, has decreased by nearly 80 percent from 2013 to 2022. The presented LIB prices are adjusted for inflation to reflect real USD values as of 2022. The LIB prices have exhibited notable deviations from the long trend, as detailed in Table 6.3.

Table 6.3: Summary real battery price – cycle values as percentage deviation from trend

Indicator	Data Range	Lambda	Global	
			Peak	**Trough**
Battery price	2013-2022	100	206% (2022)	-27% (2017)

Figure 6.5 illustrates a more gradual decline in LIB prices post-2017. The first year-over-year increase in LIB prices was observed in 2022 to be approximately seven percent, significantly influencing the cycle value of the corresponding year.

Figure 6.5: HP-filter and percentage cycle values of real global battery prices (Statista Research Department, 2023)



6.3.2 Mineral prices

The analysis of mineral prices aims to investigate the relationship between price fluctuations of critical minerals and batteries. Mineral prices are determined by various metal exchanges globally, with the IMF's global benchmarks, reflecting the largest import market, serving as a reference for examining the global mineral trends (IMF, 2023b). As explained in Section 3.2.1, minerals like lithium, cobalt, nickel, and manganese, are integral to the production of NMC batteries, the dominant chemistry in the Western market, and will be considered in the structural time series analysis.

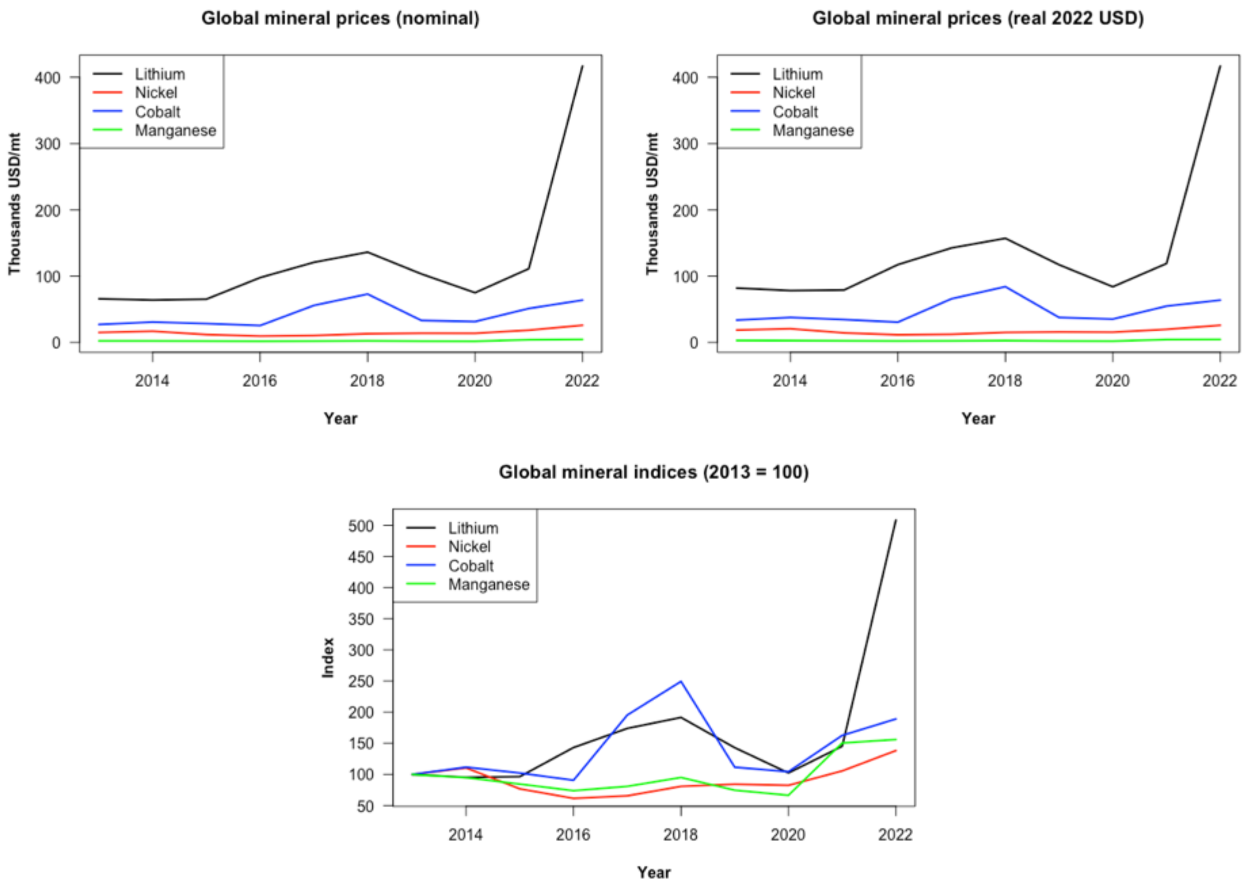
Table 6.4: Summary mineral prices – cycle values as percentage deviation from trend

Indicator	Data Range	Lambda	Global	
			Peak	**Trough**
Lithium	2013-2022	100	73% (2022)	-55% (2020)
Cobalt	2013-2022	100	69% (2018)	-35% (2020)
Nickel	2013-2022	100	32% (2014)	-27% (2016)
Manganese	2013-2022	100	28% (2021)	-39% (2020)

By investigating the results presented in Table 6.4, it is evident that lithium exhibits the highest degree of variation, reaching a peak of 73 percent in 2022 and experiencing a negative deviation of 55 percent in 2020. Additionally, both cobalt and manganese prices displayed their lowest values in 2020.

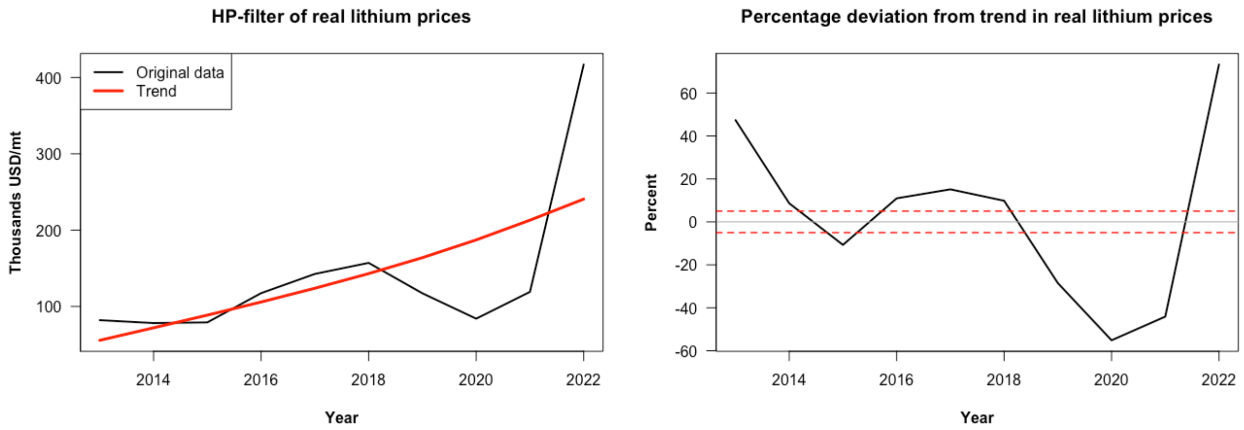
Converting nominal mineral prices to US dollars as of 2022 enhances the significance of the local peak observed in both lithium and cobalt prices in 2018. However, the most noteworthy finding for further analysis is the global maximum in lithium prices of USD 416,958 per metric ton (mt) in 2022, where lithium prices quadrupled between 2020 and 2022. Nevertheless, the price increases in cobalt (81 percent), nickel (68 percent), and manganese (135 percent) are also prominent.

Figure 6.6: Evolution in global mineral prices from 2013-2022 (IMF, 2023b)



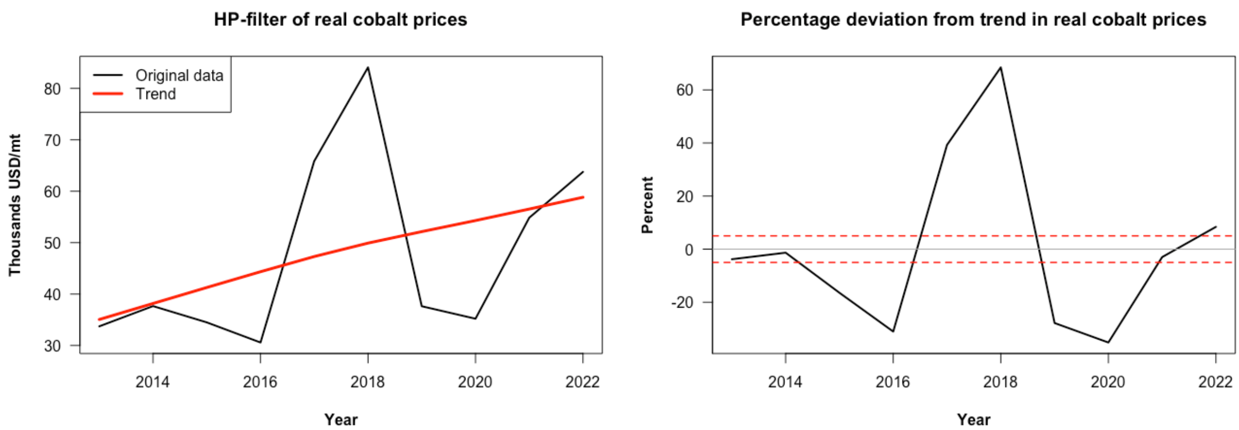
Conducting the structural analysis in Figure 6.6 reveals significantly negative deviations from the long term trend from 2019 to 2021, and significantly positive deviations from the long term trend in 2013, 2016 to 2018, and 2022. A comparative assessment of lithium and LIB prices indicates positive deviations from the trend in both variables in 2013 and 2022. However, LIB and lithium prices demonstrate countercyclical development between 2016 and 2018.

Figure 6.7: HP filter and percentage cycle values of real lithium prices (IMF, 2023b)



The cobalt prices demonstrate two contracting cycles with negative deviations below -20 percent: the first from 2015 to 2016 and the second from 2019 to 2020. Moreover, there was a noteworthy surge in cobalt prices from 2017 to 2018, resulting in a 69 percent deviation from the long term trend. This observation implies that the negative cycle in battery prices during the same period was not influenced by the irregularly high cobalt prices.

Figure 6.8: HP filter and percentage cycle values of real cobalt prices (IMF, 2023b)



The cycle values in nickel prices exhibit a pattern closely aligned with the cycles in LIB prices from Figure 6.9, revealing notable positive deviations in 2013 and 2014, as well as in 2022. The figure also illustrates a period of significant negative cycle values from 2015 to 2020.

Figure 6.9: HP filter and percentage cycle values of real nickel prices (IMF, 2023b)

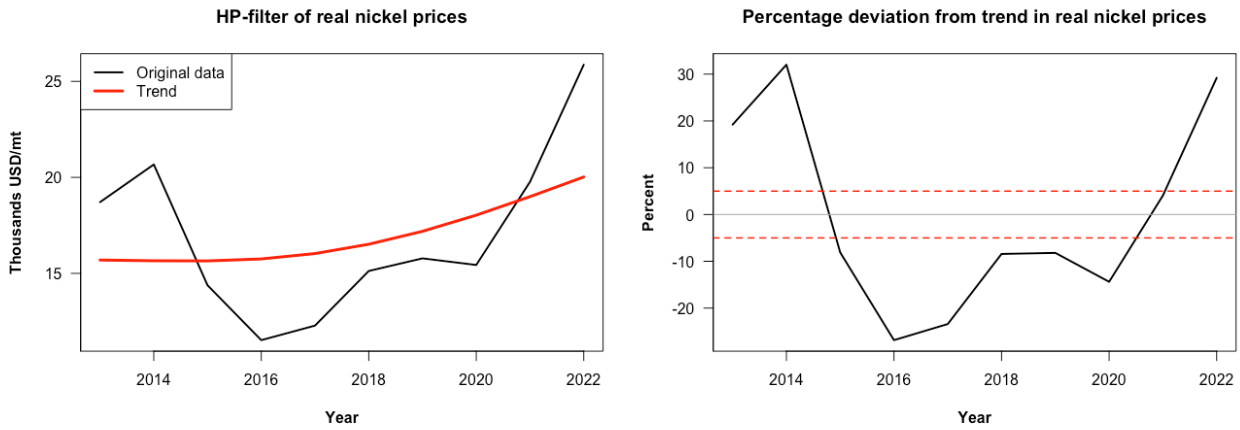
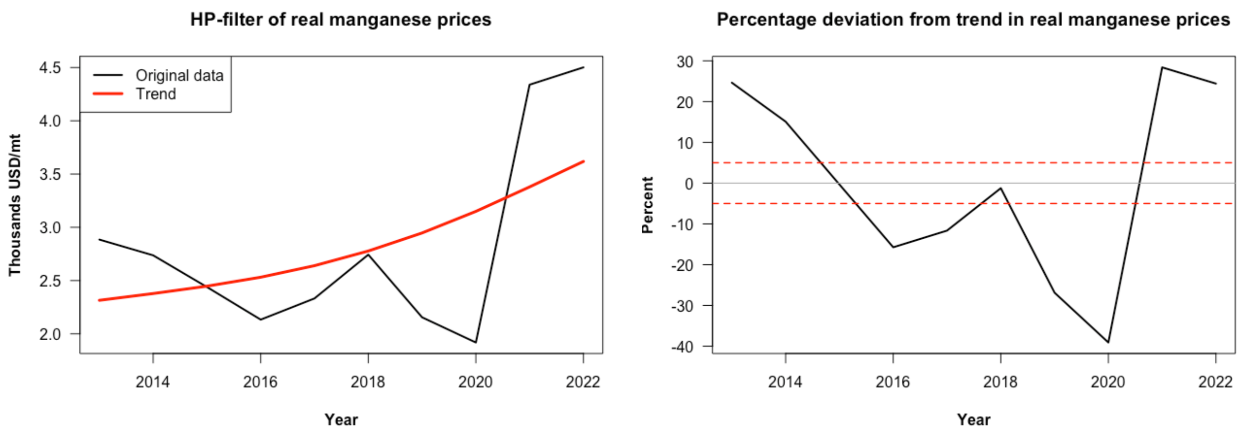


Figure 6. showcases a reduction in manganese prices from roughly 3,000 USD/mt in 2013 to approximately 2,000 USD/mt in 2020. The substantial upswing in manganese prices from 2020 to 2022 indicates an overall positive trend in manganese prices despite the slightly negative trend prior to 2021. The most salient observation from the accompanying cycle diagram is the swift transition from a substantial negative deviation from the trend in 2020 to a significant positive deviation in the preceding year of 2021.

Figure 6.10: HP filter and percentage cycle values of real manganese prices (IMF, 2023b)



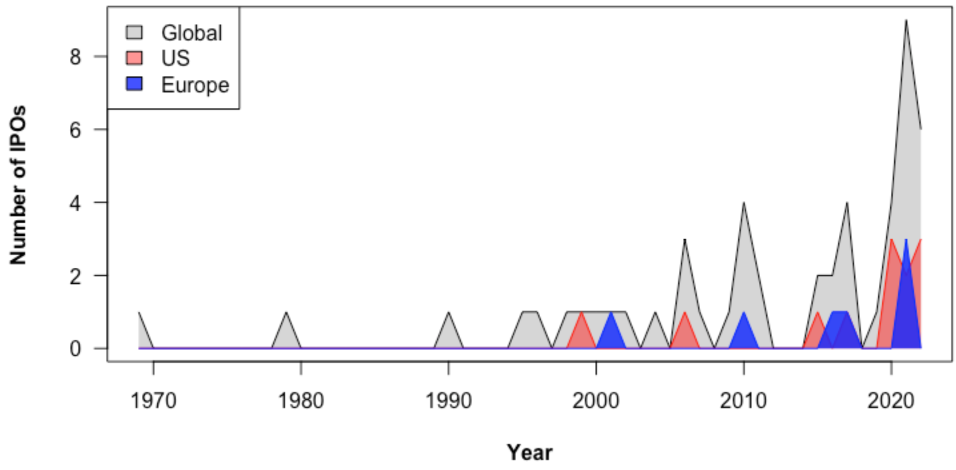
All examined mineral prices exhibit a positive trend evolution with numerous noteworthy cycle values within the analysed data range. The trajectories of LIB and mineral prices exhibit contrasting directions, and the cycle values do not align to a significant extent.

7. Stock market

7.1 Market concentration

In this section, the evolution in market concentration in public LIB companies are examined to acquire a deeper understanding of the stock market dynamics. The investigation considers the evolution in IPOs, cumulative number of public companies, number of shares outstanding, and delistings.

Figure 7.1: IPO evolution in the LIB industry from 1969 to Q2 2023 in the US, Europe and globally (Refinitiv Workspace, 2023)



The Japanese LIB company, FDK Corp, was listed in 1969 and the first IPO in the analysed data range. Ten years after, Samsung SDI Co. Ltd. went public on the Korea Exchange in 1979, followed by the Indian listing of Panasonic Energy Co. Ltd. in 1990, as depicted in Figure 7.1. The first company to go public in the US was Flux Power Inc. in 1999, followed by the first European listing in 2001 of Seri Industrial S.p.A. The number of IPOs after the 2000s has increased, showing peaks in the global and European markets in 2021, as well as peaks in the US with two IPOs in 2020 and 2022.

From Table 7.1, the US exhibits the highest variance in cycle values. Notably, the global market experienced its peak and trough earlier in the data range compared to both the US and European markets.

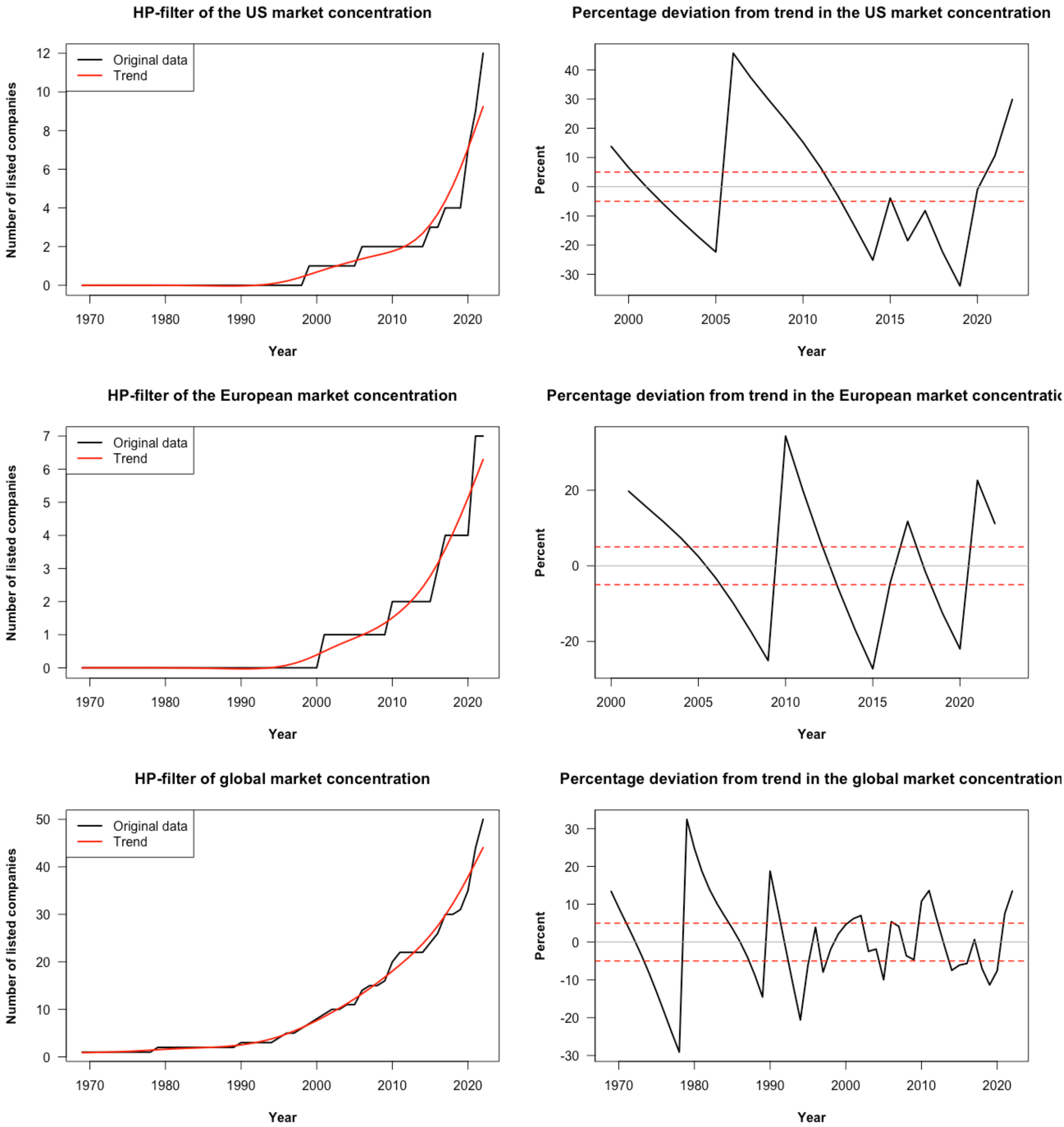
Table 7.1: Summary market concentration – cycle values as percentage deviation from trend

Indicator	Data Range	Lambda	US		Europe		Global	
			Peak	**Trough**	**Peak**	**Trough**	**Peak**	**Trough**
Market concentration	2016-2022	100	46% (2006)	-34% (2019)	34% (2010)	-27% (2015)	33% (1980)	-29% (1978)

As Figure 7.2 illustrates, all regions have experienced exponential growth in market concentration among public companies. The global cycle values have larger fluctuations early in the analysis period and decrease over time. There have been roughly 20 new listings in the global market from 2020 to 2022, with a cycle value revealing an approximate ten percent deviation from the trend in 2022. Additionally, the global market experienced a significant deviation from the trend in 1980, 1990, and 2010 of approximately 30, 20, and ten percent respectively.

The US market has experienced a tripling in public companies in the market from 2020 to 2022 with an accompanying cycle value exceeding 20 percent in 2022. The negative deviation from the trend in 2020 suggests unfavourable market conditions for new establishments. The significant positive cycle value in 2006 of approximately 40 percent must be interpreted with caution as a small number of observations early in the data range may affect the cycle values. The findings show that marginal changes in nominal values early in the data range provide huge fluctuations. The biggest leap in new listings in the European market was observed in 2021, nearly doubling the number of battery companies in the region, resulting in an approximate 20 percent positive deviation the from trend.

Figure 7.2: HP filter and percentage cycle values of market concentration (Refinitiv Workspace, 2023)



The quantity of outstanding shares reflects the equity supply within the LIB stock market. The results in Table 7.2 reveal substantial deviations in the number of shares outstanding. The analysis utilises three different lambda values to examine the smoothing effect on daily observations. Conducting the analysis on various lambda levels provides a broader perspective regarding the implications of the findings. The peak of trough cycle values observed in Europe attract significant attention, surpassing 60 percent and -70 percent for all lambda values. Despite these substantial cycle values, the differences across the three lambda values are moderate, approximately four percent at most. In contrast, the US exhibits a difference exceeding ten percent between lambda values of $100K$ and $1B$. Global values show less variation in both cycle values with fixed lambda values and when employing different lambda values.

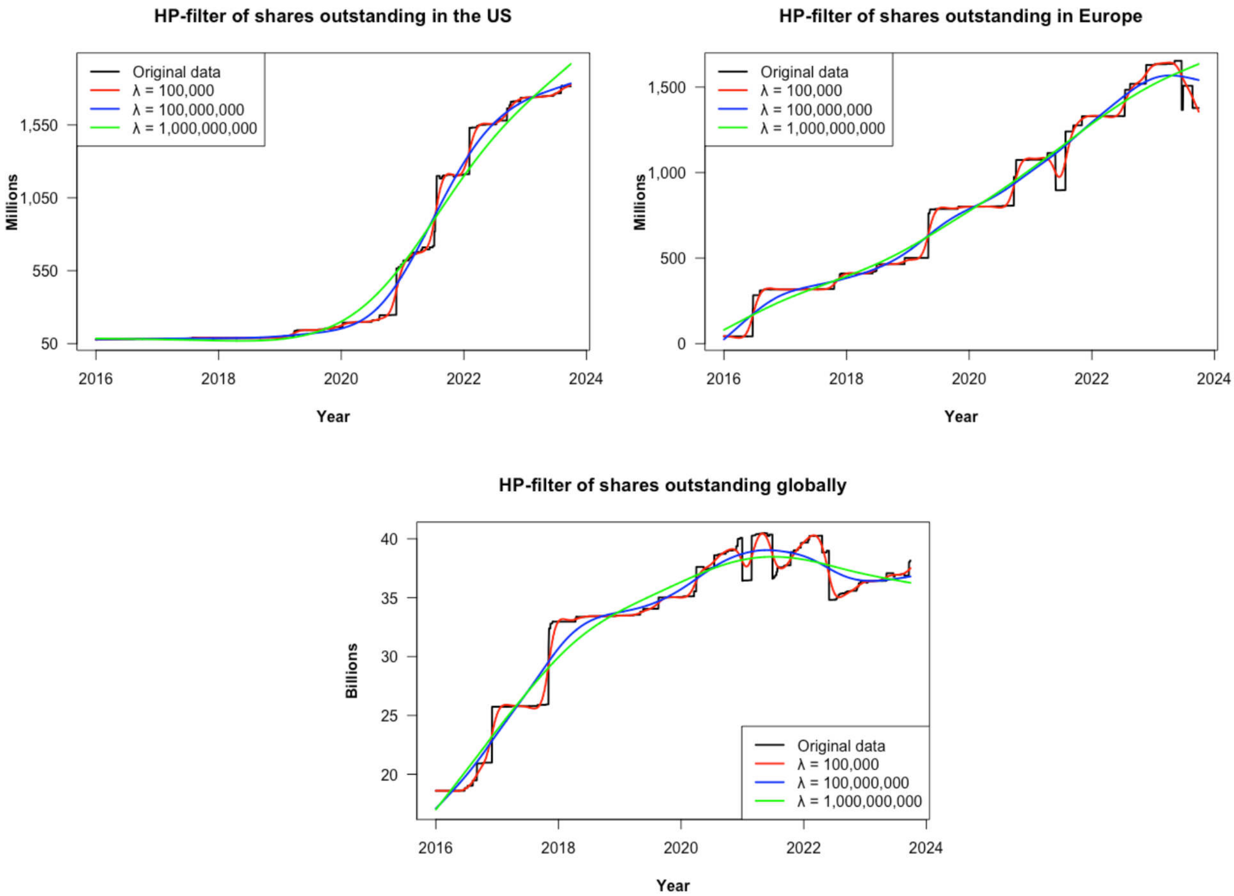
Table 7.2: Summary market concentration – cycle values as percentage deviation from trend

Indicator	Data Range	Lambda	US		Europe		Global	
			Peak	Trough	Peak	Trough	Peak	Trough
Shares outstanding	01.01.2016-29.09.2023	100,000	36%	-40%	63%	-73%	10%	-11%
		100,000,000	29%	-45%	67%	-75%	13%	-12%
		1,000,000,000	48%	-54%	67%	-75%	12%	-11%

Figure 7.3 shows a positive trend in shares outstanding in the US market with the most significant deviation from the trend observed in the second half of 2021. The European market has an overall positive, almost linear, trend, with the most notable deviations in 2019, 2021, and the first half of 2023. The following interpretation must be taken with precautions as it is an endpoint, but the decline in shares outstanding at the end of the analysed data range suggests a market correction in Europe. Globally, the number of outstanding shares had a positive development until 2021, when the HP filters showed a decline.

From January 2016 to September 2023, there has been no evidence of delisting or bankruptcies within the LIB sector.

Figure 7.3: HP filter and percentage cycle values of shares outstanding (Refinitiv Workspace, 2023)



7.2 Lithium-ion battery company index (BCI)

This section presents the findings of statistical analysis of various lithium-ion BCIs, which serve as indicators for assessing the performance within this industry. The indices include the BCI International, West, US, and Europe.

Figure 7.4: Developments in BCIs: West, US, Europe, and International (Refinitiv Workspace, 2023)

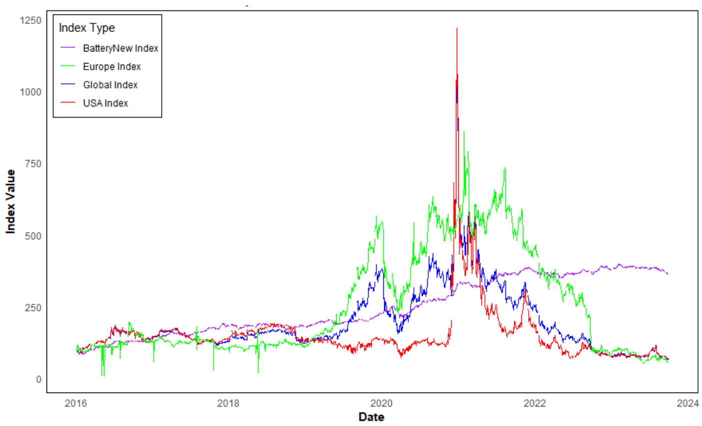
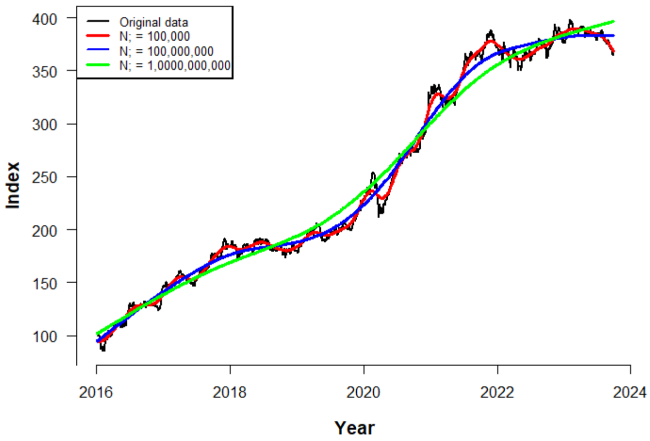


Figure 7.4 graphically portrays the trajectories of the BCIs from the 4th of January 2016 to the 29th of September 2023. It manifests the comparative performance and volatility of each index, with notable fluctuations, especially from 2019 to 2022. In subsequent sections, extended findings in the HP filtration of the BCIs' development and comparison of the BCIs against comparative indicators such as GDP and media trends, in addition to other sectorial or geographical indices, will be presented. Like the analysis of Shares Outstanding and Market Concentration (Section 7.1), a usage of three different lambda values in the HP filtration of the BCIs will be employed.

7.2.1 International

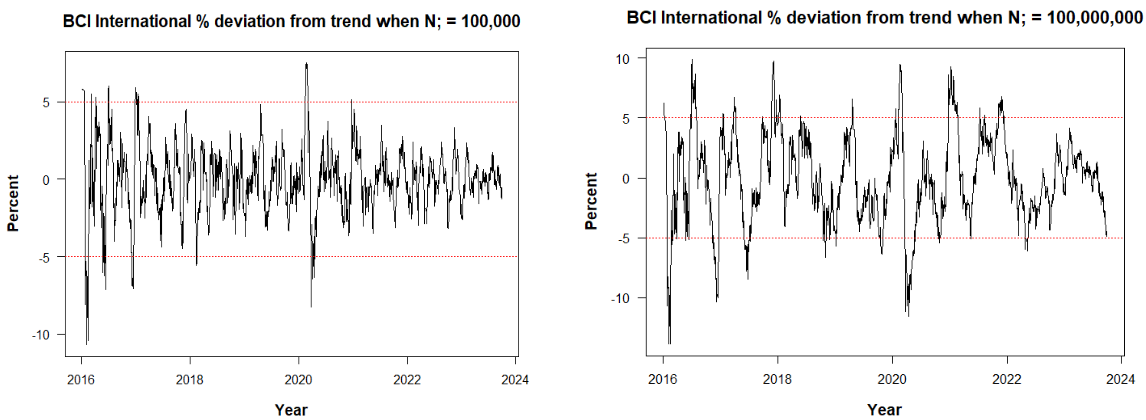
The analysis of BCI International, encapsulating the performance of 50 companies operating within the global LIB market, illustrates a consistent upward trajectory in the index value over time from 2016 to 2023.

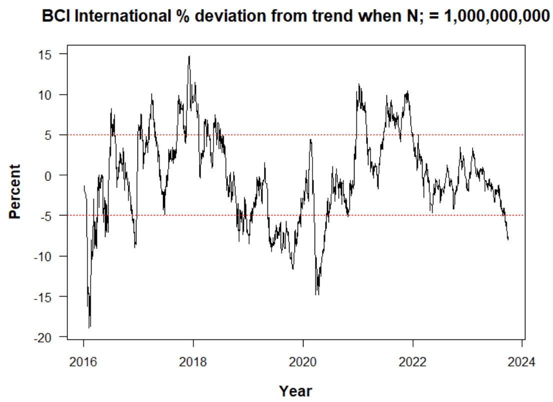
Figure 7.5: HP filtration of the BCI International (Refinitiv Workspace, 2023)



As observed in Figure 7.6, BCI International's deviations from the trend have variations within a margin of less than ten percent in the years 2020, 2021, and 2022. Table 7.3 provides a summary of the maximum and minimum deviations from the trend for BCI International using different lambda values. Notably, as the lambda values increase, the range of deviations in the BCI International also widens. With $\lambda = 100K$, the year 2016 is noted as a year of significant fluctuation, displaying both the highest and lowest deviations. In this setting, 2016 again marks a period with peak and trough deviations. Further increasing the lambda to $1B$ results in even larger deviations, with the maximum deviation seen in 2018 and the minimum in 2016.

Figure 7.6: BCI International deviations from trend with lambda = 100k, 100m, and 1B (Refinitiv Workspace, 2023)

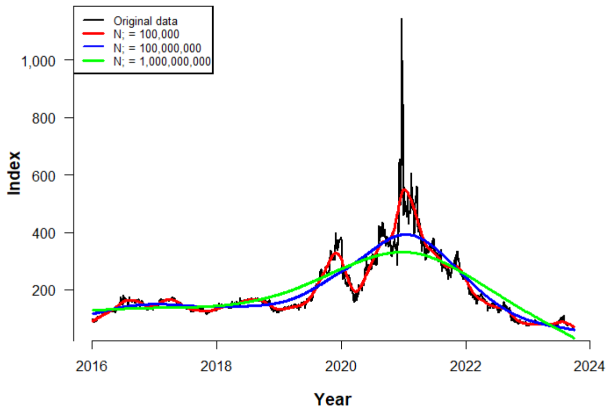




7.2.2 West

The Western BCI's trajectory, as depicted in Figure 7.7, was marked by stability and modest growth until the end of 2019. A transition is observable commencing in late 2020 where the index exhibits a pronounced increase in volatility.

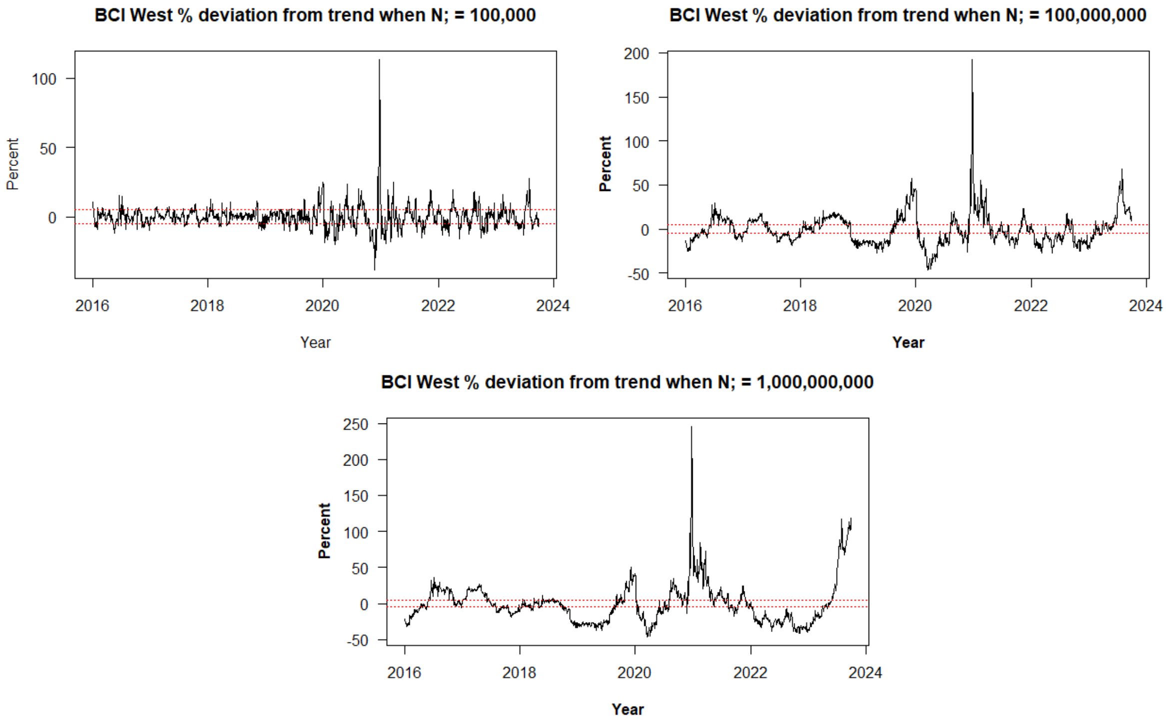
Figure 7.7: HP filtration of BCI West (Refinitiv Workspace, 2023)



This change in the index's behaviour is further illustrated by the variations in peak and trough deviations at different lambda values. For example, at a lower lambda ($\lambda = 100K$), the peak deviation was substantial in 2921, while the corresponding trough in 2020 was also notable. As the lambda values increases to $100M$ and $1B$, the peaks and troughs become more pronounced, indicating steeper increases and deeper declines.

The observed deviation from trend in 2021 rose significantly from 192 to 245 percent as the lambda value was increased, reflecting a higher level of volatility in the index. This trend of increasing peaks and troughs with higher lambda values signifies a greater sensitivity and fluctuation of the Western BCI, especially in the period post-2019, highlighting a shift towards more volatile market conditions.

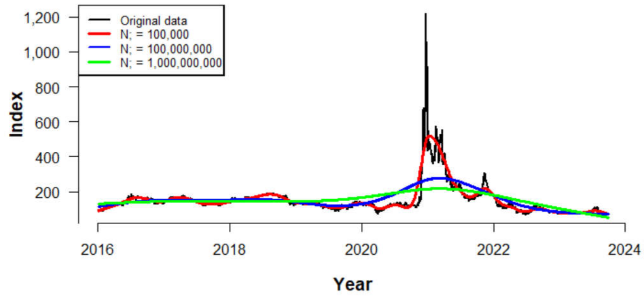
Figure 7.8: BCI West deviation from trend when lambda = 100k, 100m and 1B (Refinitiv Workspace, 2023)



7.2.3 The United States

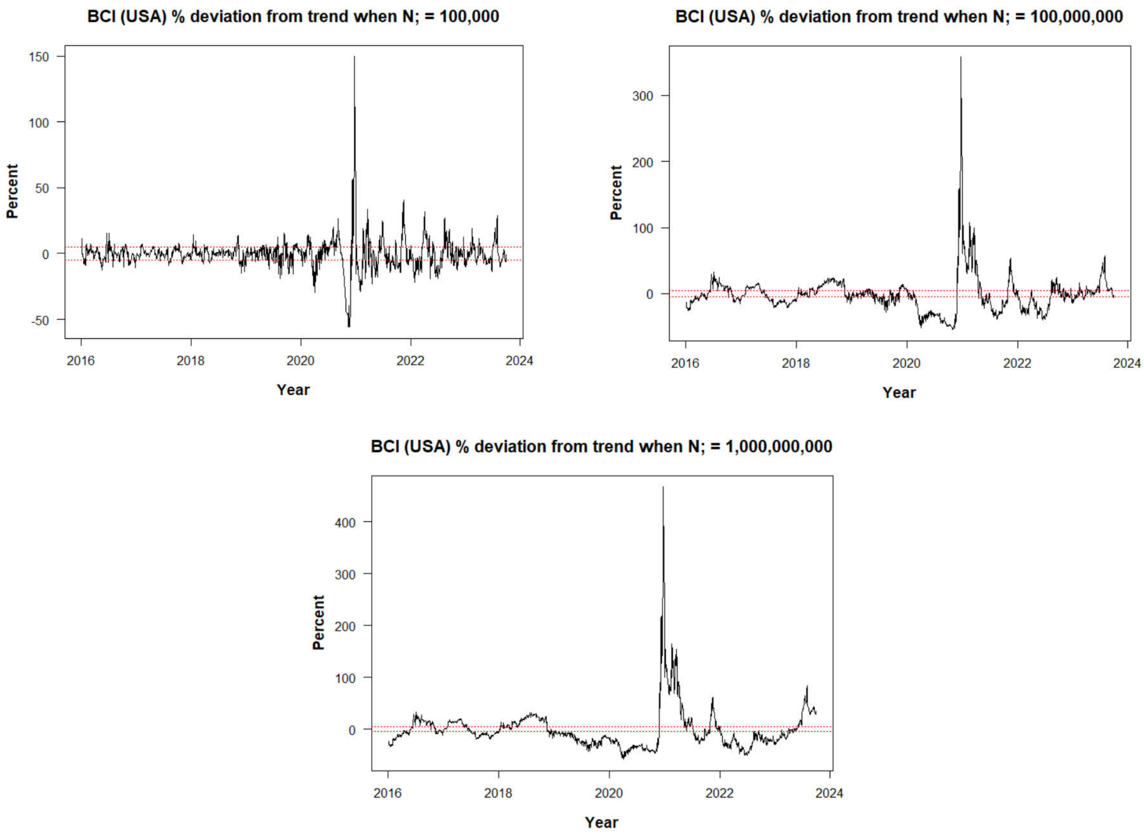
The BCI US, which aggregates the stock performance of publicly listed LIB companies on the Nasdaq and NYSE, has demonstrated significant volatility. This is illustrated in Table 7.3 and Figure 7.9. Like the BCI West, the index displays low variations until 2019, where the index fluctuates in a short timeframe.

Figure 7.9: HP filtration of BCI US (Refinitiv Workspace, 2023)



The analysis across different lambda values reveals that the years 2020 and 2021 emerge as periods of notable volatility in the analysis of BCI US. This year stands out for having both the highest peaks and lowest troughs. At a $\lambda = 100K$, there was a notable maximum deviation in late 2020, and a significant minimum deviation in early 2021. This variation within a brief period highlights the intense volatility during this time. As the lambda values increase, the extent of these fluctuations becomes more marked. The highest lambda value used in the analysis resulted in a dramatic increase in the peak in 2020. Concurrently, the trough in 2021 also displayed significant variations, though they were slightly less extreme compared to the peaks.

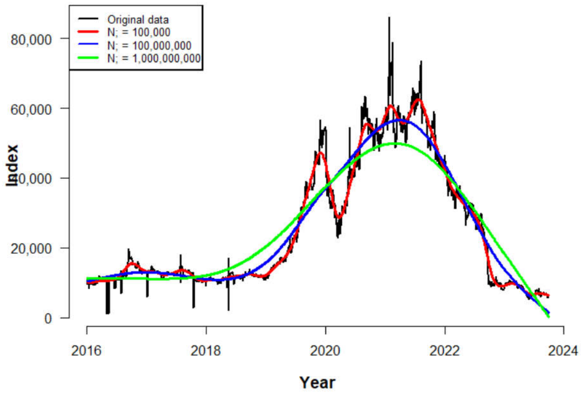
Figure 7.10: BCI US deviation from trend with lambda = 100K, 100M, and 1B (Refinitiv Workspace, 2023)



7.2.4 Europe

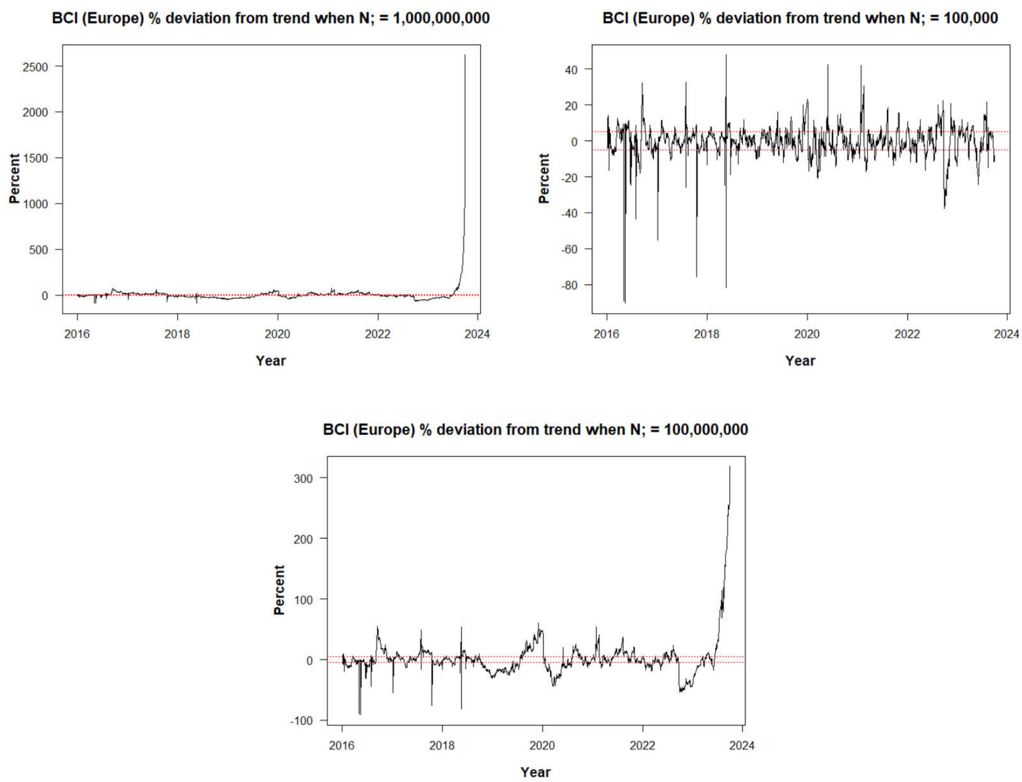
The BCI Europe consists of seven publicly listed European companies. While graphically illustrating this index while applying the HP filter and analysing the deviation from trend, the findings will be presented in this section.

Figure 7.11: HP filtration of BCI Europe (Refinitiv Workspace, 2023)



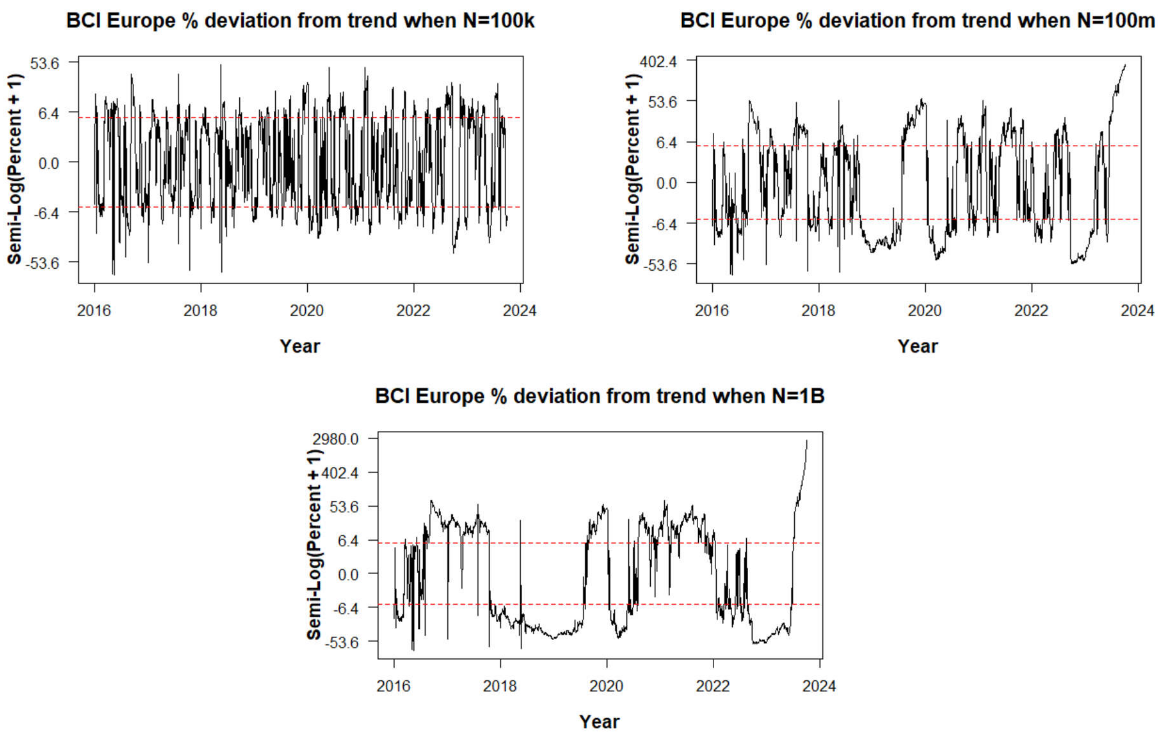
When the BCI Europe was analysed using $\lambda = 100K$, a substantial peak was observed in 2018 and a deep trough in 2016. Increasing the lambda value to $100M$, revealed an even more dramatic peak in 2023, while the trough in 2016 remained notably low. Further elevating the lambda to $1B$ showed an even more pronounced peak in 2023, with the trough marginally adjusting in 2016.

Figure 7.12: BCI Europe deviation from trend with lambda = 100K, 100M, and 1B (Refinitiv Workspace, 2023)



The presentation of data in a semi-logarithmic format was necessitated due to the extensive range of deviations, especially the vast peak observed with the highest lambda value. Such a scale helps in effectively visualising data that spans several orders of magnitude, which is particularly useful when dealing with percentage changes that can experience exponential growth or decay. The semi-logarithmic depiction allows for a clearer comparative analysis of the variations over time and provides a more intuitive understanding of proportional changes, especially when the data includes both large positive and negative values.

Figure 7.13: BCI Europe deviation from trend semi-logarithmic with lambda = 100K, 100M, and 1B (Refinitiv Workspace, 2023)



7.2.5 BCI comparison

Figure 7.14: Development of the BCIs, West, US, Europe, and International (Refinitiv Workspace, 2023)

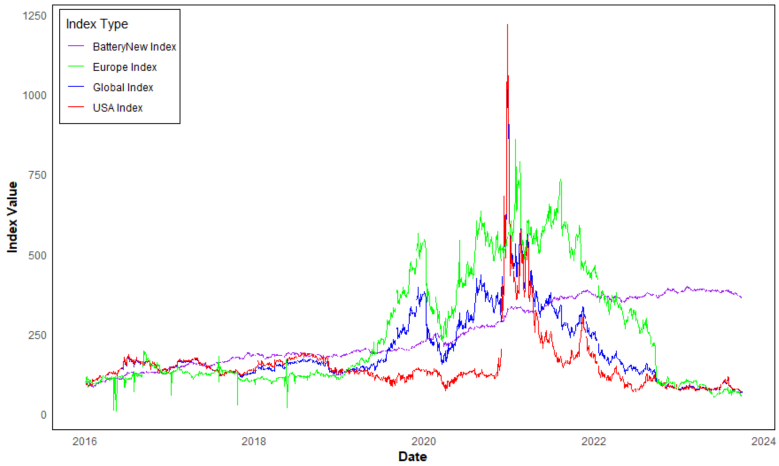


Figure 7.14 illustrates the progression of all BCIs. The BCI West is distinguished by a notable maximum positive deviation exceeding 100 percent across all lambda values in the year 2021. In contrast, the BCI International index is characterised by markedly smaller deviations, with a peak at ten percent and a trough at -11 percent for a $\lambda = 100K$, suggesting a more stable market. The BCI US experienced a period of intense volatility in 2020 and 2021, although this period was relatively short-lived compared to other indices. The BCI Europe, particularly in 2023, shows a highly significant positive deviation from the trend for a $\lambda = 1B$, a value that could be reflective of unique market events or data endpoint anomalies.

When contrasting BCI West with BCI International, the former demonstrates marked fluctuations in 2021, with a maximum deviation of 113 percent, against the latter's more stable and conservative disposition.

7.2.6 Comparison to other indices

Researching and comparing different market indices, particularly in the dynamic sectors of LIB manufacturing and renewable energy, is vital for grasping investor sentiment and understanding market dynamics. A comparative analysis with other indices such as the S&P 500, EuroStoxx 50, and Nasdaq 100, reveals that these broader market indices do not exhibit deviations surpassing 22 percent at any lambda level, unlike the BCI West's peak of 245 percent. This suggests that broader market indices respond to general market trends as opposed to sector-specific developments, indicative of their diversified nature. Similarly, when comparing the BCI West to the Nasdaq Global Clean Energy Index and the European Renewable Energy Price Index, the deviations are significant but not as pronounced as those of the BCI West, reflecting a heightened market sensitivity to sector-specific developments.

In summary, the BCI West's volatility markedly surpasses comparable indices', whether they are aligned geographically or sectoral, showcasing significantly higher peaks and deeper troughs.

Table 7.3: Summary of indices – Comparison of maximum and minimum deviations, BCIs and similar indices (Refinitiv Workspace, 2023)

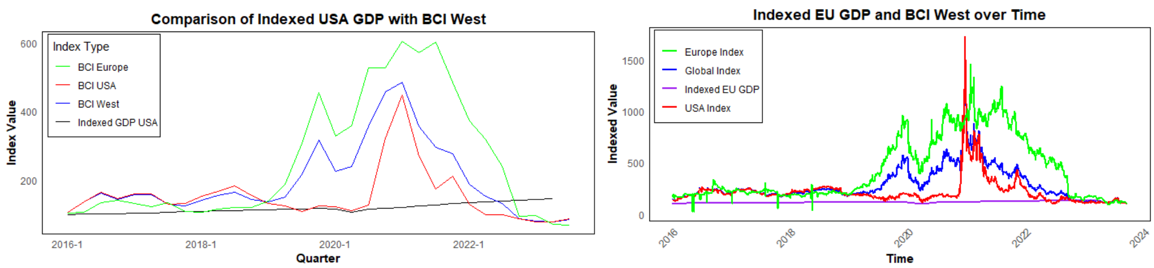
Index	Choice of Lambda	Max	When Max	Min	When Min
BCI West	100,000	113%	2021	-38%	2020
	100,000,000	192%	2021	-46%	2020
	1,000,000,000	245%	2021	-46%	2020
BCI US	100,000	150%	2020	-56%	2021
	100,000,000	358%	2020	-55%	2021
	1,000,000,000	467%	2020	-59%	2021
BCI Europe	100,000	47%	2018	-91%	2016
	100,000,000	318%	2023	-91%	2016
	1,000,000,000	26,211%	2023	-91%	2016
BCI Global	100,000	10%	2016	-11%	2016
	100,000,000	12%	2016	-19%	2016
	1,000,000,000	13%	2018	-25%	2016
S&P 500	100,000	11%	2020	-21%	2020
	100,000,000	11%	2022	-28%	2020
	1,000,000,000	16%	2022	-31%	2020
EuroStoxx 50 Index	100,000	13%	2020	-22%	2020
	100,000,000	16%	2020	-29%	2020
	1,000,000,000	14%	2022	-31%	2020
Nasdaq 100	100,000	12%	2020	-16%	2020
	100,000,000	16%	2022	-25%	2020
	1,000,000,000	23%	2022	-29%	2020
	100,000	22%	2020	-28%	2020

Nasdaq Global Clean Energy Index	100,000,000	16%	2021	-44%	2020
	1,000,000,000	64%	2021	-53%	2020
European Renewable Energy Price Index	100,000	16%	2021	-19%	2020
	100,000,000	41%	2021	-29%	2020
	1,000,000,000	51%	2021	-33%	2020

7.2.7 Comparison of BCIs and key macroeconomic indicators

This section undertakes an analytical comparison of the BCIs and key macroeconomic indicators, primarily GDP and M2. The rationale for this comparison is founded on the premise that these indicators may reflect potential economic overheating.

Figure 7.15: Comparison - Index GDP US and Europe compared with BCIs (Refinitiv Workspace, 2023)



Accompanying the visual comparison in Figure 7.15, Table 7.4 quantitatively assesses the correlation between the BCIs and the M2 or GDP from both the US and the EU. The correlation coefficients are as follows:

Table 7.4: Summary – Correlation BCIs and M2 or GDP (European Central Bank, 2023) (Federal Reserve Bank of St. Louis, 2023) (Refinitiv Workspace, 2023)

Indicator	**BCI West**		**BCI US**		**BCI Europe**		**BCI International**	
M2 US	0.276	Low correlation	0.089	Low correlation	0.526	Moderate correlation	0.994	Very high correlation
M2 EU	0.175	Low correlation	0.001	Low correlation	0.403	Low correlation	0.993	Very high correlation

GDP US	0.007	Low correlation	-0.118	Low correlation	0.239	Low correlation	0.951	Very high correlation
GDP EU	0.156	Low correlation	0.002	Low correlation	0.156	Low correlation	0.863	High correlation

The correlations indicate a predominantly low synchrony between BCI West, BCI US, and BCI Europe with economic activities within their respective regions, suggesting an insensitivity to domestic economic policies and market dynamics. In stark contrast, BCI International correlates strongly with both US and EU GDP, implying a close tracking of global economic activities and a significant influence from worldwide market trends and conditions.

Given these correlations, it is apparent that BCI West, the US, and Europe do not move in lockstep with GDP and M2, alluding to their limited reactivity to shifts in economic policy and market dynamics. Conversely, the pronounced correlations of BCI International with these economic indicators highlight its greater alignment with global economic movements.

It is crucial to interpret these correlation coefficients with precaution, recognising that while they serve as useful statistical measures, they only provide a narrow glimpse into the intricate relationships between the indices and economic measures like M2 or GDP. A more nuanced analysis of the BCIs necessitates the consideration of additional indicators and analytical approaches.

7.2.8 Comparison of BCIs and equity indices

The examination of BCIs in relation to equity indices seeks to elucidate the relationships between specialised market sectors and broader market movements. This analysis encompasses four indices from the US market and three from the European market, selected based on sectoral relevance and geographical representation.

Table 7.5: Comparison of other US indices and BCIs (Refinitiv Workspace, 2023)

Indicator	S&P 500		Nasdaq		S&P Global Clean Energy Index		Nasdaq Clean Edge Green Technology	
M2 US	0.963	Very high correlation	0.941	Very high correlation	-0.262	No correlation	0.810	High correlation

BCI West	0.267	No correlation	0.346	No correlation	0.492	Moderate correlation	0.443	Low correlation
BCI US	0.115	No correlation	0.166	No correlation	0.380	No correlation	0.342	No correlation
BCI Europe	0.499	Moderate	0.565	Moderate correlation	0.634	Moderate correlation	0.609	Moderate correlation
BCI International	0.969	Very high correlation	0.956	Very high correlation	0.882	High Correlation	0.908	Very high correlation

Refinitiv Workspace (2023) provides the data for comparison in Table 7.5, which details the correlation coefficients between the BCIs and other US indices. The correlations with the M2 in the US are notably high for the S&P 500 and Nasdaq 100, registering at 0.963 and 0.941 respectively, suggesting a significant synchronisation with US liquidity trends. Conversely, the S&P Global Clean Energy Index shows an inverse relationship with M2, indicating that liquidity trends do not have a uniform impact across all sectors, particularly clean energy. The Nasdaq Edge Green Technology index correlates strongly with M2, paralleling the patterns observed in broader global indices.

Among the BCIs, BCI International exhibits very high correlations with all listed US indices, with coefficients exceeding 0.882, which may imply a strong response to global financial conditions. BCI West, US, and Europe, however, present lower correlations, all below 0.634, which could suggest a certain degree of independence from US market trends or reflect different sectoral impacts.

In the European context, as shown in Table 7.6, the M2 in Europe displays a varied correlation with European indices such as the FTSE 100, EuroStoxx 50, and the European Renewable Energy Price Index, with coefficients of 0.441, 0.809, and 0.508, respectively. These figures align to some degree with the region's macroeconomic conditions, albeit not strongly indicative of direct tracking of liquidity fluctuations within the European market.

Table 7.6: Comparison of other European indices and BCIs (Refinitiv Workspace, 2023)

Indicator	**FTSE 100**		**EuroStoxx 50**		**European Renewable Energy Price Index**	
M2 EU	0.441	Low correlation	0.809	High correlation	0.508	Moderate correlation

BCI West	-0.343	No correlation	-0.064	No correlation	0.479	No correlation
BCI US	-0.140	No correlation	0.049	No correlation	0.313	No correlation
BCI Europe	-0.287	No correlation	0.243	No correlation	0.652	Moderate correlation
BCI International	0.265	No correlation	0.787	High correlation	0.916	Very high correlation

When observing the BCIs in relation to European indices, only the correlation between BCI Europe and the European Renewable Energy Price index breaches the moderate level, registering at 0.652. BCI International again stands out with high correlations, particularly with the EuroStoxx 50 and the European Renewable Energy Price Index, reinforcing its position as a global economic barometer due to its strong linkage with European market indices.

Collectively, the correlations identified between the BCIs and the equity indices in both the US and European contexts offer insights into the interconnectedness of these specialised and broader markets. The pronounced correlations of BCI International with global indices underscore its integration with international market trends, whereas the modest correlations of the others may signify localised market influences or distinct sectoral dynamics.

7.2.9 Comparison of media trends

This segment addresses the relationship between the BCIs and media trends through correlation analysis. The focus is on the frequency of buzzword mentions in US media correlated with BCI's performance, presented in Table 7.7. The analysis spans from 2016 to 2023 and utilises data from Nexis Uni (2023).

Table 7.7: Correlation analysis of BCIs and media trends – percentage (Nexis Uni, 2023)

Indicator	**Data Range**	**US**		**Europe**		**West**	
Lithium-ion	2016-2023	0.356	No Correlation	-0.069	No Correlation	-0.096	No Correlation
Battery market	2016-2023	-0.041	No Correlation	-0.348	No Correlation	-0.105	No correlation
Energy storage	2016-2023	0.871	High correlation	0.592	Moderate correlation	0.591	Moderate correlation

Electric vehicle	2016-2023	0.901	Very high correlation	0.592	Moderate correlation	0.591	Moderate correlation
Green tech	2016-2023	0.784	High correlation	0.600	Moderate correlation	0.624	Moderate Correlation
Energy crisis	2016-2023	0.227	No Correlation	0.790	High correlation	0.188	No Correlation

Table 7.7 presents correlations which range from very high to non-significant across different BCIs and buzzwords. The high correlation in certain cases suggests that media coverage on these topics might be a strong indicator of market behaviour in BCIs. For instance, the very high correlation between "Electric vehicle" mentions and BCI US implies that news and developments in electric vehicles are likely to impact the index. On the other hand, the lack of correlation with terms like "Lithium-ion" and "Battery market" indicates that general industry buzz might not be as influential in driving market dynamics.

8. Discussion

In this comprehensive analysis, the discussion on whether there are bubble tendencies in the LIB market of both the US and Europe will be presented. Empirically validated characteristics and the course of bubble creation will constitute the logical structure of the argumentation. We assess how various external factors, including government policies, global events, and stock market fluctuations contribute to the potential formation of financial bubbles. This chapter aims to provide a nuanced understanding of the intricate market behaviours in the US and Europe, reflecting the complex interplay of forces shaping the LIB industry. Incorporating insights from past analyses, this chapter will weigh the evidence for and against the presence of a bubble in these markets. The sum of these perspectives will lay the foundation of our conclusions, providing a balanced and comprehensive assessment of the market's state.

8.1 The United States

The exploration into the presence of bubble tendencies in the US LIB market involves a multi-faceted analysis of various economic indicators and market dynamics, particularly focusing on the period after 2020.

8.1.1 Economic shocks

The emergence of a potential bubble in the US LIB market might trace its roots to the Obama administration's heightened focus on RD&D in 2009. This period symbolised a pivotal policy shift, evidenced by the expenditure's substantial rise from approximately USD one billion in 2000 to USD three billion by 2022. Notably, this upsurge, peaking at a deviation from the trend of 153 percent in 2009, coincided with The American Recovery and Reinvestment Act, a legislative initiative designed to counter the effects of the financial crisis and ensuing economic downturn. However, in Figure 5.2 there is an observable decline in RD&D after 2020, suggesting a reorientation away from earlier trends.

Analysing this policy shift through Kindleberger's hegemonic stability theory, it becomes evident that governmental actions significantly influence capital inflows, impacting financial stability and predictability. Nonetheless, the diminishing support for RD&D in the US LIB sector post-2020 potentially threatens profitability and valuations, underscoring the necessity of implementing energy efficiency policies that evolve gradually. This approach is essential to avoid the risks associated with abrupt policy shifts that could lead to market instability and potential bubble formations.

The COVID-19 pandemic introduced an additional layer of complexity, introducing dual shock – a negative supply shock alongside a positive demand shock in the stock market (Brinca, Duarte, & Miguel, 2020). This was further amplified by increased liquidity, a result of rising M2 and federal debt. Within the AD-AS framework, this situation could potentially result in increased output and lower battery prices, driven by innovation in battery technology. This period underscores the intersection of diverse elements – policy shifts, market expectations, and external economic shocks. It highlights the delicate balance required in governmental intervention and market regulation to maintain financial stability in a technology-intensive sector like the LIB market, as discussed in Kindleberger's hegemonial theory.

8.1.2 Overheating

The convergence of heightened liquidity and external shocks culminated in an obvious overheating of the US LIB market after 2020. Shocks and overheating might catalyse market speculation, setting the stage for potential bubble formation. Overheating manifested in three distinct areas: money stock, debt dynamics, and LIB production.

As depicted in Figure 5.1, notable divergences between M2 and GDP growth in the US economy signalled overheating. This was particularly pronounced in 2021 when M2 growth increased more steeply than GDP. Such a trend, indicative of a response to the economic crisis triggered by the COVID-19 pandemic, suggests an expansionary monetary policy. Concurrently, an atypical surge in common stock issuance in 2021, reaching a peak deviation of 140 percent, as presented in Section 5.1.3, further evidence of overheating. This surge, alongside the increased IPO activity in 2020 and 2022, raises questions about market alignment with economic fundamentals, resonating with Minsky's financial instability hypothesis. Minsky associates such trends with vulnerability to rapid market shifts. As shown in Figure 7.1 there was a stable trend of common stock before 2020, indicating that the long term positive trajectory is primarily driven by developments in 2021 and 2022. Also, per the real business cycle theory, an economic expansion typically sees an increase in the value of common stock due to favourable market conditions. However, it is crucial to note that these data are annual and span from 2016 to 2022, which could exaggerate deviations from the trend.

A significant uptick in gross sectorial debt in 2019, culminating in a 28 percent deviation from its long term trend, indicates intensified market activities and potential bubble formation. In contrast, the 2020 peak of gross federal debt at seven percent and the 2008 trough at -eight percent reflect the oscillation of fiscal policies in response to economic conditions. Aligned with Minsky's financial instability hypothesis, which associates increased leverage with economic expansion and potential overheating, US market trends after 2019 are particularly telling. As both US M2 and federal and sectorial debt increase more steeply and experience higher deviations from trend than US GDP at two percent in 2022, signs of overheating are indicative.

The US LIB market experienced dramatic leverage fluctuations, with a peak of 353 percent in 2018 and a significant drop to -99 percent by 2021. These shifts underscore a market reacting to external shocks and fiscal policies, indicative of an overheating economy. Notably, variations in the IPI for the US during the COVID-19 pandemic, particularly the marked trough at -28 percent in April 2020, highlight the LIB sector's susceptibility to disruptions, suggesting overheating risks. The sector's dependency on both equity and debt, coupled with the ease of capital access through mechanisms like credit liberalisation, raises concerns about resource allocation efficiency and potential overproduction. As per the AD-AS framework, such overproduction could depress asset prices. A failure of the market to adjust prices in response to this surplus might indicate a euphoric bubble, characterised by a disconnect between short term price expectations and long term market realities.

8.1.3 Minsky moment

The culmination of these factors led to a potential Minsky Moment on the 23rd of December 2020, with an approximate fall in the BCI US of 17 percent. This phase, characterised by a transition from speculative enthusiasm to cautious investment, aligned with bubble theory, which suggests inherent market fluctuations between boom and bust. Supporting this observation are several key elements: Firstly, the substantial fluctuations in stock values throughout 2020 and 2021, with sharp increases and declines, indicate a market sensitive to investor sentiment and speculation. This is further evidenced by the pronounced peaks and troughs in the stock market, especially the surge of more than 45 percent from the 21st to the 22nd of December in late 2020, suggesting the presence of a euphoric bubble. Also, as depicted in Figure 7.10 the differences between $\lambda = 100K$ and $\lambda = 1B$ in late 2020 suggests euphoria as the gap between the two lambda values is so prominent. Secondly, the theory of financial instability by Minsky finds relevance here, where financial markets are seen to inherently oscillate between phases of enthusiasm and restraint.

Secondly, the financial markets of LIBs experience cycles of enthusiasm and restraint, a concept that gains further complexity when considering the structure of the BCI US. The index is weighted by the market capitalisation of the included companies, implying that price performance and market capitalisation are interlinked. Therefore, a notable increase in both could signal an augmented index value as well as a well-performing company gaining market share. Furthermore, since the index disproportionately weights the best performers, the performance of underachieving companies within the observed period can be overshadowed.

As per Table 7.3 in Section 7.2.5 the BCI US exhibited both higher peaks (150 percent) and troughs (-56 percent) compared to other commercially traded indices in 2020. For instance, the S&P500 peaked at only 11 percent, and the Nasdaq 100 at 12 percent, both in 2020 all at $\lambda = 100K$. In contrast, the Nasdaq Global Clean Energy Index, which includes companies in the renewable energy sector, reached its peak at 22 percent in 2020. This comparison highlights the distinctive volatility and market dynamics of the BCI US, particularly in relation to similar indices focused on renewable energy.

The patterns of swift growth followed by steep declines in stock values within the BCI US, particularly in 2021, align with the cyclical nature of financial markets as described by Minsky. This period in the US BCI exemplifies the typical boom and bust cycle, highlighting the sector's vulnerability to rapid changes in market dynamics and investor behaviour. The situation underscores the speculative tendencies inherent in financial markets, where periods of rapid growth can swiftly turn into market corrections, reflecting the innate cyclical and speculative characteristics of these markets.

8.1.4 Has the US LIB market experienced bubble tendencies?

In conclusion, while there are signs suggestive of speculative behaviour in segments of the US LIB market, particularly in the stock market, asserting a widespread economic bubble requires cautious analysis. After the increased RD&D investments since 2009, alongside the Covid-19 pandemic's impact, significant divergences in money stock and federal and sectorial debt took place. These trends, coupled with unusual stock issuance patterns, align with Minsky's financial instability hypothesis, indicating a market prone to speculative behaviour and rapid shifts. The considerable fall in the BCI US in December 2020 further suggests a Minsky moment, reflecting the market's vulnerability to credit availability. This scenario underscores the occurrence of bubble tendencies in the US LIB market. However, all bubbles are unique, meaning that indicators are not applicable in all situations. According to bubble theory, a bubble can only be detected with certainty by observing a crash substantiating the overheating and bubble tendencies in the market.

8.2 Europe

In this section, the results from the three prior chapters will be discussed considering relevant theory from Chapter 2, to examine whether signs of financial bubbles are to be found in the European LIB stock market.

8.2.1 Economic shocks

The European LIB market has experienced several exogenous shocks equivalent to the US stock market. Firstly, the eruption of the COVID-19 pandemic in Europe in early 2020 caused a negative supply shift due to restrictions on business activities. The reduced production output led to higher prices as anticipated by the AD-AS framework. The narrowing of supply and consumption possibilities caused an increased demand pressure, often resulting in increased savings in stocks and other assets (Brinca, Duarte, & Miguel, 2020).

Secondly, the outbreak of the Russia-Ukraine war in February 2022 shrunk the supply of vital energy sources, suggesting the AS curve shifting inwards, resulting in higher inflation and lower output when using the AD-AS framework (Wyplosz, et al., 2022, p. 14). The sudden cut in Russian oil and natural gas, elaborated in Section 3.1.2, can be perceived as a paradigm shift, leading European policymakers towards de-risking and hawkish energy security policies.

Thirdly, the energy efficiency industry witnessed a noteworthy upswing in governmental RD&D spending across Europe in both 2009-2011 and 2020-2021, exhibiting deviations from a trend above ten percent. Unlike subsidies to commercial operations that may sustain unprofitable entities, RD&D support stimulates market participants to enhance productivity, potentially shifting the AS curve outward. The AD-AS framework suggests increased output and lower LIB prices associated with innovation. A study conducted by MIT professors and graduates found that expansive market policies and R&D investments, whether from governmental or private sources, are key contributors to the rapid reduction in prices.

(Chandler, 2021). As Section 6.1 showcases, the reversing trend in battery production output in 2009 and the accelerating battery production output of approximately 120 percent from 2020 to 2022 may substantiate such AS shift.

8.2.2 Overheating

Acknowledging the capital gap prevalent in clean energy investments, Europe has strategically opted for governmental intervention to secure essential clean energy technologies, as outlined in Section 3.1.3. As discussed in the US section, these findings resonate in Kindleberger's hegemonic stability theory, wherein governments actively adjust capital inflows into the energy efficiency sector to ensure financial stability and heightened predictability. However, a substantial reduction in RD&D support for LIB manufacturers may precipitate increased uncertainty and a noteworthy decline in both profitability and valuations. The EUR two billion cut in European RD&D spending between 2021 to 2022 may explain the heightened volatility in IPI from 2021 to 2023. Consequently, one can reasonably argue that financial stability in the European LIB industry requires the implementation of energy efficiency policies characterised by gradual, rather than abrupt, changes, as the latter approach increases the risk of bubble creation and crashes.

Established bubble theory suggests significant monetary expansions during the course of overheating and bubble creation. Several leverage indicators analysed in Chapter 5 show significant positive deviations from the trend, potentially suggesting overheating. Empirically, M2 rarely shrink (Grytten, 2023). However, the decrease in European broad money supply after September 2022, as depicted in Figure 5.1 suggests substantial monetary expansion prior to mid-2022, leading the economy to run faster than long term equilibrium. Furthermore, the European gross federal debt expanded in the aftermath of crises, both from 2010 to 2012 and from 2020 to 2021. Amid crises, often fostering overly pessimistic economic growth expectations, deficit budgeting is a common and, according to Kindleberger's hegemonic stability theory, a necessary measure to stimulate economic activity if markets fail to autonomously realign market expectations. As depicted in Figure 5.5 both credit expansions led to credit levels exceeding long term trends in the following years in 2009-2015 and 2020-2022, reaching cycle values of approximately five and three percent, respectively.

On the sector level, the European LIB companies are subject to an unsustainable credit expansion from 2021 to 2022, exceeding the long term debt level by 27 percent in 2022.

Looking at the credit expansion in relation to equity financing, the unsustainable leverage ratio in 2022, with a corresponding cycle value of approximately 50 percent, suggests a heightened preference for debt financing. If Minsky's hypothesis, regarding increased leverage in times of economic expansion, is true, then it may seem that the European market experienced overheating in the LIB market in 2022. Economic historians broadly agree that the expansion of the money supply and credit plays a pivotal role in the genesis of financial bubbles, as elaborated in Chapter 2. Nevertheless, there exists considerable debate regarding the suitability of the relationship between equity and debt financing as an indicator for discerning bubble tendencies.

Moreover, an increase in supply and demand, as well as economic growth, signals market overheating. In 2021, the European sector witnessed a boom in the number of battery companies, evidenced by three IPOs, indicating heightened supply in publicly traded battery stocks. Furthermore, there was observed a pronounced surge in demand for LIBs in 2017 and 2021-2022, surpassing the HP-trend significantly by 60 and 17 percent, respectively. The European industrial production index tends to suggest substantial growth in the LIB market, exceeding sustainable levels during several months registering cycle values up to 15 percent in 2011 and 27 percent in 2021. Additionally, the graphical presentation of European BCI's tripling in 2019 and quadrupling from 2020 to 2022 in Figure 7.11 reinforces the argument for periods of overheating.

8.2.3 Stock market bubble tendencies

As presented in Chapter 2, bubbles arise in saturating markets when excess demand is reflected in increased investments in assets, causing the prices to rise due to a surplus of buyers. The European BCI exhibited a nearly sixfold increase in 2019, followed by a significant correction exceeding -50 percent, predating the initial Covid-19 infection incident in 2020. Discrepancies between trend lines using high and low lambdas suggest euphoric bubble tendencies in the second half of 2019. Subsequently, the European BCI quadrupled from its 2020 trough to the 2021 peak, as graphically depicted in Figure 7.11.

The trend reversed on the 29th of January 2021, witnessing a nearly 20 percent drop in the European BCI from the preceding day. The point where optimism is substituted with pessimism and asset prices fall is according to Minsky the beginning of the crash and crisis, described in Chapter 2. The distinct downturn in BCI Europe proceeded until August 2021, when the negative trend stagnates. It is plausible to suggest that the reversion of BCI Europe has caused huge losses as the index registered below 60 as of the 29th of September 2023, implying an approximate -90 percent loss in value from the 28th of January 2021.

The graphical presentation in Figure 7.13 showcases signs of negative bubble tendencies at the end of 2022, potentially serving as a counterresponse to over-optimistic price expectations. Delisting and bankruptcies are often a sign of an overheated market disturbing the natural selection of companies due to easy access to credit. No delisting or bankruptcies have been observed as of September 2023. The real-time issue of this study suggests that the implications of potential bubble tendencies in 2020 and 2021 are not totally reflected in the market yet.

In determining significant cycle values, a comparable analysis of prior financial bubbles in clean tech markets would increase the substance of the findings, clearly suggesting the existence of financial bubbles. In this study, BCI Europe has been compared to several indices where BCI West, BCI International, Eurostoxx 50, and the European Renewable Energy Price Index are the most interesting peers. Comparing peak and trough values across comparable indices in Table 7.6, the European index does not coincide with any index peaks. This may suggest that the European BCI showed signs of bubble tendencies in 2018 and/or 2023 as the index deviated more than comparable indices these years. Comparing Table 7.6 reveals that European LIB index trough coincides with the international LIB index, showing signs of a global stock market bubble, also applicable to the European market. Notably, 2016 and 2023 are endpoint values, suggesting biased interpretations.

When testing for correlation between BCI Europe and comparable indices, only the European Renewable Energy Price Index show a moderate correlation of 0.652. However, the peak and trough values do not coincide. This might suggest diminishing value of using the indices in peer review. On the other hand, the correlation between the indices changes over time suggesting a different picture if using longer time series. High correlation indicates that both indices experience either bubble tendencies or not – that the market values coincide. A low correlation between the indices implies that the indices cannot be reliably used as indicators for bubble tendencies, as the overpricing of the comparable indices occurs arbitrarily in relation to BCI Europe. A moderate correlation coefficient indicates that the two indices' stock market evolution coincides with a 65 percent chance, implying that substantial differences between BCI Europe and the European Renewable Energy Price Index might show signs of bubble tendencies in the LIB sector.

8.3 Suggestions for further research

A preliminary study within a field opens the door for several topics to be studied further. Using crisis theory in a delimited sector has been highly educational, providing new insights and provoking new questions. Our suggestions for further studies are numerous, but a selection will be presented in the following.

To improve the certainty regarding the results in this thesis, we suggest research of similar green sectors to provide peer cycle values in order to find a commonly accepted significance level. Both wind and solar are older sectors with longer time series data, potentially providing comparable insights in asserting normal cycle values using different lambdas.

Considering de-risking policymaking, a study incorporating international trade theory could suggest economically efficient solutions for the global energy transition. Domestic re-industrialisation and less global cooperation mean economic losses and slower technological development. A study seeking to find the optimal balance between economic efficiency and resource risk reduction could provide valuable solutions to an affordable and secure energy transition.

Another related topic to study is the effect on LIB prices, both equity and asset, after the implementation of regional support in the US and Europe in 2023. Adding foreign direct investment as an indicator in the study would provide insights into the structural changes in the LIB market, in result of altered regulatory conditions.

Lastly, any correlation between battery and oil prices would be interesting to investigate. From qualitative sources, it seems that developments in battery technology gain momentum when oil prices plunge. A quantitative analysis of the relationship between the two alternative energy sources might provide interesting findings on how clean technology disruptions and other potential innovations evolve.

9. Conclusions

The master's thesis has by using crisis theory and acknowledged methodologies conducted an analysis to answer the following research question:

Can one find signs of financial bubbles in the US and European lithium-ion battery market?

In Chapter 2, carefully selected theoretical frameworks were presented. Minsky's financial instability theory, Kindleberger's hegemonic stability theory, and Kydland and Prescott's real business cycle theory offered perspectives into important financial and real-economic factors leading to changes in fundamental market conditions. The AD-AS framework was explored to comprehend potential causes for shifts in short term price expectations. Literature from esteemed academics on bubble theory was investigated to learn about different types of financial bubbles, the process of bubble formation, and the potential consequences of a burst.

The study was contextualised in Chapter 3. International trends within energy transition and security policy with emphasis on the Western markets were presented. Furthermore, the section aimed to equip the reader with the required sector knowledge focusing on the product technology, value chain, key actors, and performance of the LIB sector.

Economic macro and sector data have served as indicators in identifying bubble tendencies. The HP filtration of structural time series data, detailed in Chapter 4, represents an established methodology for capturing deviations between observations and long term trends, thereby indicating either euphoric or non-euphoric bubble tendencies. The correlation analysis of key indicators offered insights into the weighting of numerous results, with greater importance assigned to findings associated with indicators demonstrating high correlation.

The results were presented per indicator in Chapters 5, 6, and 7, emphasising the direction of the HP-trend and cycle values over time. The quantitative results were analysed considering qualitative data and evidenced bubble detection frameworks. A great portion of the indicators revealed significant deviations from trends both on macro and sector levels. The most profound result was the BCIs' significant positive cycle values in both the US and European markets.

The results from Chapters 5, 6, and 7formed the core of the discussion in Chapter 8. Empirically validated characteristics and the course of bubble creation constituted the logical structure of the argumentation. Based on the discussion of the US stock market, there are signs of significant overpricing of the US BCI in 2021 and in the European BCI in 2019 and 2021. Multiple factors substantiate these assertions. There are several observations of exogenous shocks both on the supply and demand side. The COVID-19 pandemic resulted in a global shift in supply and increased demand pressure on available assets. Increased government support to the LIB industry in anticipation of stock price increases can be interpreted as regional hegemony shocks disturbing the short term performance of the companies in the respective regions. Additionally, the Russia-Ukraine war has reduced the global energy supply, especially effecting the European market.

The economic expansion during COVID-19 was reflected in increased production output, expansion in money and credit supply, record number of stock listings, surge in battery and lithium demand, and sharp increase in stock prices. The US BCI increased by approximately 1,100 percent from the trough to the peak in 2020, while the European LIB index quadrupled from March 2020 to the peak in 2021. The large deviations between the trend lines with high and low lambda values suggest euphoric bubble tendencies. The US experienced a turning point on the 23rd of December 2020 where the corresponding LIB shares fell by roughly 17 percent, while Europe witnessed a Minsky moment on 29th of January 2021 with a day-to-day decrease of roughly 20 percent. As of September 2023, all BCIs are a fraction of the peak 2020/2021 values.

Considering the analysis presented in this thesis, it can be concluded that there are discernible bubble tendencies in the US and European LIB markets. This is evidenced by significant deviations from trends in the BCIs and the impact of external factors like exogenous shocks and overheating economies. The revealed bubble tendencies in this study imply further investigation and monitoring of the LIB market in the US and Europe and provide an anchoring point in further research within this field.

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Appendix

Appendix 1: Most relevant IRA subsidies for battery actors in the US (H.R. 5376, 2022).

	Direct subsidies		Indirect subsidies		
	Battery producers		EV commercial use	EV personal use	Residential battery storage
Paragraph	§45X	§48C	§45W	§30D	§25D
Applies for	Advanced Manufacturing	Advanced Energy	Commercial Clean Vehicles	Consumer Clean Vehicles	Home-owned battery storage technology
Type of support	Production Tax Credit (PTC)	Investment Tax Credit (ITC)	Investment Tax Credit (ITC)	Consumption Tax Credit (CTC)	Investment Tax Credit (ITC)
Amount	Not mutual exclusive[4]: Electroactive materials: 10% of production cost. Battery cell: USD 35/kWh. Battery module: USD 10/kWh (USD 45kWh if the module does not use battery cells). Critical material: 10% of production cost.	Mutual exclusive: Base: 6% of capex in new or upgraded factories. Bonus: 30% of capex in new or upgraded factories.	The lesser of 30% of the purchase price and additional cost of the EV compared to the equivalent internal combustion engine vehicle. ITC should not exceed USD 7,500 for smaller vehicles and USD 40,000 for larger vehicles.	Not mutual exclusive[1]: Critical minerals: USD 3,750 Battery components: USD 3,750	30% of project expenditures.
Requirements	None.	Base: None Bonus: Prevailing	Several requirements	Critical minerals subsidy: as of 2024, 40% must	Restricted to primary and secondary

[4] Adjusted for inflation. Absolute numbers as of USD 2022.

		wages and apprenticeship.	for the car and engine.	be processed in the US or a country with a free-trade agreement or recycled in the US. The threshold grows linearly to 80% by 2027. Battery components: as of 2024, 50% must be manufactured in North America. The threshold grows linearly to 100% by 2029. Ceiling on gross income and limitations on retail price.	residence. Capacity cannot be less than 3 kWh.
Horizon	Effective until 31st of December 2029. Phasing out with 25% per year between 2030 and 2032. From 2033 and after, the subsidy amount is 0.	Investments from 1st of January 2023. Until the budget of USD 10 billion is depleted[5].	Vehicles were placed in service between the year of 2023 and 2032.	Vehicles were placed in service between the year of 2023 and 2032.	Must be placed in service before 1st of January 2033. Phasing out to 26% in 2033, 22% in 2034, and 0% after 2034.
Business fit	Large-scale producers of battery components and/or batteries.	Pilot projects and/or R&D heavy companies.	Indirect effect on commercial EV value chain.	Indirect effect on personal EV value chain.	Indirect effect on battery energy storage and systems (BESS) value chain.

[5] The budget is not exclusively designated to battery producers.