# Extreme weather-related supply shocks: The case of the river Rhine

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# Abstract

In this paper, I analyze the impact of variations in the water levels of the Rhine on the share prices of the German manufacturing industry to analyze the impact of weather-related supply shocks. The analysis shows that brief periods of low water do not impact share prices, whereas extensive periods of low water cause a significant and meaningful decrease in share prices. This indicates that the industry is resilient to brief supply chain disruptions, but is unable to withstand extensive disruptions. The analysis stresses the impact of weather-related supply chain disruptions and the importance of a well-managed supply chain.

# Contents

# 1 Introduction

In 2018, inland shipping in Germany was severely disrupted as unusual weather conditions led to record-breaking temperatures and droughts, causing a prolonged period of low water in the second half of the year. The Rhine fell to its lowest water levels ever at several points throughout the river, making it almost impassable for industrial shipping. Freighters were forced to reduce their cargo loading or to stop sailing the river altogether, posing serious challenges for the German manufacturing industry, since the Rhine is the lifeline that connects downriver factories to the North Sea ports. If transportation on the Rhine is disrupted, the supply of industrial goods that are necessary for upstream production processes is jeopardized, which could lead to a serious reduction in overall industrial output. Therefore, the economic losses associated with disruptions on the Rhine are extensive, as the manufacturing industry in the Rhine states is a driving force of the German economy.

The exceptional situation in 2018 has highlighted the importance of inland shipping on the Rhine and fueled the debate on the economic impact of weather-related disruptions. However, 2018 is not the only year in which inland shipping on the Rhine was disrupted due to weather conditions, as periods of low water have occurred more often in the past and are expected to reoccur in the future. In fact, due to global warming, the frequency and intensity of weather related disruptions is likely to increase. This outlook is rather troublesome, as several studies have shown that low water levels of the Rhine lead to serious transportation disruptions and increase the costs associated with production. This has also been substantiated by the manufacturing industry and has become a topic for national concern, as disruptions can reduce the levels of industrial output. Since almost 20% of the value added in Germany's gross domestic product (GDP) results from the manufacturing industry, the overall effects can cause a significant decrease in macroeconomic activity.

Therefore, this paper focuses on the economic impact of weather-related disruptions in the supply chain. More specifically, this research utilizes a historical database of water levels of the Rhine to analyze the impact of variations in water levels on a specific economic indicator, namely share prices. The river Rhine is employed, since the Rhine is crucial for the transportation of cargo, required for the production processes of the manufacturing industry. Variations in the water levels are utilized, since water levels can be seen as indicators of possible disruptions in inland shipping. The economic impact is examined by measuring changes in share prices, since share prices reflect the general health of a firm. Only the share prices of the manufacturing industry are considered, since disruptions in the supply chain should, in theory, only affect production firms. Hence, the main research question of this paper is as follows:

*What is the relationship between variations in water levels of the Rhine and the share prices of the German manufacturing industry?*

The situation in 2018 clearly demonstrated the impact of a long-lasting period of low water, but reveals little about the nature of this relationship. It is obvious that reduced water levels can hinder inland waterway transport and lead to significant disruptions in the production processes, but it remains debatable if, or at which point, the share prices of the manufacturing industry will be impacted (Ademmer et al., 2020). The question arises if water levels have a direct impact, or if water levels beneath a certain threshold, perhaps for a certain period of time, have an impact. Current literature has identified two main thresholds at which inland shipping is affected. Jonkeren et al. (2007) established that there is a negative relationship between water levels and freight rates, when the water levels are below 260 centimeters, whereas Ademmer et al. (2020) establish that inland waterway traffic is disrupted when the water levels fall below 78 centimeters. Both threshold imply that the costs associated with production increases, when the water levels fall below these thresholds.

Since the relationship between share prices and water levels is unexplored, the goal of this research is to examine the nature of this relationship. This paper also aims to determine at which point and under which conditions water levels affect share prices, taking into account both the water levels and their persistence in terms of duration.

The approach of this research consists of three main components. First, the direct relationship between water levels and share prices is studied by means of a regression analysis, while accounting for several endogenous and exogenous variables that are known to influence share prices. The variable to account for the water levels is manipulated as such, that the model accounts for the effect of information anticipation, information lags, and the effect of water levels beneath certain thresholds. Second, the effect of periods of low water is examined. By measuring if share prices decreased over a period of low water, ranging from 3 to 19 weeks, the cumulative effect of disruptions caused low water levels is measured. This method excludes the influence of variations in water levels, but measures the impact of a period of low water, by which the manufacturing industry might be hindered. Third, the returns associated with periods of low water are examined. By calculating the weekly abnormal returns, the effect of periods of low water is quantified in terms of a loss in value.

In this paper, I make use of water level data of the Rhine from 2015 to 2019, to analyse the economic impact of weather-related supply shocks. This work contributes to the existing literature in several ways. First, this paper contributes to the growing body of literature on the economic consequences of extreme weather events and weather-related supply shocks (Ademmer et al., 2020). Second, this paper shows the economic significance of a well-managed supply chain and contributes to the limited body of literature on the relationship between supply chains and shareholder value (Hendricks & Singhal, 2003). Third, this research extends the work of Ademmer et al. (2020) who analyze the impact of the exogenous variability in the Rhine on economic activity by measuring the levels of industrial output. This research can be seen as an extension, as the impact on share prices rather than on the industrial output is measured. Lastly, this paper aims to bridge the gap in the existing literature between disruptions caused by the water levels of the Rhine and the impact of supply chain disruptions in the equity market.

To my knowledge, this paper is the first to analyze the impact of low water levels of the Rhine on the share prices of the manufacturing industry in Germany. Furthermore, this is the first paper to analyze the impact of the duration of a disruption, rather than only the occurrence of a disruption.

The remainder of this paper is structured as follows. In Section 2, the global economic context of the chosen time period is discussed, since the manufacturing industry is not a stand-alone industry and is highly dependent on the global business cycle. The industry is also dependent on global trade, as many of the products require both imports for the production process and exports for reaching the final consumer.

In Section 3, the main factors that constitute share prices are discussed. Share prices are influenced by a multiplicity factors, that can relate to the underlying firm or exogenous influences. To examine the relationship between water levels and share prices, the influence of other factors must also be considered.

In Section 4, the effect of disruptions in the supply chain is discussed in the broader context of supply chain management. Supply chain management is part of firm's value creation capabilities, which is also partly represented in the share prices.

In Section 5, the case of the Rhine is discussed. In order to understand the relationship between water levels of the Rhine and the share prices of the German manufacturing industry, the characteristics of the Rhine and the manufacturing industry should be examined.

In Section 6, the data used for the empirical analysis is described. Section 7 covers the first part of the analysis and studies the direct relationship between water levels and share prices.

Section 8 covers the second and third part of the analysis, in which the effect of a period of low water is examined. Section 9 concludes.

# 2 The Global Economic Context

The global economic context sketches the state of the world and is the overarching factor that captures the global conditions under which the German manufacturing industry was operating from 2015 until 2019. It can explain part of the change in share prices, that are due to global conditions rather, than variations in water levels (CCNR, 2019).

This context is especially important to consider when examining the manufacturing industry, since the performance of the German manufacturing industry does not only depend on the German economy, but primarily depends on the global economy. This is due to the large share of German exports, as Germany is the third largest exporting country worldwide, following China and The United States. Most of the products are exported to the United States ($131B), France ($115B), China ($107B), The Netherlands ($87.7B), and the United Kingdom ($86B) (OECD, 2021). It follows logically that the performance of the manufacturing industry and the associated exports, depend on the general economic circumstances.

The global economic context consists of a multitude of components and is driven by an infinite number of forces, which would make it shortsighted to assume that the entire context can be fully captured by only a small amount of factors. However, the goal of this paper is not to exclude which factors are influential, but rather, identify those that are important when examining the general economic conditions under which the manufacturing industry was operating. Therefore, this section focuses on a few, high-level indicators of the global economic context, namely the global business cycle, world trade and business confidence.

## 2.1 Global business cycle

The global business cycle is one of the main factors that determines the global economic context, since the global business cycle represents the cyclical fluctuations in growth that characterise economies. These fluctuations are largely influenced by factors that also influence the global economic context, making the global business cycle a decent factor to capture part of the economic context.

Generally, the business cycle consists of four recognised stages, in which the economy is either expanding or contracting. The economy is expanding when there is rapid growth, the level of industrial production is increasing and the level of GDP is growing. After this period, the economy reaches a peak stage, at which the growth of the level of industrial production and GDP stagnates. Imbalances start to arise that the market needs to correct, which is the start of the contraction stage. During the contraction stage, the economy starts to shrink and the level of economic activity diminishes. The economy reaches the last stage, trough, when the decline starts to stagnate. After this stage, the cycle renews as the economy begins to expand.

The stages of the global business cycle are important to consider when examining the manufacturing industry, since the level of industrial production can decrease when the economy is contracting, independent of the influence of water levels (Ademmer et al., 2020).

## 2.2 World Trade

A second factor, that influences both the global economic context, as well as the global business cycle, is world trade (IMF, 2021). The level of world trade sketches the global economic context, as global trade is an indicator of economic growth and global conflicts (WTO, 2021).

International affairs and trade agreements are important precedents of world trade. Fruitful geopolitical relationships and new trade agreements enhance the trade between countries and improve the future economic outlook, as increasing global trade can contribute to the expansion of the economy and an increase in GDP (CCNR, 2019). However, rising geopolitical tensions can have a negative impact on global trade. Countries might withdraw from existing trade agreements and can impose extra trade barriers if relationships deteriorate. This negatively impacts the future economic outlook, as trade is an import driver of economic activity and trade barriers signal a worsening investment landscape (Schneider & Troeger, 2006).

World trade can influence the German manufacturing industry and explain changes in share prices, since the exports of Germany are part of, and depend on, world trade. However, this factor should be considered in the global economic context, since it is independent of water levels.

## 2.3 Business Confidence

The third, and last factor this section considers it the level of business confidence. Business confidence relates to the uncertainty investors face and their expectations about the future. It is an indirect measure of the global economic context and strongly related to global trade and the business cycle.

The stock market accounts for the level of uncertainty investors face and corrects itself and the price levels when the level of uncertainty changes. Low uncertainty about the future economic outlook improves investors' expectations and positively impacts the level of investments. Low uncertainty is often associated with a so-called bull market, which is when stocks are appreciating in value and investors' attitude about the economy is generally positive. High uncertainty about the future economic outlook lowers investors' expectations, making investments less attractive and riskier. High uncertainty is often accompanied by a bear market, which is the opposite of a bull market, as the share prices are depreciating and investors have a negative view on the state of the economy. Hence, increasing uncertainty will negatively impact the stock market, whereas decreasing uncertainty positively impacts the stock market.

The level of business confidence is important to consider when examining changes in share prices, as a decrease is share price might be unrelated to the manufacturing industry itself, but could be related to investors' general opinion about the future of the market (CCNR, 2019). Even though the level of business confidence is somewhat difficult to quantify directly, it is an important aspect to consider when deriving implications about the cause of changes in share prices.

# 3 The stock market

The global economic context sketches the state of the world and is a precedent of global economic activity and growth. One of the dependents of the global economy, is the stock market. The stock market is part of the capital market, where, among other financial securities, stocks are being traded. Listed manufacturing firms are concerned with changes in their share prices, as they give an indication about the market's perception of their vitality and financial health. However, not all changes in share prices reflect changes in the perception of the underlying firm.

Daily evidence of the stock market displays that stock prices do not only respond to endogenous economic variables, but are also susceptible to external forces (Chen et al., 1986). It is therefore important to first distinguish between the effects and interaction of several (macroeconomic) factors, before dissecting the impact of water levels on share prices.

Hence, the approach of this section is as follows. First, the underlying value of share prices and the components are reviewed. Second, the fundamental factors that relate to the idiosyncratic risk of stocks are discussed. Third, the technical factors that constitute the systematic risk of stocks are explained. And lastly, the impact of the overall market conditions are examined.

The goal of this paper is to analyze the impact of water levels on share prices. Therefore, the focus is on the interpretation of the identified factors, rather than examining the underlying econometric models. Consequently, the number of included factors is limited and the discussion of the financial concepts is concise. An overview of the discussed factors is shown in table 1.

Table 1: Share Price Predictors

| Share price factors | |
|---|---|
| Fundamental Factors | Technical factors |
| Earnings Base | Industria Production |
| Valuation Multiple | Yield Curve |
| | Inflation |
| | The Economy |
| | Stock Co-Movement |

## 3.1 Share Prices

Share prices are an indication of the value of a firm, as they represent both the current value of a firm and its future growth prospects. The prices are determined on the stock market, where the demand and supply of a stock, determine the price. In essence, share prices represent the expected discounted dividends and can be written as:

$$p = \frac{E(c)}{k} \tag{1}$$

where $E(c)$ is the expected dividend stream and $k$ is the discount rate (Chen et al., 1986). It follows logically that, in order for the price the change, the expected cash flow or the discount rate should change.

Even though share prices represent the expected discounted dividends, individual asset prices are believed to be sensitive to a wide variety of factors and to be strongly influenced by economic developments (Chen et al., 1986). In a perfectly efficient market, stock prices would rapidly adjust to all available information and the consecutive share prices should reflect all information relevant to that specific security. This hypothesis, better known as the efficient market hypothesis (EMH) has been a central debate in asset pricing. However, trading stocks can be quite a lucrative endeavour and investors have been continuously challenging the EMH, by attempting to predict share prices.

Despite the attention given to predicting share prices, there is no clear equation that fully incorporates the determinants and/or predictors of share prices. However, contrary to the EMH, certain factors have been proven to affect and even predict the movement of the share prices. These factors mostly fall into two categories, namely fundamental factors and technical factors.

## 3.2 Fundamental factors

Fundamental factors are inherent to a specific firm and are driven by the ability of a firm to produce and sell goods and/or services. For the manufacturing industry, these capabilities will be mostly related to their ability to deliver and sell their industrial output.

Since fundamentals are firm-specific, they also constitute a firm's idiosyncratic risk. Idiosyncratic risk is firm-specific risk that is unique to an individual security and it is a kind of risk that does not affect the entire market. Idiosyncratic risk is important to consider in the context of disruptions in the supply chain, as it can indicate whether a firm should have been able to counter the effects of a disruption, or if the entire sector was affected, making it impossible to completely avoid the negative consequences.

A firm's capabilities are translated into the most important fundamental factors, namely the earnings and valuation multiples. If capital markets were perfectly efficient, stock prices would only be determined by a firm's fundamentals (Malkiel & Fama, 1970).

### 3.2.1 Earnings base

Earnings are part of a firm's financial statement and represent the after-tax net income. It is a measure that shows the viability of a firm and its performance compared to competitors. Earnings are one of the main determinants of a firm's stock price, as earnings can be used to pay out dividends to shareholders or can be reinvested into the firm, to increase earnings in the future.

There are many common measures for valuing a company that indicate the earnings and account for different degrees of profitability, such as earnings per share, cash flow per share or dividends per share. The most suitable measure depends on the investors preferences and on the industry of the firm. Manufacturing industries, which mostly have a high degree of fixed assets, are often better represented by earnings before interest, taxed, depreciation and amortization (EBITDA) than, for instance, earnings before taxes (EBT).

Earnings announcement are a crucial moment for the stock market, as the expectations of investors are offset against the reality. Recent studies have shown that share prices tend to converge to their true fundamental price around earnings announcements dates (Jiang & Zheng, 2018). If earnings are different than expected, investors have to reevaluate the value of firm, and the prices of mispriced stocks are corrected, which can have a large impact on the stock prices, for both the short- and long-term. Generally, earnings are announced on a quarterly basis, though firms can deviate from the supposed announcement dates.

### 3.2.2 Valuation multiple

The second fundamental factor is the valuation multiple. The earnings base represents the current or past performance of a firm, whereas expectations about future income are represented by the valuation multiples. Valuation multiples are important for the manufacturing industry, as they give an indication about the value of the expected cash flows and the discount rate, which can be influenced by disruptions in the supply chain.

One of the key drivers of the level of the expected cash flows are innovations in the level of real production. Changes in real production do not only impact a firm's past performance, as captured by the earnings, but also influence a firm's expected future performance. If the uncertainty surrounding the industrial production increases, or if the real production levels decrease, the expected profitability of a firm decreases, lowering the value of the expected cash flows (Chen et al., 1986). Therefore, changes in the rate of productive activity of manufacturing firms can influence their share prices through the level of expected cash flows.

A second factor that influences the level of expected cash flows are the growth options and (expected) growth rate of a firm. A high growth rate increases the value of the expected cash flows, as investors predict growth in the near future, and has a positive relationship with share prices (Smit & Trigeorgis, 2012). Growth options, which are related but not equal to the growth rate, also influence the expected cash flows. Growth options refer to the opportunities a firm has to undertake projects that have a predicted positive net present value. The more growth options a firm has, the higher the value of the expected cash flows and the higher the level of the share prices.

Typically, innovative industries, such as the pharmaceutical, information technology and consumer electronics industry, have many growth options and a large growth rate. These markets are characterised by unexpected technological changes and highly strategic moves, which results in positive valuation multiples, such as a high price-earnings and market-to-book ratio (Smit & Trigeorgis, 2012). These firms derive most of their market value not from assets in place, but from the potential of growth in the (near) future.

Traditional industries, such as the chemical and transportation industry, generally have fewer growth options and a lower growth rate. These industries are often capital intensive and derive most of their value from the assets in place, contrary to growth firms. The market of traditional industries is mostly established and the level of innovations and highly strategic moves is moderate, which means that these firms often have lower rated valuation multiple (Smit & Trigeorgis, 2012).

The difference in growth options and growth rate per industry is not only reflected in the valuation multiples, but is also reflected in the average volatility of an industry (Smit & Trigeorgis, 2012). The associated volatility of a firm is partly derived from the changes in price levels of securities, and constitutes a measure of risk. The volatility of an industry is relevant when considering the impact of disruptions, as the share prices of highly volatile industries tend to react stronger to negative information.

The second aspect, important for valuation multiples, is the discount rate. The discount rate is an average of rates over time and is used to calculate the net present value of the future stream of income (Chen et al., 1986). The rate depends on the perceived risk of a stock; the higher the perceived level of risk, the higher the discount rates, which in turn lowers the perceived value. Innovative industries, that are subject to high levels of uncertainty, can generate large returns, but are also accompanied by higher risk levels. Traditional industries are generally less risky, but the returns are also less lucrative compared to other sectors.

The discount rate is also a function of factors that are unrelated to the underlying firm, namely inflation and the term structure of interest rates (Chen et al., 1986). Both the level of inflation and the interest rates have a positive relationship with the discount rate, as the discount rates increase if either inflation or the interest rates increase. However, this component of the discount factor is not a fundamental factor, but rather, a technical factor.

## 3.3 Technical factors

Technical factors are factors that influence share prices, but are independent of the underlying firm. The main difference between technical factors and fundamental factors, is that a manufacturing firm cannot influence technical factors, whereas a firm can influence fundamental factors.

Technical factors constitute a firm's systematic risk, whereas fundamental factors are part of a firm's idiosyncratic risk. Systematic risk is risk that is inherent to the entire market or a specific industry and cannot be fully avoided by a firm. Systematic risk is important to consider in the context of weather-related disruptions, as disruptions can be considered systematic risk if an entire industry is affected, which has implications for the affected firms.

Technical factors should be considered as the impact of macroeconomic factors or unanticipated events has made the co-movement of assets prices evidently clear, which is a strong indication of common underlying exogenous influences (Chen et al., 1986). An example of a common underlying exogenous influence, could be the impact of weather-related supply shocks.

Since the goal of this study is to determine the influence of water levels on share prices, other technical factors that have already been identified in the literature should be considered. In theory, macroeconomic factors should have no predictive powers on stock prices, since stock prices should reflect the underlying fundamental factors of firms (Maysami et al., 2005). However, evidence has been building in the literature that technical factors, in fact, can have a predictive power on stock returns.

Identifying technical factors has been a central topic in asset pricing and there is wide variety of factors already identified, ranging from central bank policies to changes in average temperature (Cecchetti et al., 2000; Cao & Wei, 2005). However, the goal of this study is not to exhaust the list of possible factors, but rather, identify relevant factors. Therefore, this study only considers currently identified factors that are most relevant to the manufacturing industry in Germany.

### 3.3.1 Industrial production US

Chen et al. (1986) wrote a seminal paper on the impact of economic forces on the stock market. One of the key variables identified, is the U.S. industrial production growth rate. The level of industrial production is of macroeconomic importance, as it is highly correlated with interest rates, monetary policies and consumer demand (Shapiro et al., 1989). This makes industrial production part of the indicators that are analyzed when the level of future economic performance and gross domestic product (GDP) is determined.

The utilization rates of production facilities give an indication of the overall consumer demand. There is a positive relationship between the two factors, meaning that if the utilization rates are high, the consumer demand for goods is high. This is strongly related to inflation. If production facilities are producing at their full capacities, while the demand keeps increasing, it could lead to a shortage of supply in goods. This in turn, can lead to a strong increase in price levels. Stock prices reflect changes in the industrial production growth, since inflation is reflected in the discount rate. However, share prices incorporate the changes in rates many months before the actual change occurs, as the changes are anticipated (Shapiro et al., 1989).

### 3.3.2 Yield curve

The yield curve represents the difference in interest rates and is the graphical representation of bonds with an equal credit rating, but with different maturities (Fabozzi, 2008). The shape of the yield curve gives an indication about future inflation and economic activity (Chen et al., 1986). The economy is said to be growing if the yield curve is positive, whereas the economy is expected to contract if the yield curve is inverted. The yield curve affects the prices of securities since it is related to the discount rate, which determines the value of the expected cashflows. Chen et al. (1986) find that the spread between long and short term interest rates systematically affects stock market returns. If the yield curve becomes negative, the real return on capital decreases and investors will seek for options to hedge themselves against the corresponding risks (Chen et al., 1986). Therefore, stocks that have a negative relationship with the yield curve are more valuable and will carry a negative risk premium.

### 3.3.3 Inflation

Inflation reflects the rise in price levels of goods ans services and reduces the purchasing power of a single unit of currency. Changes in inflation cause a shift in wealth and can cause a deterioration of an individual's capital, if no countermeasures are taken (Chen et al., 1986). Common stocks have long been considered a long-term inflation hedge against the loss in purchasing power, because stocks represent ownership of physical capital (Anari & Kolari, 2001). The value of physical capital should, in theory, be independent of the rate of inflation (Bodie, 1976). Fisher (1930) proposed that the expected returns on equity consist of the real returns plus the rise in inflation. This implies a positive relationship between inflation and the return on equity, as a rise in inflation should cause an equal rise in return on equity. However, there is no definitive consensus in the current literature about this relationship. Studies show that inflation can have both a negative and a positive impact on stock prices, depending on the time period and the geographical location of the data. Numerous studies have shown that inflation has a negative effect on stock prices in the short-run (Anari & Kolari, 2001). However, in line with Fisher's hypothesis, certain studies also report that inflation has a positive effect on stock prices in the long-run (Anari & Kolari, 2001; Fisher, 1930). Overall, it seems that inflation has a dual effect; negative in the short-run and positive in the long-run (Anari & Kolari, 2001).

### 3.3.4 The Economy and the Stock market

The economy and the stock market are closely related, yet, they are not interchangeable. The stock market only represents the expectations about future income of listed firms, whereas the general economy encompasses all aggregate demand and supply of goods and services and the money supply. However, despite the fundamental differences, the stock market and the economy often move in similar directions (Bosworth et al., 1975). This does not necessarily imply a causal relationship, rather, it shows that the economy and the stock market mirror similar developments (Bosworth et al., 1975). Former literature indicates that the stock market tends to precede the movements of the economy by an average of four months (Bosworth et al., 1975). This characteristic makes the stock market a decent indicator for changes in the business cycle and future economic conditions.

Non-equity economic variables, such as inflation and interest rates, can have the ability to influence the stock market. However, macroeconomic variables are slow in incorporating information and their effects are smoothed over time (Chen et al., 1986). Therefore, the influence of macroeconomic variables is not represented properly over a short time horizon. The stock market however, is very responsive and quick to incorporate information. As a result, the correlation between non-equity economic variables and the stock market will be weak and relatively noisy, despite their co-movement (Chen et al., 1986). Therefore, the return on traditional stock market indices, could be validated as a decent proxy for the influences of macroeconomic variables in the short-run, as proposed by Chen et al. (1986). The returns on these indices should reflect the influence of non-equity economic variables, since capital markets incorporate this information into share prices.

### 3.3.5 Stock co-movement

Individual stocks tend to co-move with the overall stock market and their corresponding industry. Generally, a firm's $\beta$-coefficient determines the level of co-movement. There are certain risk premia associated with the market and individual industries, which generates excess returns associated with the factor. Determining the individual $\beta$-coefficients and the different risk premia lays outside the scope of this study, however, the market and sector movement can be compared to the movement of the manufacturing industry.

If the stock market or the manufacturing industry gains momentum, all stocks that have a positive $\beta$ should also gain momentum, albeit depending on the $\beta$-coefficient. The co-movement of assets can be positive if there is an upward trend, but co-movement in not necessarily good for share prices. Share prices of firms that operate in the same sector often experience similar trends, even though certain events might not affect the entire industry. This is due to guilt by association. For example, if one manufacturing firm in Germany makes a statement that the production is hindered by disruptions, the share prices of other firms in this industry can be affected by this announcement, even though they are not affected by the disruption.

# 4 Supply chain management

Share prices are influenced by both endogenous and exogenous factors, but principally represent the expected discounted future cash flows, as shown in Equation 1. A company has little influence on the discount rate, as this partly depends on exogenous factors, but has a substantially larger influence on the level of expected future cash flows.

The manufacturing industry is concerned with making strategic decisions to increase the value of the firm, which will be reflected in the expected future cash flows in the long run. One aspect of value creation, specific to production and distribution firms, is supply chain management. Supply chain management is a broad concept, mainly concerned with the flow of goods and service, and affects almost all fundamental equity drivers.

Weather-related disruptions in the supply chain are closely related to an individual firm's supply chain management, since firms can mitigate the risks associated with disruptions through the management of their supply chain. Effective supply chain management can ensure that a firm is able to maintain its industrial output at competitive prices, even when disrupted. However, if a firm's supply chain management is insufficient to counter the effects of a disruption, a firm can be forced to halt or lower production.

Hence, the approach of this chapter is as follows. First, the components of firm-specific fundamental value creation is discussed. Second, supply chain management and its role in value creation is discussed. Third, the effects of disruptions in the supply chain are discussed.

The goal of this chapter is to identify the firm-specific components of value creation that are relevant for the manufacturing industry and that explain the influence of supply chain management. There are several extensive models that take numerous different variables into account, however, the goal is not to dissect all possible value creation models. Therefore, only a brief model, that can be related to supply chain management, is given.

## 4.1 Value Creation

Firms are principally concerned with increasing their value, since the value of a firm is not fixed, but changes continuously throughout the lifetime of a firm. Listed firms are not only concerned with increasing the firm's value, but also have the responsibility to increase their shareholder value. Shareholder value consists of the financial value created by the firm for its shareholders and is made up from the share price appreciation and dividend yield (Christopher & Ryals, 1999).

When increasing shareholder value, firms tend to focus on increasing their profits and increasing the level of expected future cash flows, as this is a direct result of the strategic decisions made by the management of a firm. However, firms have less influence over the associated discount rate, as the discount rate also depends on external factors. Therefore, value creation by lowering the discount rate is excluded for this section.

There are numerous models that identify several value drivers behind shareholder value creation, ranging from the regulatory environment to acquisitions and disposals (Fernández et al., 2002; Trotta, 2003; Srivastava et al., 1998; Christopher & Ryals, 1999). Fernández et al. (2002) propose a model that identifies 21 different equity drivers, categorised into expected company growth, expected return on investment, operating risk and financial risk. Trotta (2003) identifies only 3 equity drivers, namely revenue, competitive repositioning and efficiency. Srivastava et al. (1998) propose a model that focuses on the value of a strategy, consisting of the acceleration and increase of cash flows, a reduction in the level of risk and the residual value of the business. As can be seen, there does not seem to one comprehensive model put forward in the literature yet, as to how firms can increase their shareholder value. However, these models have in common that firms need to increase profits and reduce risk.

The strategies put forward in the literature to increase shareholder value, tend to be focused on improving three factors, namely the operating margin, the revenue growth and capital efficiency (Christopher & Ryals, 1999). The operating margin is the profit a company makes after accounting for the variable costs of production. Firms can mainly improve the operating margin by lowering the costs of the goods sold and reducing general costs, such as overhead. The revenue growth refers to, as the name implies, the growth in revenue. Firms can increase the revenue growth by either selling more products, selling products at a higher price or a combination of both. Capital efficiency refers to the ratio between the amount a company is spending on growth and the return a company receives. Capital efficiency can be improved by increasing the return on assets and increasing inventory turnover.

## 4.2 Supply Chain Management

Supply chain management is a measure by which firms can increase shareholder value, as it influences all of the three previously identified components of value creation. Countless literature emphasises the contribution of a well-managed supply chain to shareholder value creation, however, there seems to be little concrete evidence on this relationship (Hendricks & Singhal, 2003; Christopher & Ryals, 1999). This is likely due to the fact that supply chain management is not a specific value driver, but regards the managerial decisions of a firm, which affect the value drivers.

Supply chain management is a concept, and the primary objective is to manage the flow of goods and services, from the beginning of the production process until the distribution of the finalized product. However, it extends beyond merely logistics, as supply chain management is a process of strategic decision making that focuses on the inter- and intra-firm integration of logistics activities (Mentzer et al., 2001). Firms in a supply chain share the belief that they are interdependent, since each firm directly and indirectly affects the performance of the entire supply chain, and attempt to create customer value through the synchronization of their supply chain activities (Cooper et al., 1997).

A supply chain consists of a set of firms that are jointly responsible for bringing products or services to the market. It is a network of different organisations that are connected through upstream and downstream linkages (Christopher, 2016). Each linkage conducts different activities and contributes to the final value of the good or service. Generally, most manufacturing processes are dependent on the entire supply chain, as they rely on multiple firms, ranging from the raw material producers to the wholesalers (La Londe & Masters, 1994). Therefore, supply chain relationships require strategic coordination between the different linkages.

A well-managed supply chain should be reliable and responsive (Hendricks & Singhal, 2003). Reliable relating to the adequate delivery of a product at the lowest cost, and responsive relating to the ability to react to changing market conditions(Hendricks & Singhal, 2005a). In order to ensure the reliability and responsiveness, supply chain management requires the integration of key processes over different linkages. As firms in a supply chain are interdependent and no party is fully in control of the performance of the supply chain, they need to be willing to cooperate and to share information to maximise the benefits. Despite this interdependence, individual firms should still be able to meet short-term changes in demand and be able to adapt quickly, if certain aspects in the supply chain change.

There are several key objectives that are identified as the drivers behind supply chain management. Current literature asserts that one of the main goals is to lower the costs, while ensuring the adequate level of customer satisfaction (Mentzer et al., 2001). A second goal is to improve the level of customer service, by increasing the stock availability and diminishing the order cycle time (Cooper & Ellram, 1993). Lastly, supply chain management is focused on creating a unique customer experience, suited to the individual's needs and generating customer service value (Mentzer et al., 2001).

The consequences of a well-integrated supply chain are improved profitability, competitive advantage and customer value (Mentzer et al., 2001). Through information sharing and integration, firms can transform fragmented operations into a synchronized system. This lowers the costs, such as inventory costs, and increases productivity, e.g. by a reduction in idle times. It also increases the reliability of the supply chain, which improves the overall customer satisfaction. Both the enhanced profitability and the increased customer value contribute to the two components of competitive advantage, namely cost leadership and differentiation (Porter, 1985).

It follows logically that, given its goals and consequences, supply chain management is crucial to the German manufacturing industry. The industry consists of an intricate network of supply chains with various firms, where each firm is dependent on the performance of every linkage in the network. Through supply chain management, the industry can ensure a smooth flow of goods between linkages and increase shareholder value creation, as displayed in Figure 1.

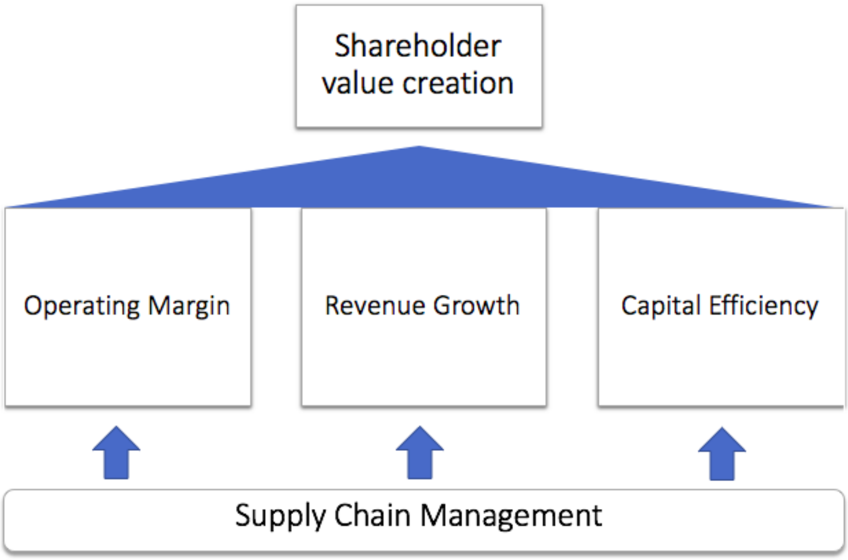


Figure 1: Supply chain management and shareholder value creation

### 4.2.1 Reliability of transportation modes

Supply chain management is also concerned with selecting the modes of transport that are used to move goods forward. There are several different transportation modes that can be used, each with their own advantage and disadvantage. The transportation modes are important to consider since the reliability of a supply chain also depends on the reliability of the transportation mode.

There are four main modes of transportation, namely road, rail, shipping and aviation, and each mode has it own advantages and disadvantages. The advantage of road transport lays in its flexibility and its ability to reach the final consumer. However, road transport is also quite expensive and negatively associated with pollution and congestion. Rail transport is cheaper than road transport over longer distances and less polluting, but most railways systems are fairly unreliable and road transport is still needed to deliver the product to its final destination. Shipping is the cheapest mode of transport, due to the ability to transport large volumes at once. However, parties do need access to waterways to fully benefit of the advantages of shipping. Aviation is a less common method of transport and mostly used when the other transport modes are no a viable option. It is expensive and highly polluting, however, it has the ability to reach a destination quickly.

The utilized transportation modes can differ for each supply chain, as each supply chain is unique and is built up from different downstream and upstream linkages. For example, the German manufacturing is highly dependent on inland shipping, whereas other supply chains might not make use of inland shipping at all.

## 4.3 The effect of supply chain disruptions

Supply chain management is concerned with increasing the efficiency and effectiveness of a supply chain through strategic decisions, however, firms are still unable to fully exclude the possibility of a disruption occurring (Mentzer et al., 2001). Disruptions in the supply chain can have a detrimental effect, if the performance of a firm is affected.

The competitive advantage gained by strategic supply chain management can be weakened by disruptions, if firms are not able to counter the associated negative effects. For example, disruptions can reduce customer value if it causes a delay in shipment, or disruptions can reduce a firm's profitability if the associated operational expenses increase.

If disruptions result in production or shipment delays, it can affect the operating performance metrics of a firm (Hendricks & Singhal, 2005a). Operating performance metrics are quantifiable indicators of a firm's performance and viability. Hendricks & Singhal (2005a) study the effect of disruptions that resulted in production or shipment delays. Firms that are affected by disruptions in the supply chain are associated with a drop in operating income, return on sales and return on assets. Firms also experience a lower sales growth, a higher growth in costs and a higher growth in inventories. These negative effects are long-lasting, since firms do not recover to their initial levels of operating income, sales and total costs, during a two-year period after the disruptions occurred (Hendricks & Singhal, 2005a).

Disruptions in the supply chain can also lead to a decrease in share prices (Hendricks & Singhal, 2003, 2005a). Hendricks & Singhal (2003) measure the effect of shipment and/or production delays, and establish that firms experience a reduction in shareholder value due to these disruptions. As shown in Equation 1, share prices depend on the value of the expected cash flows and the discount rate. The effect of disruptions on share prices is indirect, but rather, straightforward. For example, a shortage in resources due to a shipment delay, can lead to the inability to meet demand, which lowers the projected sales, and therefore, the expected cash flows. Or, a decrease in credibility due to production delays, can cause an increase in a firm's perceived level of risk and hence, increase the discount rate (Hendricks & Singhal, 2003). Therefore, firms that experience disruptions in their supply chain and that are not able to counter these effects, can experience a loss in shareholder value.

Hendricks & Singhal (2005b) build onto the findings of Hendricks & Singhal (2003) and investigate the impact of supply chain disruptions on long-term stock prices and equity risk. The evidence indicates that firms do not quickly recover from the effects of supply chain disruptions, which is in line with the findings of Hendricks & Singhal (2005a). There is a significant decrease in share price, measured over a 3-year time period, starting one year before the announcement and ending two years after the announcement. Hendricks

& Singhal (2005b) also find that disruptions cause a prolonged increase in total equity risk. The increase is mainly due to an increase in idiosyncratic risk, as the authors do not find any evidence that disruptions cause a change in a firm's systematic risk.

# 5 The Case of the Rhine

Supply chain disruptions have the potential to negatively impact the equity value of a firm, by affecting a firm's performance. Through supply chain management, firms can mitigate the risk of disruptions, but are ultimately still susceptible to the negative consequences. Since every supply chain is unique, there is a variety of reasons that can cause disruptions and the predictors of the disruptions are not easily pinned down to a single factor. Therefore, this research examines one specific disruption, caused by the water levels of the Rhine.

The German manufacturing industry operates in a global context and plays a significant role in the strength of the German economy, since the four largest industries in Germany are all manufacturing industries. The industry consists of many different firms, that each operate in their own unique segment. It follows logically that the performance of each firm will depend on different factors, which will ultimately influence the share prices. It would be almost impossible to differentiate between each of the factors that affect every individual firm, however, these firms have in common is that they, to a certain extent, depend on the water levels Rhine in their supply chain.

In general, variations in water levels are not necessarily an indication for disruptions. Water levels vary continuously and most industries are resilient to or not impacted by, changes in water levels. However, in the case of the Rhine, the year 2018 made it painfully evident that low water levels can cause severe disruptions.

The reason for these disruptions are quite extensive and cannot be pinned down to a single factor. This is in part due to variety of differentiating factors between firms, ranging from the location of the firm to the products it produces. But it is also due to the effect of water levels, since changes in the water levels set off a chain of events, rather than only one specific event.

Current literature would indicate that the effect of low water levels should be noticeable in share prices if firms experience a disruption. However, there is no clear definition or threshold when exactly the industry is disrupted by water levels, since there is a large variety of reasons why the industry can be disrupted. Therefore, changes in water levels are used as an indication of disruptions, rather than being the actual disruption.

Hence, the approach of this section is as follows. First, the characteristics of the river Rhine and the inland waterway transport characteristics, that are relevant to the manufacturing industry, are described. Second, the effects of low water levels on the industry are examined. Third, the counter measures that firms can undertake to mitigate the impact of low water levels are explained. And lastly, the relationship between water levels and share prices is discussed.

## 5.1 Characteristics of the Rhine

The industrial production hubs of the German manufacturing industry are mainly concentrated in Western Germany, in the Rhine states. The location of these hubs is strategically determined, since it provides access to one of the cheapest means of transport, namely inland shipping. The Rhine also provides cooling water to firms, which is required for certain industrial processes. As a result, the Rhine has become the most important river in Germany and is vital to the manufacturing industry.

### 5.1.1 The Rhine

The Rhine starts in the Swiss Alps, crosses through Germany and empties into the sea in The Netherlands. After the Danube, it is the longest river in Central and Western Europe, and stretches over 1230 km.

The Rhine consists of three segments. The first is the Lower Rhine, starting in Rotterdam, The Netherlands, and ending in Bonn, Germany. At this segment of the Rhine, the water levels are generally at their highest. The second segment is the Middle Rhine, continuing from Bonn to Mannheim, Germany. This segment is very important to consider for the effect of low water levels, as there is a crucial choke point in the river at Kaub, where the water levels are at their lowest. The third segment is the Upper Rhine, ranging from Mannheim to the source of the river in Basel, Switzerland. Figure 2 displays the river Rhine and the segments.

Due to its geographical location, the Rhine is a rain-snow river, meaning that its water levels are dependent on rain and snow (Jonkeren et al., 2011). The average water levels are generally higher in the winter and lower in the summer. As the Rhine does not have an artificial nature or a river-sea nature, like the Kiel Canal or the upper Danube respectively, it is especially susceptible to periods of droughts and increased volatility of the water levels. It is expected that the Rhine will be more rain-oriented in the future, due to climate change, which will further increase the volatility of the river (Jonkeren et al., 2011).

The Rhine connects Germany and Switzerland with Dutch seaports and acts as a key conduit for inland waterway transport, both internationally as domestically. International transport between Germany and the Netherlands is especially important, because a large fraction of goods first arrive via the ports at the North Sea and are transported farther upstream via the Rhine. This is reflected in he high share of inland waterway


Figure 2: The Rhine
Source: CCNR (2019)

export of the Netherlands and the relatively large imports of Germany (CCNR, 2019). Domestic German inland waterway transport is also essential, as goods are shipped between manufacturers. However, the economic gross value added of inland water transport in Germany is small; in 2017, only 6% of the total volumes transported was carried out by inland shipping (Ademmer et al., 2018).

#### 5.1.2 Transportation on the Rhine

The transport performance of inland shipping on the Rhine is subject to large fluctuations, which can mitigate or increase the impact of disruptions (Ademmer et al., 2018). If the intermediate inputs and end products are being increasingly transported via other modes of transport, the impact of a disruption on the Rhine will be mitigated. However, if the quantity of goods transported via inland waterways has increased, the negative impact of a disruption can be more extensive.

Inland shipping on the Rhine is mainly concerned with the transport of intermediate inputs and end products (Ademmer et al., 2018). Figure 4 shows the main quantities transported from 2013 to 2018, split by the type of goods. It should be noted, that the low water levels in 2018, caused all of the volumes transported to decrease for each of the the type of goods (CCNR, 2019).

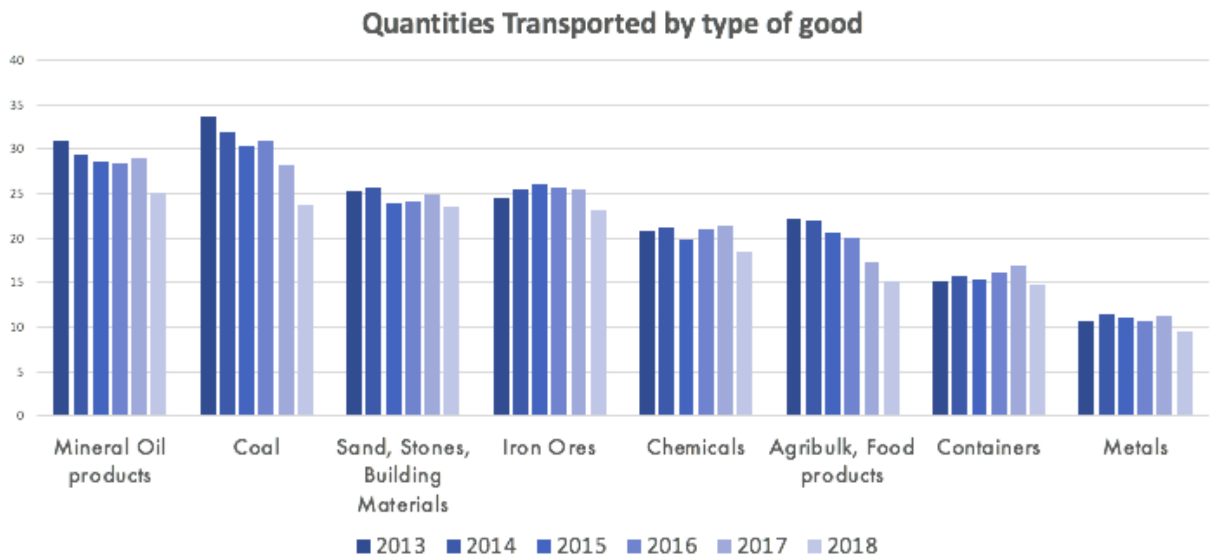


Figure 3: Goods transported on the Rhine transported
Source: CCNR (2019)

The trend of the quantities transported differ per type of good, with divergent underlying reasons. Transportation of chemical products via inland waterways has been increasing in Germany since 2008, albeit not monotonically (CCNR, 2019). This is due to the decrease in road transport of chemicals in the Netherlands over the past years, whereas international inland waterway transport of chemicals has been increasing. The reduction in road transport is partly due to safety standards, as higher safety standards apply to tankers, which provides an advantage compared to road and rail transport. Especially petroleum is mainly transported via inland waterways; in 2017, more than 90% of all petroleum in The Netherlands and 34% in Germany was transported via tankers CCNR (2019).

There is also a slightly increasing trend in the transportation of iron ores, sand, stones and building materials through inland waterways, however, not as pronounced as for chemicals. The transportation of metal has remained relatively stable over the past years, whereas the transportation of agricultural products has slowly been moving towards rail and road transport in Germany.

These developments have especially made the chemical industry more dependent on inland waterway transport over the years (CCNR, 2019). However, the chemical industry is a catalyst for other industries, as the chemical industry is upstream in the supply chain. As a result, a large fraction of the manufacturing industries has become more dependent on inland waterway transport, either directly or indirectly (CCNR, 2019).

The number of vessels in the fleet of the Rhine countries has been decreasing since 2005 (CCNR, 2019). The Rhine countries are The Netherlands, Germany, France, Belgium, Luxembourg and Switzerland. However, the total tonnage has been increasing, since smaller vessels leave the market, whereas larger vessels enter the market (CCNR, 2019). This trend is present in the dry cargo fleet, as well as the liquid cargo fleet.

The fleet development of the Rhine is an important factor to consider, since the draft of the vessel determines the required water levels. Generally, larger vessels have a deeper draft than smaller vessels, making smaller vessels more advantageous during days of low water levels. However, smaller vessels are not as cost-efficient as larger vessels during normal circumstances.

## 5.2 Low water levels of the Rhine

The intermediate inputs and end products, required for the manufacturing industry, are largely transported via inland shipping. One crucial condition to enable inland shipping, is that the waterways are navigable, meaning that they are sufficiently deep and wide. Generally, the width of the Rhine is not a prime concern, as long as the Rhine is sufficiently deep.

The depth of the Rhine determines the loading capacity of the vessels and there is a positive relationship between the water levels and the load factor (Jonkeren et al., 2007). If the water levels are above a certain threshold, the loading capacity of the vessels is unaffected and remains 100%, ceteris paribus. However, when the water levels are below a certain threshold, the loading capacity of the vessels starts to reduce. In case of extremely low water, vessels can even be prevented from sailing altogether, regardless of their load capacity. High water can also lead to a halt in shipping. If water levels exceed 8.30 m n the Rhine, barges cannot sail underneath bridges and must halt their operations until the water levels are below 8.20 metres again. This situation is rather rare however; only 12 days of high water have been measured from 2015 until 2018.

The water level threshold for a reduction in the load capacity, depends on the draft of the vessel. Typically, larger vessels have a deeper draft than smaller vessels. The result is a difference in threshold, as larger vessels require higher water levels than smaller vessels. As periods of reduced water levels occur frequently on the Rhine, vessels often experience a reduction in the load factor. The term 'reduced water levels' will be used from hereon forth, to describe water levels at which the load capacity of vessels is reduced.

Vessels will continue sailing if their load factor is reduced, however, the quantity of goods transported on a single trip will be lower. As a result, shippers face higher costs per tonne transported, which results in an increase in the price per ton transported. Consequently, there is a negative relationship between the load capacity and freight rates, and between water levels and freight rates(Jonkeren et al., 2011).

If there is a reduction in the quantity of goods transported, these shortages have to be recuperated by either other modes of transport or via inland shipping. Generally, small fluctuations in supply can be absorbed by a firm's inventory, and is not a reason of concern for the production. However, if the load capacity of the vessels is reduced for an extended period of time, it becomes increasingly hard to recuperate the volumes via inland waterway transport. Firms could recuperate (part) of the volumes through other modes of transport, though this is often quite difficult and expensive. As a result, the reduction of the load capacities of the vessels can result in a reduction of the total goods transported, which ultimately leads to a shortage in supplies (Ademmer et al., 2018).

Ademmer et al. (2018) assert that low water levels can also lead to production restrictions. These restrictions are primarily due to the significant reduction in inland waterway transport capacity, since firms are forced to lower their production if they experience shortages in supply. Firms can also be restricted by low water levels, if there is only a limited possibility of drawing off cooling water required for production processes (Ademmer et al., 2018). Certain sectors, such as the energy and chemical sector, have to reduce their production capacity if the machines cannot be adequately cooled.

In sum, insufficient water levels can cause a reduction in the load capacity of the vessels, an increase in the costs per tonne transported and the freights rates, a decrease in the total volume of goods transported and reduction in production capacity. These effects can place firms in a difficult position and eventually create conditions of financial distress.

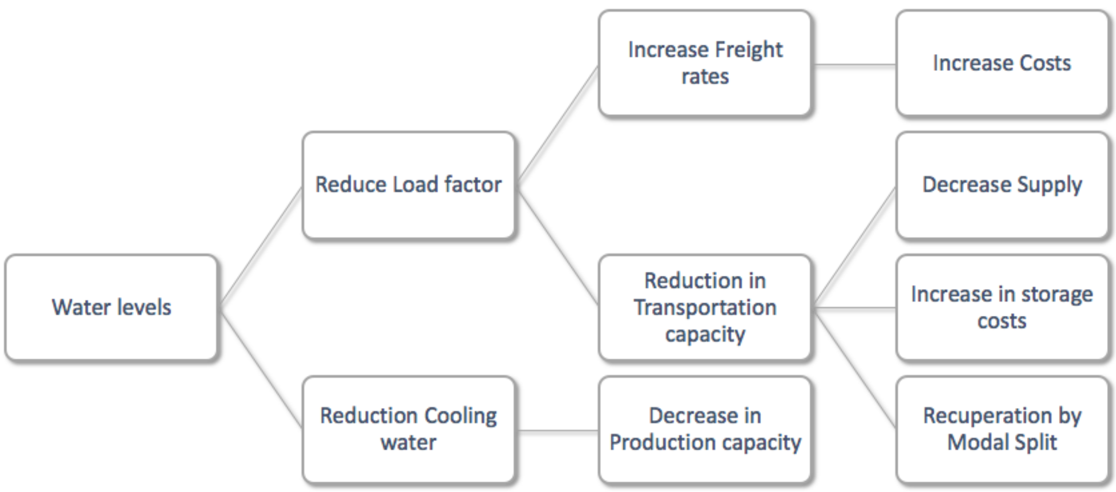


Figure 4: The effects of a reduction in water levels

### 5.2.1 Welfare effects of low water levels

The effects of low water levels can ultimately lead to disruptions in the supply chain and influence the performance of an individual firm and eventually, the entire manufacturing industry (Ademmer et al., 2020). These disruptions can have a macroeconomic relevance, as disruptions caused by low water levels of the Rhine, lead to a decrease in industrial output and aggregate economic activity (Ademmer et al., 2020).

Jonkeren et al. (2007) establish that low water levels can also lead to a significant annual welfare loss, despite the low share of total volumes transported and the relatively low gross value added of inland waterway transport. This is due to both the negative relationship between water levels and freight prices and the type of goods transported; most of the goods are intermediate inputs, which tend to be at the beginning of many production chains. Consequently, disruptions in the supply chain can lead to noticeable disruptions in the production chains, causing a loss in welfare (Ademmer et al., 2018).

The negative effect of water levels on annual welfare is enlarged by the characteristics of the inland waterway transport market. If the market was perfectly competitive, the costs increase per tonne should be equal to the increase in price per tonne. Jonkeren et al. (2011) characterise the inland waterway transport as a perfectly competitive market, as there are many suppliers who offer a homogeneous product, who can easily switch between routes and the market is easily entered compared to adjacent geographical reasons. However, this characterisation might be flawed. During the period of low water in 2018, Dutch and Belgian operators of especially smaller vessels, switched their area of operation to the Rhine, implying that the increase in price is larger than the increase in costs, enlarging the effect of a welfare loss (CCNR, 2019; Jonkeren et al., 2007).

## 5.3 Counter Measures

The two overarching negative effects of disruptions, caused by low water levels, are an increase in costs and a decrease in production capacity. These two effects also reinforce each other; as the costs associated with production increase, the production is lowered, but as the production is lowered, the associated costs of production increase. It follows logically that firms will try to limit the impact of this disruption, as this can affect the performance of a firm.

There are several measures firms can undertake to counter the negative effects of low water levels. This section focuses on strategic decisions to counter the disruption during the actual disruption and does not concern strategic decision making for the future as a preventive measure. In the past, either willingly or forced, firms have resorted to two main counter measures, namely a modal shift or lowering production.

### 5.3.1 Modal shift and lowering production

The supply of goods via inland waterways transport can be insufficient if the water levels are reduced, leading to shortages. Firms can attempt to recuperate part of the cargo volumes through other modes of transport, which are mainly rail and road transport. Aviation is not a viable option, since this is not competitive in price or efficient in handling large volumes of cargo. The ability of a firm to make use of rail and road transport depends on the location of the firm, since firms need to have access to the infrastructure required.

The ability to recuperate the cargo volumes through other modes of transport also depends on the quantity of goods that need to be transported. Barges can move large volumes of goods at once, whereas the volumes that can be transported via rail and road are considerably lower.

The main disadvantage of switching in transport modality is that inland shipping is by far the most competitive mode of transport. Switching to rail and/or road transport could therefore, substantially increase the costs of the supplies. However, it might be the case that rail transport is actually comparable in price to inland shipping, if the freight rates are severely higher than usual. It is unlikely that the price of road transport will be comparable to that of inland shipping.

If firms cannot recuperate the volumes through a modal shift, either due to their location or the required volumes, they are forced to lower their production. Firms might also choose to lower their production if there is a strong increase in the costs of production, making it impossible to produce goods at a viable price. By lowering production, firms are essentially waiting with producing until production becomes viable again.

Firms can also be forced to lower production due to a lack of cooling water required for the industrial processes. Unfortunately, firms do not have a direct counter measure in this situation.

## 5.4 Water levels and share prices

This paper analyzes the relationship between variations in water levels of the Rhine on the share prices of the German manufacturing industry, however, it does not assume that water levels have a direct effect on stock prices. Rather, the effect is indirect, since water levels are an indication of disruptions in the supply chain, which can impact the performance of a firm (Hendricks & Singhal, 2005a).

As mentioned in Equation 1, share prices reflect the expected discounted dividends. Water levels can impact the value of a share by disrupting the supply chain, which can decrease the expected future cash flow of a firm or increase the associated discount rate.

The level of expected future cash flows is primarily impacted because disruptions can reduce the level of industrial output. As mentioned before, reduced load capacities of the vessels can lead to a decrease in supplies that cannot be recuperated through other modes of transport, leading to a shortage in supplies. Or, firms have to halt industrial production processes, that rely on the availability of cooling water, which is scarce in periods of low water. In both cases, firms are forced to lower the production. If the production is lowered, the level of projected sales in the near future will also be lower, which decreases the expected cash flows.

The expected future cash flows are also impacted by the increase in the costs of production. Low water levels increase the freight rates, which increases the price of the required materials. Also, if the production is lowered, the costs associated with production increase, since the efficiency and the return on investments decrease. Again, in both cases the level of expected future cash flows decrease as the costs increase.

A more indirect effect on the level of expected cash flows, is related to the increase in costs as firm have to take preventive action in their supply chain. As firms anticipate the periods of low water, they might increase their storage of raw materials to ensure the production. However, this leads to an increase in working capital, hence, an increase in costs.

As a result of the increased volatility in costs and projected sales, the discount rate can increase. This has a negative effect on share prices, as the value of a share decreases as the discount rate increases.

Therefore, measuring the effect of water levels on share prices, indirectly measures if firms are disrupted by changes in water levels. Only if a firm is dependent on the Rhine, will the supply chain be affected by its water levels. Financial firms or service firms should, in theory, not be affected by the direct effect of periods of low water on their supply chain. However, in case of prolonged periods of low water, the effects can even diffuse to these sectors, as the level of aggregate economic activity diminishes (Ademmer et al., 2020).

# 6 Data

To measure the relationship between variations in water levels of the Rhine and the German manufacturing industry, this study examines a five-year period, starting in 2015 until 2019.

The daily data for the water levels is obtained from Interrijn Group, starting January 1st, 2015 until December 31st, 2019. The 4383 data points are carefully entered manually, as it is not possible to download the data set. The water levels are obtained for the gauging stations Ruhrort, Cologne and Kaub. Ruhrort and Cologne are located in the Lower Rhine, whereas Kaub is located in the Middle Rhine. Figure 2 also shows the location of the gauging stations Kaub and Cologne.

The summary statistics of the water levels are displayed in Table 2. The water levels are consistently lowest at Kaub, and increase at Cologne and are highest at Ruhrort. The volatility follows a similar trend, as it is lowest at Kaub and increases at Cologne and Ruhrort. The water levels of the Rhine are also seasonal, as the water levels are lower in the second half of the year than in the first half of the year.

Table 2: Water level Characteristics (in cm)

| | Ruhrort | Cologne | Kaub |
|---|---|---|---|
| Average | 382 | 287 | 199 |
| Volatility | 152 | 143 | 110 |
| Lowest measured water level | 109 | 68 | 25 |
| Highest measured water level | 968 | 872 | 679 |
| Maximum decrease | -230 | -158 | -142 |
| Maximum increase | 346 | 170 | 136 |

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The daily data for the German Stock prices is obtained through Datastream. The database only includes stocks traded on the Frankfurt Stock Exchange. Only ordinary share observations are included and other equity types are excluded from the sample. The data set consists of daily observations, starting from January 1st, 2015, until December 31st, 2019.

The data set of the firms listed on the Frankfurt Stock Exchange consists of 407 companies who are are currently active. There are 34 different industries and 1 category labeled as 'undefined'. The largest share of firms is allocated to the category undefined (75), while the three largest industries consist of Software and Computer Services (47), Financial Services (23) and Real Estate Investment and Services (22). Table 14, in the Appendix section A, gives an overview of the industries and the corresponding number of firms.

For determining which industries are part of the overarching manufacturing industry, all industries and their corresponding firms are analyzed and regrouped. 12 different industries are combined into one group, labeled as manufacturing firms, as displayed in Table 3. These firms combined form a group of 126 firms. The summary statistics are given in table 4. As can be seen from the table, the firms differ substantially in terms of share price, revenue and

Table 3: Constituents of the manufacturing industry

| **Industry** | **Number of Firms** |
|---|---|
| Aerospace and Defense | 3 |
| Alternative Energy | 9 |
| Automobiles and Parts | 18 |
| Chemicals | 17 |
| Construction and Materials | 9 |
| Forestry and Paper | 2 |
| Health Care Equipment and Services | 13 |
| Household Goods and Home Construction | 3 |
| Industrial Engineering | 18 |
| Industrial Metals and Mining | 3 |
| Pharmaceuticals and Biotechnology | 18 |
| Technology Hardware and Equipment | 13 |
| **Grand Total** | **126** |

Table 4: Summary statistics of the Manufacturing industry

| **Variable** | **Mean** | **Standard Deviation** | **Min** | **Max** |
|---|---|---|---|---|
| Share Price ($) | 44 | 72 | 0 | 1663 |
| Revenue ($ million) | 11 | 35900 | 0 | 253000 |
| Market Value ($ million) | 5.1 | 14.1 | 0 | 115030 |

# 7 Part I : The relationship between water levels and share prices

The goal of this paper is to examine the relationship between variations in water levels of the Rhine and the share prices of the German manufacturing industry. Current literature has identified that variations in water levels of the Rhine can cause disruptions in the supply chain, and that publicly announced disruptions affect share prices. However, there is no definitive threshold that determines at which point a supply chain is disrupted by water levels and there is no literature yet, on the relationship between water levels and share prices. Therefore, it is currently not known if changes in water levels impact share prices, and if so, under which conditions.

Since there is no research that gives an indication about the nature of this relationship, this study is first concerned with examining if variations in water levels are an indication of disruptions, which affects share prices. If there is a decrease in share price when the water levels decrease, this signals that the stock market is expecting the performance of the firm to be negatively affected, which signals a disruption. However, if there is no relationship between water levels and share prices, this can be seen as an indication that the variation in water levels in itself, do not necessarily predict a disruption.

This relationship is tested by a regression analysis that quantifies if water levels affect share prices, through a variety of different paths. This method is appropriate for this study since a regression analysis can determine which variables have an impact, while also determining how certain factors influence each other. Regression analysis also allows for multiple manipulations of the water level variable, to fully scrutinize the relationship.

Even though regression analysis is a standard approach in financial research, a more conventional approach could be a factor analysis. However, a factor analysis is not suitable in this case, since a factor model requires all assets to be priced according to their factor loading. Since the water levels of the Rhine are not relevant to the entire universe of assets, but only to those firms whose supply chain depends on the Rhine this method would not be valid. Event study methodology could also have been an interesting approach, however, it is unclear when low water levels can actually be considered an event, since there is no threshold. The approach of Hendricks & Singhal (2003) is also not applicable for this study, as it is a prerequisite of their method that the announcement is completely unexpected, which is not the case for low water levels.

The approach of this section is as follows. First, the construction of the water level variables is discussed. Second, the construction and the statistical characteristics of the relevant variables for determining share prices is discussed. Third, the model and the results are presented and lastly, the implications are discussed.

## 7.1 Construction of the water level variables

There are several implied relationships in the literature by which water levels can affect share prices. However, there is no concrete evidence on the nature of this relationship and the different possibilities in which water levels can affect share prices have not been excluded. Therefore, the goal of constructing several different water level variables is to scrutinize this relationship.

### 7.1.1 The gauging station at Kaub

The water levels at the gauging station at Kaub are used as a reference point for the water levels of the Rhine. Kaub is a small town located along the Rhine and is crucial as the Rhine narrows down in this segment of the river and the water levels are at its lowest. The depth at Kaub determines the maximum load factor for vessels that need to sail past this point and indirectly determines the costs per tonne transported (Jonkeren et al., 2007). If the water levels are reduced at Kaub, they are also reduced, to a certain extent, at the other gauging stations. Using the water levels of the decisive gauging station at Kaub, to determine the impact of water levels is in line with the method of both Ademmer et al. (2020) and Jonkeren et al. (2007). Figure 2 displays the Rhine and the gauging station Kaub.

### 7.1.2 Water level thresholds

The impact of water levels can be either measured directly, by simply adding the water levels to the model, or indirectly, via certain thresholds. In order to be relevant as a threshold, the threshold must be set at a point at which water levels can cause disruptions. Jonkeren et al. (2007) establish that there is no effect of water levels on the freight price per ton, the load factor and the price per trip when the water levels exceed 260 centimetres at Kaub. Therefore, in line with the finding of Jonkeren et al. (2007), only periods consisting of an average water level below 260 centimetres are considered for low water. Above 260 centimetres, it is assumed that the water levels do not have an impact and cannot cause disruption.

Ademmer et al. (2020) define a period as low water when it is below the threshold of 78 cm at Kaub, which is an official threshold of low water that serves as a benchmark for navigability (CCNR, 2019). When the water levels are reduced to 78 centimetres at Kaub, the load factor of most ships is severely reduced and logistics service providers might not guarantee their transportation services anymore (Ademmer et al., 2018). Therefore, this paper utilizes the threshold of 78 centimetres for periods of extremely low water levels, in line with Ademmer et al. (2020).

Next to the thresholds of Ademmer et al. (2020)and Jonkeren et al. (2007), this paper uses a third threshold, at 170 centimetres. This threshold reduces the interval between the formerly mentioned threshold and better fits the data, rather than only using 2 points.

The combination of these three points split the water level data into 4 segments. The first segment consists of all water levels that are equal to or larger than 260 centimetres and is referred to as high water. The second segment consists of all water levels between 260 centimetres and 170 centimetres, and is referred to moderately low water. The third period consists of all water levels between 170 centimetres and 78 centimetres, and is referred to as low water. The fourth segment consists of all water levels equal to or lower than 78 centimetres, and is referred to as extremely low water. Table 5 gives an overview of all the variables constructed for the model.

## 7.2 Accounting for the Global economic context

The global economic context is important to take into account when determining the effect of water levels on share prices. In essence, the global economic context reflects the state of the world and the level of uncertainty that investors face. However, it is

Table 5: Overview Variable construction

| **Factor** | **Variables** | **Measured as** |
|---|---|---|
| Water levels | Water levels | Absolute value |
| | High water | greater than 260 cm |
| | Moderate water | between 260 and 170 cm |
| | Low water | between 170 and 78 cm |
| | Extremely low water | less than 78 cm |
| Global Economic Context | The Business Cycle | Log relative of monthly European GDP |
| | Global Trade | Log relative of monthly growth in the value of exports. |
| Technical Factors | Industrial Production US | Log relative of monthly growth in the level of Industrial Production. |
| | The Yield Curve | The difference between long term government bonds and the US Treasury Bill. |
| | Inflation | Log relative of the change in inflation in the United States. |
| | The Economy | The return on the value-weighted NYSE index. |
| | Stock Co-Movement | The return on the manufacturing industry portfolio. |

challenging to directly quantify the state of the world, as this depends strongly on qualitative variables that depend on perception. For example, the state of the world depends on geopolitical tensions and trade agreements, that in itself cannot be quantified. Even though these variables cannot be directly quantified, the effects of qualitative variables can be quantified, meaning that certain variables can be seen as indicators of the state of the global economic context.

### 7.2.1 Global Trade

The effect of geopolitical tensions and trade agreements is partly captured by the level of global trade. It follows logically that prosperous trade agreements lead to higher levels of trade, whereas trade barriers lead to lower levels of trade. It should be noted however, that lost trade volumes due to trade barriers, can be recuperated by new trade agreements. Also, this variable captures more than only the effects of geopolitical tensions, as trade is dependent on a multiplicity of factors. With that in mind, this variable is still a valid proxy to also account for the geopolitical tensions and trade agreements.

The level of global trade is measured as the value of exports, as given by the IMF. Similar to Ademmer et al. (2020), the monthly level of global trade is used. The variable is constructed by the taking the log relative of growth in global trade.

$$Global\,Trade = log_e[(GT(t) - GT(t-1))] \tag{2}$$

where GT stands for the value of global exports in time $t$. Ademmer et al. (2020) use both contemporaneous and lagged global trade, however, their results indicate that there is no significant difference between the two variables. Therefore, only contemporaneous global trade is added to the model.

### 7.2.2 The Business Cycle

The business cycle cannot be captured in a single indicator, however, changes in the level of GDP constitute a decent proxy. If the level of GDP is increasing, the economy is expanding, and if GDP is decreasing, the economy is shrinking. Therefore, by controlling for the change in GDP, the model is controlling for changes in the business cycle. Since Germany is a European country, the level of changes in European GDP is used. The variable is constructed by taking the log relative of the monthly change in growth, as given by the European Commission.

$$Business\,Cycle = log_e[(EUG(t) - EUG(t-1))] \tag{3}$$

where $EUG$ stands for the growth in European GDP at time $t$. Even though the variable for trade uses global trade, rather than European trade, the same reasoning does not apply in this case. Share prices of the manufacturing industry in Germany are not likely to be related to the worldwide level of GDP. Economies can be simultaneously moving in different directions and controlling for multiple, unrelated business cycles would not improve the accuracy of the model. Second, Germany exports most of its products to Europe and the United States. Since the level of growth in Europe and the US is highly correlated, the model would not be enhanced by adding the level of GDP of the United

States (EuropeanCommission, 2021).

### 7.2.3 Business confidence

The level of business confidence is partly captured by the variable accounting for the business cycle and global trade. If GDP is growing, and global trade is increasing, this can be seen as an indication for prosperity and hence, a high level of business confidence. However, if the level of global trade is reducing and the level of GDP is decreasing, this can be seen as an indication of high uncertainty. Therefore, there is no specific variable added to account for the level of business confidence.

## 7.3 Construction of the Technical variables

Besides the global economic context that should be taken into consideration, there are also technical variables, since technical variables have the ability to influence share prices. A limited set of variables is introduced that has been identified in the current literature as prominent factors for determining share price movements. Besides the factors to account for the global economic context, these factors are added to the model to account for industry and macroeconomic effects.

### 7.3.1 Industrial Production US

The first factor is the level of the industrial production in the US. The level of industrial production in the US, rather than the level of industrial production in Europe, is chosen because the level of industrial production in the US is independent of the water levels of the Rhine and of Germany. The level of industrial production in Europe is largely driven by Germany, which makes it unfit to use as a variable in the model. The data is obtained from the Federal Reserve Bank of St. Louis. and consists of the monthly level of growth, with 2012 as a base year.

The variable to account for the level of the industrial production in the US is constructed by taking the log of the change in monthly growth.

$$Industrial\ Production\ US = log_e[(USP(t) - USP(t-1))] \tag{4}$$

where $USP$ stands for the industrial production in time $t$. This approach is similar to that of Chen et al. (1986), who construct the variable in the same fashion.

### 7.3.2 The Yield Curve

The second technical factor is the yield curve. The US Treasury Bill and the German Bunds are widely seen as the most risk-free loan, as both countries are extremely creditworthy. However, the return on the US Treasury Bill has been somewhat higher than the return on the German Bunds, which is why the US Treasury Bill is chosen to construct the term structure of interest rate.

The variable for the yield curve is constructed by taking the difference between the return on long term government bonds and the US Treasury Bill.

$$Yield\,Curve = LGB(t) - USTB(t-1) \tag{5}$$

where $LGB$ stands for long term government bond and $USTB$ stands for the US Treasury Bill in time $t$. The yield curve is calculated by taking the spread between the 10-year and 3-month Treasury Bill, as this spread is commonly used to measure the yield curve. This approach differs somewhat to that of Chen et al. (1986), who use the return on the 1-month Treasury Bill. However, given the current level of interest rates, the spread using the 3-month Treasury Bill is more appropriate. The data for yield curve is obtained from the Federal Reserve Bank of St. Louis.

### 7.3.3 Inflation

The third factor is the level of inflation. The level of inflation in the United States is chosen, due to the high correlation between European GDP and European inflation. However, the level of inflation still captures part of the level of inflation in Europe due to the moderate correlation between the two variables.

The variable is constructed by taking the log relative of the monthly change in inflation.

$$Inflation = log_e[IUS(t) - IUS(t-1)] \tag{6}$$

where $IUS$ stands for the level of inflation in the US in time $t$. By making the variable contemporaneous, it captures both the expected inflation, as well as the unexpected inflation. The data for the level of inflation in the US is obtained from the Federal Reserve Bank of St. Louis and consists of monthly percentage changes in the level of inflation.

### 7.3.4 The Economy

The fourth factor is the economy, represented by the return on the market. The goal of adding technical factors is to examine the influence of non-equity variables on the equity market, however, non-equity variables are rather slow in incorporating information due to their averaging and smoothing characteristics (Chen et al., 1986). The stock market on the other hand, is quick to incorporate information. As a result, the relationship between non-equity variables and share prices is likely to be noisy. Therefore, it is probable that there is a stronger relationship between the return on the stock market and individual share prices.

The variable representing the economy is the return on the market, for which the value-weighted return on the New York Stock Exchange (NYSE) is taken as a proxy.

$$The\ Economy = return\ on\ the\ value-weighted\ NYSE \tag{7}$$

The value weighted return is taken, as opposed to the equally weighted return, since the equally-weighted return overvalues micro-stocks. This approach is comparable to the methodology of Chen et al. (1986), who also use the return on the NYSE as a benchmark for the market. The NYSE has the largest market value of all stock indices and is therefore most likely to capture the largest share of the overall market. According to Chen et al. (1986), the return on the NYSE should also capture the influence of real information about the production levels and the influence of inflation. The data is obtained from the Center for Research in Security Prices (CRSP).

#### 7.3.5 Stock Co-movement

The fifth factor is the level of stock co-movement with the global manufacturing industry. The German manufacturing industry is in essence part of the overall manufacturing industry. Certain equity sectors can gain momentum, meaning that the entire sector will be associated with this momentum, regardless of the individual firm's performance.

The variable that accounts for the stock co-movement is constructed from the Kenneth-French industry portfolios.

$$Stock\ Co-Movement = return\ on\ the\ Manufacturing\ Industry\ Portfolio \tag{8}$$

The portfolios consist of all stocks that fall into the manufacturing category on the NYSE, AMEX, and the NASDAQ index. Certain manufacturing firms that are listed in Germany are also listed on these exchanges, however, the share of these firms in the portfolios is rather small given the size of the portfolios. Therefore, the correlation between the variables will not be driven by the presence of German firms in the indices.

#### 7.3.6 Statistical Characteristics of the Economic variables

Table 6 shows the correlation matrix between the variables to account for the global economic context and the technical variables.

The highest correlation is between the return on the NYSE and the return on the manufacturing industry portfolio. This is unsurprising, as the return on the manufacturing

Table 6: Correlation matrix

| | World Trade | Business Cycle | US production | Yield curve | Inflation | The Economy |
|---|---|---|---|---|---|---|
| Business Cycle | 7% | | | | | |
| US production | 0% | 70% | | | | |
| Yield curve | 6% | 55% | 75% | | | |
| Inflation | 1% | 12% | 11% | 4% | | |
| The Economy | 7% | 4% | 6% | 15% | 12% | |
| Stock Co-movement | 2% | 1% | 5% | 10% | 10% | 84% |

portfolio consists of stocks partly listed on the NYSE. As a result, there is multicollinearity between these two variables, which limits their predictive power.

The yield curve is moderately negatively correlated with the change in European GDP and highly negative correlated with the growth of the industrial production in the US. The former is unsurprising, as the yield curve can be seen as an indicator of future economic growth. The higher the term structure of interest rates, the lower the growth. The latter is also unsurprising, as the yields are low when the level of production is high. These correlations are similar to the results of Chen et al. (1986).

The variables for European GDP and the level of industrial production in the US are also strongly correlated. This is logical, as the the European business cycle is strongly correlated with the business cycle of the US (IMF, 2021).

The other variables display moderate levels of correlation that are important to take account. However, none of the variables can be dropped from model as no variable perfectly captures the importance of the other variables.

## 7.4 The Model

The goal of this part of the analysis paper is to analyze the relationship between share prices and water levels. This relationship can be estimated by the following model:

$$\begin{aligned} Share\,Prices_t = \alpha\, +\, \beta_1 Kaub_t \\ +\, \beta_2 Revenue_t \\ + \beta_3 Business\,Cycle_t \\ + \beta_4 Global\,Trade_t \\ + \beta_5 Industrial\,Production_t \\ + \beta_6 Yield\,Curve_t \\ + \beta_7 Inflation_t \\ + \beta_8 The\,Economy_t \\ + \beta_9 Stock\,Co - Movement_t \\ + \epsilon \end{aligned} \tag{9}$$

where the $\beta$ is the degree of change in the outcome variable, $\alpha$ is the constant and $\epsilon$ is the error term. The variable revenue is added to the model to account for the differences in revenue between firms.

Initially, the Breusch-Pagan test indicates that the model displays levels of heteroskedasticity. A visual analysis of the data also shows that there are, though very limited, certain outliers. A robust regression analysis is used to account for the heteroskedasticity and the outliers.

Robust regression can be used to overcome certain limitations in the data set. It should be noted however, that the difference in results between the ordinary least squares regression and the robust regression are marginal. Therefore, the results of this study are not biased by the use of a robust regression model. The results of the ordinary least squares regression are shows in the Appendix, section B.

## 7.5 Results

To determine the relationship between water levels and share prices, the monthly water levels are regressed on the share prices, while accounting for the state of the world and technical variables. The results are shown in Table 7.

### 7.5.1 Water levels

Water levels have no significant impact on share prices, as can be seen from Table 7. Multiple combinations of the variables all indicate that the relationship between water

Table 7: Regression results

| | Absolute Value Water Levels | One-Week Lag | Extreme low water |
|---|---|---|---|
| Water levels Kaub | 0.001 | 0.005 | -1.422 |
| | (0.16) | (0.53) | (-.45) |
| Revenue | 0.000*** | 0.000*** | 0.000*** |
| | (33.16) | (23.58) | (33.19) |
| Industrial Production US | 22.978 | 22.253 | 26.572 |
| | (0.4) | (0.41) | (0.47) |
| Yield Curve | 3.711** | 3.628** | 3.836** |
| | (2.02) | (1.97) | (2.06) |
| Inflation | -0.019 | -0.052 | 0.017 |
| | (0.03) | (-0.08) | (0.02) |
| The Economy | 11.912 | 14.857 | 11.63 |
| | (0.22) | (0.28) | (0.21) |
| Stock Co-movement | 0.018 | -0.007 | 0.010 |
| | (0.06) | (-0.02) | (0.03) |
| Business Cycle | 1252.555*** | 1251.609*** | 1252.104*** |
| | (3.78) | (4.13) | (3.78) |
| Constant | -5845.617 | -5838.794 | -5859.778 |
| R-squared | 10.98% | 10.99% | 10.99% |
| F-Statistic | 0.0000 | 0.0000 | 0.0000 |

levels and share prices is insignificant.

The relationship was tested with several variations of the water levels at Kaub. The water levels were added with a one, two and three week lag, to allow the stock market to incorporate the information about the water levels. The water levels were also included with one week prior, as forecasts of the water levels are available around one week in advance. The same procedure was executed for the dummy variables, assuming that the stock market might need time to react to water levels below a certain threshold. The results, however, continuously indicate that water levels have no significant impact on share prices.

Even though the relationship between water levels and share prices is insignificant, the sign of the relationship is in line with the expectations based on the literature. High water levels have a positive relationship with the load capacity of the vessels and cause fewer disruptions for the supply chain, which is why the expected relationship is positive. A negative relationship would indicate that share prices actually increase when the water levels decrease, which would be challenging to logically interpret.

The relationship between the categorical variables for high, moderate and low water levels is positive, however, the relationship between extremely low water levels and share prices is negative. The positive relationship between the variables is unsurprising, since water levels between 260 centimeters and 78 centimeters are very common. In the period from 2015 until 2019, the water levels were between 260 centimeters and 78 centimeters for 68% of the time. Therefore, it is likely that these variables do not have an impact, as they represent the normal situation. The negative relationship between extremely low water levels and share prices also matches the expectations, as water levels below 78 centimeters significantly hinder inland waterway traffic. The negative sign indicates that share prices decrease when the water levels are extremely low. Regardless, the relationship between the dummy variables and share prices remains insignificant.

It is unsurprising that the variable for the absolute value of the water levels has no significant relationship with share prices. This is likely because the fluctuations of the water levels of the Rhine are common and should already be incorporated into the share prices. Even days with critically low water levels are not rare and the effects should therefore already be incorporated. The results of Ademmer et al. (2020) show that a period of 30 days of water levels below 78 centimeters would reduce industrial production by 1%, however, most days below 78 centimeters do not occur in a row. Therefore, measuring the absolute value does not fully capture the effect of periods of low water

The dummy variables most likely do not capture the impact of the water levels as periods of reduced water levels are too frequent without any decisive effect on the industry. Brief periods of low water are to be expected by the manufacturing firms, hence, manufacturing firms anticipate low water levels and take the appropriate measures. As a result, the firms will likely still be to produce at the usual levels and prices, when the water levels are lowered for a brief period.

The variable for periods of extremely low water most likely does not capture the impact due to the frequency of extremely low water levels; in the period from 2015 until 2019, the water levels were below 78 centimeters for %10 of the time. Therefore, the occurrence of water levels below 78 centimeters is not a surprise to the stock market, and already incorporated.

### 7.5.2 Global Economic Context

The variable to account for the business cycle is significant, indicating the business cycle influences share prices. This result is in line with current literature, since the business cycle partly reflects the state of the economy. As GDP increases, the uncertainty in the investment landscape decreases, attracting more investors that are willing to invest in stocks.

The level of global trade is not significant in all variations of the model. This is likely due to the time lag between the incorporation of information about trade, and the actual effect of increased or decreased levels of trade.

### 7.5.3 Technical factors

Most of the technical factors do not have a significant impact on share prices, except for the variable to account for the yield curve. This is partly in line with the findings of Chen et al. (1986), who also find that the spread between long and short term interest rates has a significant impact on share prices and that the return on the NYSE does not have significant impact.

The level of US production and inflation are not significant, however, this contradicts the findings of Chen et al. (1986), who find a significant relationship between the level of US production and inflation. This difference could be driven the time period, as Chen et al. (1986) use a data set ranging from 1953 until 1983 , whereas this study uses data from 2015 until 2019. Second, the markets under examination are different. Chen et al. (1986) measure the effect of these variables in the US market, whereas this study measures the effect in the German equity market. Even though these markets are comparable, they are not necessarily equal and might react differently to information. Third, the difference might arise from the construction of the variables. Chen et al. (1986) use both expected inflation and unexpected inflation to account for changes in inflation, whereas this study examines the actual changes in inflation.

The changes in share prices are not driven by co-movement with the global manufacturing industry, as the relationship between share prices and stock co-movement is insignificant.

The variable accounting for the revenue is highly significant in all combinations of the model. This is line with the expectations based on the literature, as share prices represent the expected discounted future dividends. The larger the revenue of a firm, the larger the expected discounted dividends.

### 7.5.4 Results per industry

The difference in results is marginal if the results are re-examined per sub-industry. The variable for the yield curve and the business cycle is significant for most variables and the variable for revenue is highly significant for all the sub-industries. This indicates that fundamentals are eminently important across the different sub-industries and can be seen as the main driver of share prices in this model. The results for the sub-industries can be found in the Appendix, section C.

The one outlier is the Aerospace and Defense industry, as the water levels at Kaub are highly significant. The model also has an extremely high R-squared for this industry industry, namely 89.4%. However, the water levels are only significant for this sub-category, but the sample size is too small to make strong inferences. A deeper analysis of this result also shows that there is no relationship between low or extremely low water levels of the Rhine, but a positive significant relationship between moderate water levels. Therefore, this result does not give any reliable indication about the relationship between water levels and share prices.

### 7.5.5 Robustness

The number of variables and the high correlation between certain variables could be seen as a weakness of the model that taints the results. However, running the model with different combinations of variables that lower the correlation does not give any difference in result, indicating that the model is robust to over-specification and correlation between variables. If only the variables accounting for the business cycle, the yield curve and the revenue are included, the adjusted R-square of the model remains almost unchanged. The results of this model are shown in the Appendix, section D.

## 7.6 Implications

The multiple variations of the model all indicated that water levels do not have a significant impact on share prices. These findings imply that the stock market does not react to changes in water levels and that the stock market does not consider changes in water levels to be an indication of disruptions.

Even though the regression analysis shows that the relationship between share prices and water levels is insignificant, the severe impact of the period of low water in 2018 on the manufacturing industry remains undisputed. The chemical conglomerate BASF reported a loss of around 250 million Euros and steel producer Thyssenkrupp was forced to call force majeure due to the difficult circumstances. Given the findings of Ademmer et al. (2020) regarding the level of industrial output and the findings of Hendricks & Singhal (2005b) regarding the impact of disruptions, it is likely that the situation in 2018 caused a reaction of the stock market.

Given the fact that water levels are quite volatile and are frequently below optimal levels, it is likely that the impact of low water water levels does not lay in the occurrence of low water levels, but in their persistence. The current model cannot fully capture if there is an impact of periods of low water, depending on the duration of a period of low water. If there is a relationship between extended periods of low water levels and share prices, the effect is probably subsumed in the current model by the brief periods of low water that do not affect share prices. Therefore, the second part of this study will not focus on the impact of water levels, but will specifically focus on the impact of periods of low water.

# 8 Part II: The effect of periods of low water on share prices

The results from the analysis of Part I, indicate that low water are not directly perceived as disruptions that impact share prices. The results however, do not exclude the possibility that periods of low water might impact share prices, when accounting for the duration of the period. Therefore, this sections aims to determine if a period of low water has an effect on the share prices, and if the duration of period is a factor.

The approach of this section is primarily centered around determining if, and under which conditions, periods of low water affect share prices. Based on the current literature, the expected relationship is negative (Hendricks & Singhal, 2003; Ademmer et al., 2020; Jonkeren et al., 2007). However, extrapolating the impact of such a specific event, without having a framework that determines if and when share prices should be affected, is rather difficult. If it was established that a certain threshold constitutes a disruptive event that is measurable in share prices, the abnormal returns around the disruption date could be measured. Unfortunately, there is no threshold identified in the literature that distinguishes when a periods counts as a disruption and when exactly the manufacturing industry will be affected. A second factor that enlarges the difficulty is that share prices are extremely hard to predict and susceptible to many forces, which makes it challenging to extrapolate the effect of an event over a period.

Despite these obstacles, this paper attempts to examine if periods of low water negatively impact share prices, by treating periods of low water as an event. This approach differs from Part I, since the water level fluctuations during the period are disregarded. Standard event study methodology would have been appropriate if it was determined at which point low water levels become a disruption, however, since this is the question under consideration, this paper follows a somewhat different approach.

This section starts by determining what the requirements are for low water levels to be counted as a period of low water. The first step of the analysis is to determine if share prices significantly changed over the period of low water. It is expected that the share prices will decrease if the performance of the firm was impacted during this period. The advantage of this approach, is that only the cumulative effect over the period is considered and the interim fluctuations are disregarded. The second step, is to distinguish if the duration of a period of low water plays a role in affecting share prices. One considerable limitation of this approach is that no other variables can be included when determining if there was a significant change in share prices. Therefore, the third step of the analysis is to determine the abnormal returns over the period, based on a benchmark. This ensures that the results are corrected for market movements.

The general limitation of this approach, is that the chances that the share prices of a firm significantly changed over a period of time, increase the longer a period lasts. Therefore, the results must be examined with careful consideration.

This section is structured as follows. First, the construction of the periods of low water is discussed. Second, the construction of the model is explained and lastly, the results and the implications are discussed.

## 8.1 Periods of low water

To determine when the persistence of low water levels can be described as a period of low water, two factors must be considered. The first, is which threshold to use to refer to a measurement as 'low water'. The second factor is the duration, which refers to the number of days water levels should be below this threshold to count as a period of low water.

### 8.1.1 Threshold

The characteristics of the water levels at Kaub are important to consider, before determining when a period should be considered as a low water period. At Kaub, the water levels are the lowest of the entire Rhine, and are often below optimal levels. The yearly average of the water levels is around 2 meters, which is below the threshold of 260 centimers as identified by Jonkeren et al. (2007). The water levels are also very seasonal; in the period between 2015-2019, the average for the first half of the year is around 250 centimeters, whereas the average of the second half of the year is around 160 centimeters. Therefore, it should be taken into account that the water levels at Kaub are frequently affecting the load capacity of the vessels, but that this situation is rather usual.

The threshold of 78 centimeters at Kaub is an official benchmark for low water, as inland navigability is severely affected (CCNR, 2019). Between 2015 and 2019, there have been 181 days of water levels below 78 centimeters, which is roughly 10% of the total number of days. However, these results are largely driven be the period of severe drought in 2018. If the year 2018 is excluded, water levels are below 78 centimeters around 5% of the time. It should be noted however, that these extremely low water levels do not occur every year. Instead, days of extremely low water are preceded by a number of days where the water levels were already diminishing and the extremely low water period last for several days. These findings are also captured by Ademmer et al. (2020), who measure the incidences of low water from 1991 until 2018.

For share prices to be affected by periods of low water, the water levels must be significantly low to hinder inland waterway traffic, but also infrequent enough to still count as new information that has to be incorporated by the stock market. Jonkeren et al. (2007) establish a negative relationship between the freight rates and water levels below 260 centimeters, however, water levels are frequently below 260 centimeters at Kaub. Therefore, it would not be logical to count water levels below 260 as a period of low water, as the increase in freight rates should already be calculated into the cost models of the firms and hence, into the share prices.

The threshold of 78 centimeters could be seen as a more appropriate indicator for periods of low water, despite the fact that these levels are measured roughly 5% of the time. This is because these levels do not occur every year and there could be several years between the occurrence of these water levels (Ademmer et al., 2020). Since Ademmer et al. (2020) establish that water levels below 78 centimeters pose serious logistical difficulties and significantly affect the level of industrial production, the effect of this threshold can be significant, but likely not already calculated into the share price. Therefore, 78 centimeters is used as the threshold for a period of low water.

### 8.1.2 Duration

The second factor to consider, is the required duration of low water levels to count as a period of low water. In total, there have been 181 days below 78 centimeters at Kaub between 2015 and 2019. These days could be split up into periods, where a period consists of one or more days of water levels below 78 centimeters. However, certain instances of low water only last for a few days, and are not likely to have a real impact. Therefore, only low water levels that last a week or longer are considered as a period.

There are 4 periods when the water levels are below 78 centimeters for more than a week. It should be noted that a period is counted as a single period if the water levels are mostly below 78 centimeters, but increase slightly above 78 centimeters for a few days. Splitting the period into multiple periods when the water levels are above the threshold for only a few days would be illogical, as the circumstances in the supply chain have not changed in a few days.

## 8.2 The Model

The goal of this section is to determine if periods of low water have an effect on share prices. A paired sample t-test is used to determine if the share prices differ significantly before and after the period of low water. This is measured for the entire manufacturing industry, but also per sub-industry.

Weekly share prices are used to determine the effect, rather than daily share prices.

This is because the volatility of weekly share prices is lower than daily share prices. Also, the stock market might need time to incorporate information, which is better reflected in the weekly average.

A period is considered as lower water when the weekly average is equal to or below 78 centimeters at Kaub. It follows, that days of low water are preceded by a number of days where the water levels were already diminishing. Therefore, a period starts one week before the low water levels and ends one week after the low water levels. In total, there are 4 periods. Table 8 gives an overview of the periods and their duration. As can be seen from the table, the periods differ substantially in their duration, ranging from 3 weeks up to almost 4 months. However, all periods occur in the second half of the year.

Table 8: Overview of the Periods

| | **Begin** | | **End** | | **Duration (in weeks)** |
|---|---|---|---|---|---|
| | year | week | year | week | |
| Period 1 | 2015 | 43 | 2015 | 48 | 6 |
| Period 2 | 2016 | 40 | 2016 | 42 | 3 |
| Period 3 | 2016 | 50 | 2017 | 5 | 8 |
| Period 4 | 2018 | 30 | 2018 | 49 | 20 |

#### 8.2.1 Step 1: The impact of low water levels

The first part of the analysis determines if there is a significant difference in share prices before and after the period of low water levels, while taking the difference between industries into account. Table 9 gives an overview of the industries. There are 4 industries that have been regrouped into the category "Other", as they consisted of too little industries to make a sensible conclusion. The Wilcoxen signed-rank test is used to analyze the effects per industry, as the number of firms in the sub-industries is quite low.

The results are displayed in Table 10. In period 1, which lasted a total of 6 weeks from week 43 in October until week 48 in November, there is a significant difference ($M = 36.9, SD = 54.5$) in share prices before and after the period of low water, $t(111)$ = -2.3, $p$ = .01. However, these results are contrary to what one would expect, as the share prices actually increased slightly during this period. The Wilcoxen signed-rank tests indicates that these results seem to be driven by only two industries, namely the Automobiles and Parts and the Health Care Equipment and Services industries. These two industries experienced a strong decrease in share price, whereas no other industry experienced a significant decrease or increase.

In period 2, which lasted 3 weeks from week 40 until week 42 in October, 2016, there is no significant difference in ($M = 40.8, SD = 55.2$) in the share prices before and after the

Table 9: Overview Sub-Industries

| **Industry** | **Count** |
|---|---|
| Alternative Energy | **9** |
| Automobiles and Parts | 18 |
| Chemicals | 17 |
| Construction and Materials | 9 |
| Health Care Equipment and Services | 13 |
| Industrial Engineering | 18 |
| Pharmaceuticals and Biotechnology | 18 |
| Technology Hardware and Equipment | 13 |
| Other | 11 |
| Total | 126 |

Table 10: Results of the t-test

| Period | Before Low Water Mean | After Low water Mean | Change | t-Test |
|---|---|---|---|---|
| 1 | 39.8 | 41.1 | -1.3 | -2.32** |
| 2 | 40.8 | 40.1 | 0.7 | 0.98 |
| 3 | 40.2 | 41.1 | -0.9 | -1.22 |
| 4 | 47.8 | 37.9 | 9.9 | 6.52*** |

period of low water levels, $t(113) = -0.98, p = .33.$. The Wilcoxen signed-rank test furhter confirms this, as there is no industry that witnessed a significant increase or decrease.

In period 3, which lasted 8 weeks from week 50, in December 2016, until week 5, in February 2017, there is no significant difference ($M = 40.1, SD = 55.7$) between the share prices before and after the period of extremely low water levels occurred, $t(113) = -1.22, p = .23$. The Wilcoxen signed-rank test further indicates that there are no true effects for the manufacturing industry, rather, the effects differ per industry without a clear line. However, the one exception is the Pharmaceuticals and Biotechnology industry, as the share prices of almost all firms increased.

In period 4, the longest period, which lasted 20 weeks starting from the last week of July, 2018 until the last week of November, 2018, there is a significant difference ($M = 37.9, SD = 48.4$) between the share prices before and after the period, $t(119) = -1.22, p = .23$. The share prices of every industry significantly decreased, except for the Alternative Energy and Pharmaceuticals and Biotechnology industry, where the decrease was insignificant. The decrease in share prices is quite considerable; the Automobiles and Parts, Chemicals and Construction and Materials industry, which make up 34% of the sample, have an average decrease of over 20%. Table 11 shows the equal-weighted average loss per industry. Even though the results are not significant for every industry, a quick scan of the table gives a clear indication that, at least on average, the share prices strongly decreased.

Table 11: Overview of share price change in period 4

| **Industry** | **Percentage change** |
|---|---|
| Alternative Energy | -13% |
| Automobiles and Parts | -24% |
| Chemicals | -23% |
| Construction and Materials | -21% |
| Health Care Equipment and Services | -16% |
| Industrial Engineering | -16% |
| Other | -12% |
| Pharmaceuticals and Biotechnology | -12% |
| Technology Hardware and Equipment | -16% |

### 8.2.2 Step 2: determining the impact of duration

The next step is to determine if the duration of the drought has an effect on the share prices. The percentage increase and/or decrease is calculated for every firm and for every period. A visual representation of the average changes per period are displayed in the Appendix, section E, Figure 8. By means of a one-way ANOVA, the difference between the periods is statistically examined. The advantage of this approach is that the level of change between the periods are compared, indicating if the effect differs per period.

The results of the one-way ANOVA indicate that there is a statistically significant difference between the means of the groups, as given in Table 12 . The average price changes per period differ substantially; in period 1, the average price change is around 6%, whereas the average price change in period 4 is -18%. A Bonferroni post-hoc correction is used to account for the fact that the probability of a significant result, increases with every test. The longest period of low water levels, namely period 4, differs significantly from all other periods. This indicates that the influence of the duration of period 4, differs from the other periods. However, the difference between the others periods is less pronounced. Period 1 does not differ significantly from period 2 and 3, whereas period 2 and 3 do differ significantly. It is challenging to interpret these differences in the context of low water levels, since the share prices actually increased, rather than decreased.

The full output of the results of the Bonferroni correction and the Anova analysis are given in the Appendix, section E in Figure 10 and Figure 9.

Table 12: Results Anova and Bonferroni Correction

| Anova | | | | | Bonferroni correction | | |
|---|---|---|---|---|---|---|---|
| | Sum of Squares | F-value | Probability | Period | 1 | 2 | 3 |
| Variance between periods | 5.6 | 53.70 | 0.0000 | 2 | -0.06 (0.085) | | |
| | | | | 3 | 0.05 (0.202) | .11 (0.000) | |
| | | | | 4 | -0.24 (0.000) | -0.18 (0.000) | -.29 (0.000) |

## 8.3 Abnormal Returns

The previous part of the analysis determined if there is a significant change in share prices before and after a period of low water, and if these changes per period differ significantly from each other. However, this analysis does not account for the influence of exogenous factors. Therefore, the last step is to determine the extent to which the share prices decreased, while taking the market fluctuations into account. By measuring the abnormal returns, which are the deviations between the actual returns and the expected returns, the impact on the share prices of a firm is quantified.

### 8.3.1 The Model

The goal of this section is to determine the abnormal returns over a period of low water. There are multiple approaches to determine the abnormal returns over a longer period, however, this research follows the method of Hendricks & Singhal (2005b), who estimate the long-term stock price effects through buy-and-hold abnormal returns. The buy-and-hold abnormal returns approach compares the actual returns to a benchmark, over a period of time. The returns are calculated by taking the simple weekly returns of the individual securities, which ensures that the relative change is captured, rather than the absolute change. By examining the weekly returns, daily fluctuations are smoothed and the impact per week can be examined. The individual security's expected returns, based on a market model, serve as the benchmark. Hence, the expected returns are calculated by:

$$E[R_i] = \alpha_i + \beta_i(E[R_m]) \tag{10}$$

where $E[R_i]$ is the expected return on asset $i$, $\alpha_i$ is the intercept, $\beta_i$ is the sensitivity coefficient and $(E[R_m])$ is the expected return on the market. For each period $t$, the historical $\beta_i$ is taken from the month prior to the period of low water. This ensures that the sensitivity coefficient is not impacted by the period of low water and better reflects the sensitivity. The intercept $\alpha$ is measured over the entire 5-year time period. The return on the S&P 500 is taken as the return on the market, since the S&P 500 captures the 500 largest companies and comprises almost 80% of the total market value.

To determine the cumulative effect over the period of low water, the buy-and-hold abnormal returns approach is applied:

$$BHAR_i = \prod_{t=1}^{T}(1+R_{it}) - \prod_{t=1}^{T}(1+R_{bt}) \tag{11}$$

where $BHAR$ stands for the buy-and-hold abnormal returns for asset $i$, $R_{it}$ stands for the actual return of asset $i$ in period $t$, and $R_{bt}$ stands for the return of the benchmark in time $t$.

For each period of low water, the buy-and-hold abnormal returns are calculated for each individual firm and aggregated into an equal-weighted return portfolio. In line with the methodology of Hendricks & Singhal (2005b), the significance of the returns per period are examined. The results are displayed in Table 13. As can be seen from the table, the abnormal returns are significant for period 1, 3 and 4.

Table 13: Abnormal returns per period

| | Duration in weeks | Abnormal Returns |
|---|---|---|
| period 1 | 6 | 3.40%** (2.25) |
| period 2 | 3 | 0.41% (0.50) |
| period 3 | 8 | 7.72%** (3.78) |
| period 4 | 20 | -20.26%*** (-8.26) |

The abnormal returns over an extensive period of low water are around -20%. This finding implies that a period of 20 weeks of low water disrupts the manufacturing industry and negatively impacts share prices. This finding is line with the expectations based on the literature (Hendricks & Singhal, 2003; Ademmer et al., 2020; Hendricks & Singhal, 2005b). However, the abnormal returns associated with period 1 and 3, are significantly positive. These findings contradict with expectations based on the literature, and should be carefully interpreted. Abnormal returns calculation only measures if the expected returns deviate from the actual returns. Therefore, given that there is no indication whatsoever that share prices would increase due to low water levels, the positive abnormal returns are not ascribed to low water levels.

The main disadvantage of the buy-and-hold abnormal returns approach is that the longer a period lasts, the more likely it becomes that the abnormal returns are significantly different from 0. This issue is also present in this analysis, as the t-statistic increases, as the period increases. In order to ensure that the significance of period 4 is not due to the duration of the period, the same procedure is repeated for a period of 8 weeks, starting after the initial 8 of the period weeks. The results indicate that there is still a strong significant decrease in share prices of around -18%. An overview of these results is given in the Appendix, section G.

The results from the t-tests differ from these results of the abnormal return analysis with respect to period 3. The difference in share price was not significant in the first part of the analysis, but is significant in this part of the analysis. This implies that the share prices of period 3 do not differ significantly due to low water levels, but they do significantly differ when compared to the market returns.

## 8.4 The implications

The implications regarding the above-mentioned findings are strongly tied to the duration of the periods of low water levels. The periods have a varying duration, with the briefest period lasting 3 weeks, and the longest period lasting 20 weeks. However, by a simple examination of the duration of the periods, it becomes clear that there is a gap between the longest and second longest period. In 2018, the period of low water was exceptional as it lasted for 20 weeks, whereas the other periods do not stretch further than 8 weeks.

These implications are reflected in the results, as relatively short periods of low water do not seem to have an effect on share prices. To be more specific, there is no significant negative effect on share prices that can be attributed to a period of low water, if the period lasts 8 weeks or less. However, multiple tests also indicated that the results for these brief periods of low water are not identical. Regardless, this is to be expected, since they are measured over different time periods and have a different duration. The longer the time period, the more likely that share prices have changed significantly.

In period 1, the t-test analysis indicates that there is a significant decrease in share prices before and after the period of low water. However, these results are driven by a strong decrease in the Automobiles and Parts and the Health Care Equipment and Services industries. If the decrease would be caused by low water, the effect should be noticeable in at least the majority of the manufacturing industry. In this case, the effect is only noticeable in 2 out of 9 industries, indicating that this is an industry-specific result. Also, if the decrease was caused by low water, the results should also be noticeable in periods that last longer than period 1 (6 weeks), which is not the case. Lastly, when corrected for market-wide influences, the manufacturing industry actually significantly outperformed the market. Therefore, the findings of the significant decrease in period 1 is not ascribed to low water levels.

There are multiple reasons why periods of low water, that last 8 weeks or less, might not have an affect on share prices. Investors often react to information that is publicly announced, however, relatively brief periods of low water are quite common and might not be announced to the stock market. Since one might assume that most investors do not regularly check the weekly development of the water levels, brief periods of low water might simply fall under the radar of the stock market.

A second explanation regards the fact that the stock market does tends to incorporate all available information into share prices.Therefore, it might be the case that investors actually anticipate these fluctuations in the water levels and have already calculated this into the share prices. As long as the periods of low water do not exceed their expectations, there is no reason for the stock market to react.

A third explanation regards the management and counter measures of the manufacturing industry. Since firms are also likely to anticipate periods of low water, they will take the appropriate measures beforehand. This means that their supply chain management has ensured that the supply chain is resilient to brief disruptions caused by low water levels. Therefore, there is no reason that the outlook for the industry should change, as long as the risks are already incorporated into the firm's expectations and the appropriate counter measures are taken.

The results for the period of low water in 2018 indicate that there is a negative impact of extended periods of low water on share prices. This period lasted for 20 weeks, which is considerably longer than the other periods. However, the mechanisms that cause the disruptions do not differ between the periods. Therefore, it is important to consider what differentiates a significantly negative 20-week period, from an 8-week period.

The first aspect to consider is the awareness and the attention of the low water period. In 2018, circumstances were so severe that major players in the market were forced to make announcements about the disruptions. Steel producer Thyssenkrupp, which is one of the major steel producers in Europe, was forced to call force majeure. BASF, the largest global chemical concern, had to inform the market that they were expecting a loss of 250 million Euros. Announcements like these have a vast impact on the stock market, and often lead to immediate price corrections. As a result, industries that are associated with these firms or are similarly located, are also likely to experience price corrections.

The second point to consider is the impact on the production levels. During periods of low water, the production capacity decreases, either due to a shortage in supplies or a lack in availability of cooling water. In 2018, the water levels were exceptionally low, even going below 30 centimeters on certain occasions. Even if investors and firms have already taken into account that water levels are often below optimal levels, they do not account for these rare, extreme circumstances. As a result, firms are not prepared for these scenarios and are forced to lower production, whereas the stock market could not have expected these events, and will have to correct itself.

The third aspect to consider, is the increase in price, associated with production. As the low water levels lasted for an extensive period, the level of the freight rates increased strongly. Fluctuations in freights rates are normal, but in 2018, the freight rates were excessively high for an extended period of time, increasing the cost of production. If inland shipping was not possible at all, firms can also attempt to recuperate part of the volumes through other modes of transport. However, the prices associated with production will still rise substantially. This leaves firms with two choices, either pay the higher price for the goods, or reduce the level of production. The choices depend on the firm and on the industry, and will have a different impact per firm. Regardless of a firm's choice, the result is the same, since the associated costs of production increase.

Besides the immediate impact, such as the temporarily lowered production, the future outlook of a firm also changes, since the associated risks increases, lowering the share prices for a certain period (Hendricks & Singhal, 2005a). Also, firms are likely to prepare themselves against these extreme circumstances in the future. The strategic adaptations a firm will make depends on the firm, but it could lead to a relocation of production facilities, an increase in inventory or the development of new barges that have a shallower draft. Most of the strategic decisions, will be temporarily impact a stock's future financial outlook, due to the associated increase in costs.

### 8.4.1 Establishing the influence of exogenous factors

The results of the extended period of low water should be considered in combination with exogenous factors that can impact the manufacturing industry. Therefore, similar factors as those introduced in the previous sections are considered.

In 2018, the growth if the level of GDP was stagnating in almost all countries of the EU, after multiple periods of sustained growth (CCNR, 2019). In part, this was due to economic activity diminishing in Europe, but also on a global scale. According to CCNR (2019), the main cause for the slow down in growth of European GDP, was due to the decrease in global trade. Global trade is influenced by trade barriers and trade tensions, which in turn influences the level of business confidence.

In 2018, the trade tensions between the US and China were increasing, which resulted in a correction of the global stock market (CCNR, 2019). The upcoming Brexit also posed difficulties as negotiations between the EU and the UK were slow, and overall, this development further increased the level of investment uncertainty (CCNR, 2019). Despite these negative developments regarding trade certainty, there were also few positive developments. The EU made new trade agreements with Japan and the Comprehensive and Progressive agreement for Trans-Pacific Partnership came into life, which enhances trade (CCNR, 2019). However, if it hard to estimate which of these developments has a larger effect, and whether the positive developments outweigh the negative developments.

Overall, the investment landscape in the second half of 2018 was less promising than in the years leading up to 2018. The level of industrial production was diminishing and the EU exported fewer industrial goods in 2018 than in 2017 (CCNR, 2019).

The abnormal return calculation should capture these developments, as the expected returns of the benchmark depend on the movement of the market. Nonetheless, these developments are very likely to be a contributing factor as to why the share prices of the manufacturing industry decreased by such a large extent.

### 8.4.2 Robustness check

In order to test the robustness of the effect of periods of low water on the manufacturing industry, the same method is applied to a control group. The control group consists of industries that, in theory, should not be affected by water levels.

The results of the control group display similar properties as the results of the manufacturing industry, such that the longer the period, the more likely there is a significant change in share price. However, there does not seem to be a significant effect due to the low water levels. Still, the developments as described in the previous section did seem to affect these markets, as the share prices significantly decreased, albeit a lot less than the manufacturing industry. The output of the results are given in the Appendix, section F.

# 9 Conclusion

This research sets out to explore the economic impact of weather-related disruptions in the supply chain by examining the relationship between variations in water levels of the Rhine and the share prices of the German manufacturing industry. The analysis makes use of water level data from 2015 until 2019 and indicates that extended periods of low water levels can cause a significant and meaningful decrease in the share prices of the German manufacturing industry.

In Part I, this study established that fluctuations in water levels do not have significant effect on share prices, by testing for the relationship between water levels and share prices. However, this paper does not claim that all viable measures to exhaustively characterize water levels have been studied. Instead, a set of relevant water level variables was introduced that measure the direct relationship between share prices and water levels, while accounting for multiple periods of lags and several categories of water levels.

In Part II, this study established that extensive periods of low water negatively impact share prices, by testing if share prices significantly decreased over a period of low water levels. However, periods of low water that last 8 weeks or less do not have a significant negative impact on share prices. The results of the abnormal return analysis indicates that, on average, a firm loses 20% in value over an extensive period of low water. The loss in share price can be mainly ascribed to firms having to lower production or increase the price associated with production.

These results have important implications for the manufacturing industry. First, the results indicate that the industry is either resilient to brief disruptions, or that the associated risks are already calculated into the share prices, since share prices do not react negatively to brief periods of low water.

Second, the results indicate that the industry cannot withstand extensive disruptions and that extensive disruptions have severe economic consequences. Besides the clear downside of a loss in share price for the shareholders, who can witness their capital evaporate, a decrease in share price also proves difficult for the underlying firm. Access to capital markets becomes more challenging if firms experienced a recent decrease in share price and firms will have to face higher refinancing costs in the future. If firms were to issue new shares in order to raise capital, the income would also be lower, due to the lower share prices. Overall, extensive disruptions decrease the share prices, which signals that a firm is experiencing difficulties and is decreasing in value.

Lastly, but most importantly, the economic significance of the results imply that firms have to make strategic decisions to counter disruptions in the future, or suffer the negative economic consequences. If extended periods of low water levels are part of a changing weather pattern, caused by climate change, then disruptions are to be expected in the future. As a result, firms will have to adapt their supply chain management in order to maintain their performance.

A limitation of this study is that it attempts to measure disruptions caused by low water levels, but that there is no clear threshold as to when the manufacturing industry is disrupted. As a result, this study uses thresholds that are put forward in the literature, but there is no evidence on when these thresholds affect the manufacturing industry. This limitation is enhanced by the fact that share prices are used as an economic indicator, since share prices are susceptible to a wide variety of forces, making it difficult to extrapolate the effect of a disruption occurring in the supply chain. Future research could attempt to determine what the most appropriate threshold is that constitutes a disruption, noticeable in share prices. This could be done by analyzing low water levels and determining how long it takes before a firm make a public announcement of disruptions.

Another limitation of this study, is that the loss in share price is measured, rather than the loss in market capitalization. Since the results are based on equal weighted changes, the overall impact of the low water levels on shareholder value is not fully captured.

Future research could attempt to measure the loss in shareholder value lost, similar to the approach of Hendricks & Singhal (2005a).

The last limitation of this study is that there is no distinction made between the locations and production facility of a firm, since the categorization is solely done on industry. Therefore, firms that might not be affected can still be present in the sample. However, the question becomes if investors are fully aware of each of the production facilities and linkages in the supply chain of the firms they invest in, or if investors are only aware that this firm is located in Germany and part of the manufacturing industry. The latter is frankly more likely, as firms do not clearly specify the location of each of their production facilities or on which linkages in the supply chain they depend. Future research could incorporate these characteristics and analyse if the effect differs when accounting for the location facilities and supply chain of a firm.

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# A Firms

The returns for the stock of id 153 were removed from the data set, as the share prices were extremely volatile and tainting the results .

Table 14: Overview Industries

| Industry | count |
|---|---|
| Software and Computer Services | 47 |
| Financial Services (Sector) | 23 |
| Real Estate Investment and Services | 22 |
| General Retailers | 21 |
| Automobiles and Parts | 18 |
| Pharmaceuticals and Biotechnology | 18 |
| Chemicals | 17 |
| Industrial Engineering | 17 |
| Health Care Equipment and Services | 13 |
| Technology Hardware and Equipment | 12 |
| Fixed Line Telecommunications | 11 |
| Alternative Energy | 9 |
| Construction and Materials | 9 |
| Personal Goods | 9 |
| Support Services | 8 |
| Travel and Leisure | 8 |
| Media | 7 |
| Electricity | 6 |
| Industrial Transportation | 6 |
| Banks | 5 |
| Gas, Water and Multiutilities | 5 |
| General Industrials | 5 |
| Nonlife Insurance | 5 |
| Real Estate Investment Trusts | 5 |
| Electronic and Electrical Equipment | 4 |
| Food and Drug Retailers | 4 |
| Aerospace and Defense | 3 |
| Household Goods and Home Construction | 3 |
| Industrial Metals and Mining | 3 |
| Leisure Goods | 3 |
| Beverages | 2 |
| Forestry and Paper | 2 |
| Food Producers | 1 |
| Mining | 1 |
| Undefined | 75 |

# B Regression Results

As can be seen from figure 5, the results between OLS and robust regression are very limited. Therefore, robust regression does not taint the results.

| Source | SS | df | MS |
|---|---|---|---|
| Model | 1708592.4 | 8 | 213574.05 |
| Residual | 13847727.4 | 4,725 | 2930.73595 |
| Total | 15556319.8 | 4,733 | 3286.7779 |

| | | |
|---|---|---|
| Number of obs | = | 4,734 |
| F(8, 4725) | = | 72.87 |
| Prob > F | = | 0.0000 |
| R-squared | = | 0.1098 |
| Adj R-squared | = | 0.1083 |
| Root MSE | = | 54.136 |

| month_price | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| kaub | .0014942 | .0093083 | 0.16 | 0.872 | -.0167545 | .0197429 |
| totvallog | 11.91214 | 53.58564 | 0.22 | 0.824 | -93.14069 | 116.965 |
| yieldcurve | 3.711477 | 1.850713 | 2.01 | 0.045 | .0832171 | 7.339736 |
| usprodlog | 22.97826 | 55.91938 | 0.41 | 0.681 | -86.64979 | 132.6063 |
| eqManuf | .0180681 | .2947595 | 0.06 | 0.951 | -.559798 | .5959342 |
| EUgdplog | 1252.555 | 305.373 | 4.10 | 0.000 | 653.8818 | 1851.229 |
| inflationuslog | -.019313 | .6989318 | -0.03 | 0.978 | -1.389545 | 1.350919 |
| revenue | 4.99e-07 | 2.11e-08 | 23.58 | 0.000 | 4.57e-07 | 5.40e-07 |
| _cons | -5845.617 | 1287.227 | -4.54 | 0.000 | -8369.183 | -3322.052 |

Figure 5: Regression results using OLS

# C Regression Analysis per sub-industry

For each sub-industry, the same procedure is repeated and the variables are regressed. Therefore, only the output of the outlier is shown, namely the Aerospace and Defense industry, as can be seen in Figure 6.

-> industry = Aerospace and Defense

Linear regression

| | | |
|---|---|---|
| Number of obs | = | 88 |
| F(8, 79) | = | 78.48 |
| Prob > F | = | 0.0000 |
| R-squared | = | 0.8826 |
| Root MSE | = | 17.191 |

| month_price | Coef. | Robust Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| kaub | -.0685228 | .0217505 | -3.15 | 0.002 | -.111816 | -.0252296 |
| totvallog | 199.7394 | 147.1475 | 1.36 | 0.179 | -93.1503 | 492.6291 |
| yieldcurve | -43.45814 | 4.702788 | -9.24 | 0.000 | -52.81881 | -34.09748 |
| usprodlog | -114.6821 | 115.115 | -1.00 | 0.322 | -343.8127 | 114.4485 |
| eqManuf | -.9674068 | .7953805 | -1.22 | 0.227 | -2.550572 | .6157584 |
| EUgdplog | 5231.319 | 776.3435 | 6.74 | 0.000 | 3686.046 | 6776.592 |
| inflationuslog | .6909366 | 1.341825 | 0.51 | 0.608 | -1.9799 | 3.361773 |
| revenue | -.0000485 | 3.30e-06 | -14.68 | 0.000 | -.000055 | -.0000419 |
| _cons | -23141.93 | 3351.639 | -6.90 | 0.000 | -29813.2 | -16470.66 |

Figure 6: Regression results for the sub-industries: Aerospace

# D Robustness of the Regression model

The model is tested with a variety of combinations, that all indicate the same results. Therefore, only the regression with the identified variables are shown.

Linear regression

| | | |
|---|---|---|
| Number of obs | = | 6,439 |
| F(4, 6434) | = | 407.56 |
| Prob > F | = | 0.0000 |
| R-squared | = | 0.1090 |
| Root MSE | = | 53.805 |

| month_price | Coef. | Robust Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| kaub | .0064988 | .0074644 | 0.87 | 0.384 | -.008134 | .0211316 |
| yieldcurve | 2.211232 | 1.02127 | 2.17 | 0.030 | .2092019 | 4.213262 |
| EUgdplog | 1213.098 | 231.3613 | 5.24 | 0.000 | 759.5529 | 1666.643 |
| revenue | 4.96e-07 | 1.26e-08 | 39.51 | 0.000 | 4.72e-07 | 5.21e-07 |
| _cons | -5555.836 | 1067.021 | -5.21 | 0.000 | -7647.551 | -3464.12 |

Figure 7: Regression with only the significant variables

# E Analysis of Variance

This visual representation is not a parametric test, but simply gives an impression of the data. As can be seen from the figure, it seems that period 4 differs substantially from the other periods.

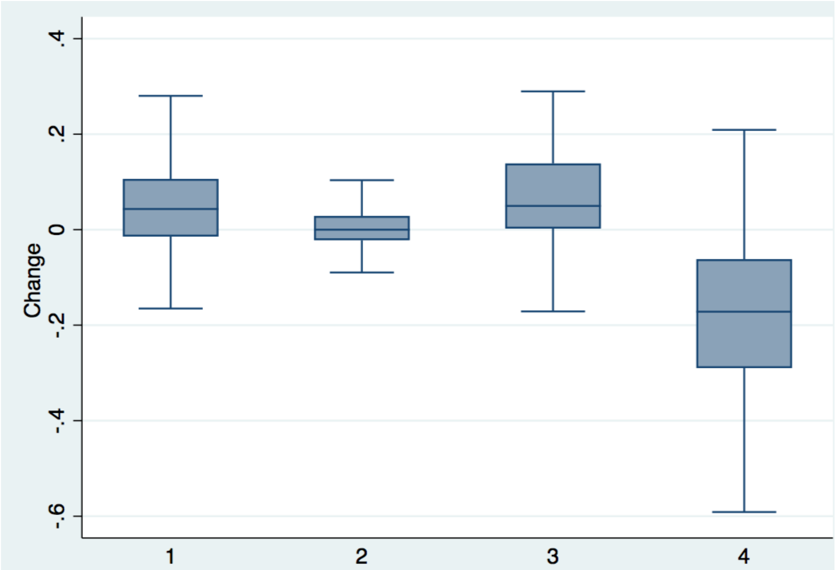


Figure 8: Graphical representation ANOVA

| Period | Summary of Change Mean | Std. Dev. | Freq. |
|---|---|---|---|
| 1 | .06253789 | .19892278 | 112 |
| 2 | .00125032 | .10172775 | 114 |
| 3 | .1157742 | .23803182 | 112 |
| 4 | -.17543199 | .18369675 | 120 |
| Total | -.00204879 | .2168862 | 458 |

Analysis of Variance

| Source | SS | df | MS | F | Prob > F |
|---|---|---|---|---|---|
| Between groups | 5.63066289 | 3 | 1.87688763 | 53.70 | 0.0000 |
| Within groups | 15.866445 | 454 | .034948117 | | |
| Total | 21.4971079 | 457 | .047039623 | | |

Bartlett's test for equal variances: chi2(3) = 74.0003 Prob>chi2 = 0.000

Figure 9: Anova results

Comparison of Change by Period
(Bonferroni)

| Row Mean-Col Mean | 1 | 2 | 3 |
|---|---|---|---|
| 2 | -.061288<br>0.085 | | |
| 3 | .053236<br>0.202 | .114524<br>0.000 | |
| 4 | -.23797<br>0.000 | -.176682<br>0.000 | -.291206<br>0.000 |

Figure 10: Bonferroni results

# F Robustness of impact of the periods

The following output shows the results of the impact of low water on the control group. These results differ to that of the manufacturing, as there is no indication that a period of low water had an impact.

Paired t test

| Variable | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| pri~5w43 | 49 | 21.00241 | 3.214218 | 22.49953 | 14.53979 | 27.46503 |
| pri~5w48 | 49 | 20.96771 | 3.224483 | 22.57138 | 14.48446 | 27.45097 |
| diff | 49 | .0346939 | .3014527 | 2.110169 | -.5714175 | .6408052 |

mean(diff) = mean(**price2015w43** - **price2015w48**) t = **0.1151**
Ho: mean(diff) = 0 degrees of freedom = **48**

Ha: mean(diff) < 0 Ha: mean(diff) != 0 Ha: mean(diff) > 0
Pr(T < t) = **0.5456** Pr(|T| > |t|) = **0.9089** Pr(T > t) = **0.4544**

Period 1

| Variable | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| pri~6w40 | 50 | 19.50926 | 3.195542 | 22.5959 | 13.08758 | 25.93094 |
| pri~6w42 | 50 | 19.90756 | 3.324005 | 23.50426 | 13.22772 | 26.5874 |
| diff | 50 | -.3983 | .287931 | 2.03598 | -.9769191 | .1803191 |

mean(diff) = mean(**price2016w40** - **price2016w42**) t = **-1.3833**
Ho: mean(diff) = 0 degrees of freedom = **49**

Ha: mean(diff) < 0 Ha: mean(diff) != 0 Ha: mean(diff) > 0
Pr(T < t) = **0.0864** Pr(|T| > |t|) = **0.1728** Pr(T > t) = **0.9136**

Period 2

| Variable | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| pri~6w50 | 50 | 20.23682 | 3.438931 | 24.31692 | 13.32603 | 27.14761 |
| pric~7w5 | 50 | 22.3861 | 4.132457 | 29.22088 | 14.08162 | 30.69058 |
| diff | 50 | -2.14928 | .9956502 | 7.04031 | -4.150114 | -.1484459 |

mean(diff) = mean(**price2016w50** - **price2017w5**) t = **-2.1587**
Ho: mean(diff) = 0 degrees of freedom = **49**

Ha: mean(diff) < 0 Ha: mean(diff) != 0 Ha: mean(diff) > 0
Pr(T < t) = **0.0179** Pr(|T| > |t|) = **0.0358** Pr(T > t) = **0.9821**

Period 3

Paired t test

| Variable | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| pri~8w30 | 54 | 25.48446 | 5.04689 | 37.08692 | 15.36168 | 35.60724 |
| pri~8w49 | 54 | 22.43963 | 4.482658 | 32.94067 | 13.44856 | 31.4307 |
| diff | 54 | 3.044833 | .8245911 | 6.059482 | 1.390913 | 4.698754 |

mean(diff) = mean(**price2018w30 - price2018w49**) t = **3.6925**
Ho: mean(diff) = 0 degrees of freedom = **53**

Ha: mean(diff) < 0 Ha: mean(diff) != 0 Ha: mean(diff) > 0
Pr(T < t) = **0.9997** Pr(|T| > |t|) = **0.0005** Pr(T > t) = **0.0003**

| id | Summary of diff2015 Std. Dev. | Freq. |
|---|---|---|
| 1 | .14619932 | 51 |
| 2 | .05683984 | 52 |
| 3 | .12709406 | 53 |
| 4 | .17884234 | 59 |
| Total | .13764273 | 215 |

Analysis of Variance

| Source | SS | df | MS | F | Prob > F |
|---|---|---|---|---|---|
| Between groups | .125803951 | 3 | .04193465 | 2.25 | 0.0833 |
| Within groups | 3.92853777 | 211 | .018618662 | | |
| Total | 4.05434173 | 214 | .018945522 | | |

Bartlett's test for equal variances: chi2(3) = **57.9673** Prob>chi2 = **0.000**

Comparison of diff2015 by id
(Bonferroni)

| Row Mean-Col Mean | 1 | 2 | 3 |
|---|---|---|---|
| 2 | .0041<br>1.000 | | |
| 3 | .034397<br>1.000 | .030297<br>1.000 | |
| 4 | -.032492<br>1.000 | -.036592<br>0.960 | -.066889<br>0.062 |

# G Abnormal Returns

This table shows the abnormal returns, obtained through the buy-and-hold abnormal returns approach, for each period, and for only the second 8 weeks in period 4.

Table 15: Significance of the Abnormal returns per period

| | *period 1* | *period 2* | *period 3* | *Period 4* | *period 4: part 2* |
|---|---|---|---|---|---|
| Mean | 0.034 | 0.004 | 0.077 | -0.202 | -0.177 |
| Variance | 0.029 | 0.008 | 0.053 | 0.053 | 0.360 |
| Observations | 126.000 | 126.000 | 126.000 | 88.000 | 125.000 |
| Hypothesized Mean Difference | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| df | 125.000 | 125.000 | 125.000 | 87.000 | 124.000 |
| t Stat | 2.248 | 0.498 | 3.777 | -8.260 | -3.302 |
| P(T<=t) one-tail | 0.013 | 0.310 | 0.000 | 0.000 | 0.001 |
| t Critical one-tail | 1.657 | 1.657 | 1.657 | 1.663 | 1.657 |
| P(T<=t) two-tail | 0.026 | 0.620 | 0.000 | 0.000 | 0.001 |
| t Critical two-tail | 1.979 | 1.979 | 1.979 | 1.988 | 1.979 |