The impact of COVID-19 and lockdowns on the US semiconductor equity market

A time series analysis in a sensitive and important sector before and after a shock

By: Ahmed Omer Rasheed & Steven Challita

Supervisor: Xiang Lin
Södertörn University | Institution of Social Sciences
Economics | Bachelor's Thesis 15 credits
Autumn Term 2021

SÖDERTÖRN UNIVERSITY | STOCKHOLM
sh.se

First and foremost, we want to express our deepest gratitude to our supervisor Xiang Lin for the help in this project. As Student of economics we also want to thank the rest of the staff in Södertörn University with the help in our journey. And lastly of course we thank our family and friends with all the support during this period.

Keywords: shortage, market, government, COVID-19, semiconductor, supply chain, industry, equity market, PHLX, SOX, S&P 500, CAPM, EMH, behavioral finance, business cycles.

Abstract

The purpose of this study is to investigate the effects of COVID-19 initial hit and the associated lockdowns effect on the semiconductor industry. The study emanates from factors of return on investment in the equity market using the CAPM model alongside the theories of EMH and behavioral finance. The semiconductor industry is represented by the SOX index, and the S&P 500 index representing the general markets. The mapping of movements in these indexes are done in a daily time series between 01/01/2018 to 29/11/2021 to find out the behavior of the market during a period of shock. The conclusion is that equity markets is affected by lockdowns, but also has other factors affecting the industry.

Abstrakt

Syftet med denna studie är att undersöka effekterna av COVID-19 och karantänregleringar på halvledarindustrin. Studien utgår från faktorer som risk och avkastning på aktiemarknaden genom att använda CAPM-modellen tillsammans med teorierna EMH och beteendeekonomi. Skiftet på aktiemarknaden observeras genom risk och avkastning på SOX-indexet som representerar halvledarindustrin och S&P 500-indexet som representerar de allmänna marknaderna. Kartläggningen av rörelser i dessa index görs i en daglig tidsserie mellan 01/01/2018 och 29/11/2021 för att ta reda på om det är värt att investera i halvledarindustrin under pandemin. Slutsatsen är att aktiemarknaderna kan överreagera på nyheter och att halvledarmarknaden initialt är motståndskraftig mot covid-19. Marknadens motståndskraft följs dock av längre prissvängningar som resulterar i högre avkastning och lägre risk vilket gör investeringar i halvledarindustrin betydligt bättre än S&P 500.

Table of Contents

1. Introduction

The thesis begins with an introduction to the subject with an overview of the semiconductor industry and then continue to explain the background issues, there upon a problematization together with a research question is brought up. Thereafter we present the research design and scope along with our contribution. Lastly the section ends with a disposition of the thesis.

> Semiconductors are the Brains of Modern Electronics. Semiconductors are an essential component of electronic devices, enabling advances in computing, communications, healthcare, military systems, transportation, clean energy, and countless other applications (Semiconductor Industry Association, n.d.).

The industry is globally valuated at 400 billion dollars where the United States (U.S.) has a 47% market share and is the fourth biggest export of semiconductors in the world. The remaining market shares are mostly divided between Japan, South Korea, and China. Collectively the countries mentioned have made semiconductors industry the biggest global export. As semiconductors are all around us the vitalness of this fundamental industry to keep thriving in societies is important (Semiconductor Industry association, n.d.). This component is a tiny chip inside all electrical products and their main function is to lead electricity for the device to operate. Semiconductors has gained its popularity through the product's low costs, high reliability, power efficiency, and ability to handle a wide range of voltages
(Batra, Nolde, Santhanam & Vrijen, 2018).

1.1. Background

Beside that the semiconductor industry is important, three core issues affect the efficiency in the field. The first being that a semiconductor takes anywhere from 4-16 weeks to finish. The second is that only certain producers can create the most high-tech semiconductors, and the most extensive issue is consumer behavior. Consumers often shift along with technological and environmental changes in the semiconductor industry which is reflected in investments (Rumbaugh, Hrbek, Hickey, Markowitz, Howell, & Awwad, 2020). The most recent environmental change was when the deadly respiratory syndrome SARS-CoV-2 (COVID-19) had an outbreak in

China, December 2019 which led to large number of human lives lost. The disease spread across the world and was declared a pandemic by the world health organization (WHO) on March 11, 2020. (Delis, Savva & Theodossiou, 2020). Governments all around the world have attempted to reduce the spread of COVID-19 by conducting policies in their respective society, the attempt has mainly been done through lockdowns. The stature of lockdowns consists of self-isolation via prevention of contact with other people in gathering places such as schools and workplaces. The shock of COVID-19 and the followed lockdowns has impacted the economy to a great magnitude (Wu, Zhang & Du, 2021). The impact of COVID-19 for companies supply and demand has been a key discussion during the pandemic where the changes are measured in the equity markets by its risk and return (Singh, 2020). This is because more immediate reactions to changes is seen in financial markets indifferent to the general markets (Zhang, 2021). The reaction seen by COVID-19 in financial markets is a crash on the 21 February 2020 and by the 23 March 2020 the markets hit their lowest point near the time where COVID-19 was declared a pandemic. During this period the overall indices declined approximately 30% in the U.S. (Delis et al., 2020).

The semiconductor industry resides with most market shares in U.S. and has seen supply chain shortages caused by COVID-19, this is evidently seen in the higher demand of consumer electronics (CE) such as smartphones and computers. The higher demand comes from the self-isolation during the pandemic as people need to have distant communication (Wu et al., 2021). The observations in the American equities give evidence of a great movement in return on investment (ROI) which is also presented in the market indexes where the pandemic has led to the fastest decline in U.S history but also the fastest rebound. This has been theorized to be a result of the exogenous nature of the COVID-19 crisis (Delis et al., 2020). Shocks that occur in markets are usually endogenous in some sense as it is related to the economics of the world, but totally exogenous shocks do not happen very often as they are a product of natural forces (Chen, Roll & Ross, 1986). Anomalies such as shocks are therefore researched as its endogenous effect, for COVID-19 the endogenous effect are governmental lockdowns (Gosak, Duh, Markovic & Perc, 2021).

1.2. Problem Statement and Research Question

Anomalies in markets and their risk related to ROI has a vast amount of research by academia that show why the economy acted the way it has in relation to the market before and after the anomaly. The most notable theory in the field is credited to John Keynes (1936) and his general theory (Lucas, 1977), efficient market hypothesis (EMH) (Naseer & Tariq, 2016), behavioral finance (Kapoor & Prosad, 2017), and the usage of capital asset pricing models (CAPM) to empirically assess the theories in terms of risk and return (Perold 2004). Given the vast amount of research in the field of shocks and that COVID-19 have evidently caused an initial negative change in the semiconductor industry but later has had a rebound, our standpoint becomes that the investor sentiment has been affected by lockdowns. Since many parts of society is influenced by the semiconductor industry our objective becomes to empirically assess and examine how the investment sentiment through ROI has changed in comparison to the market index. This will be mapped out by looking at ROI before and during the pandemic, where the most influential country's equity movement is analyzed (i.e., United Stated), therefore we ask the research question:

How has the U.S semiconductor equity market behaved before and after the shock of COVID-19 along with lockdowns?

1.3. Research Design and Scope

With this paper we take a quantitative approach by empirically exploring and mapping the U.S. semiconductor market behavior. This is done with significant lockdown dates in the countries with the most market share (i.e., USA, Japan, South Korea, and China). The dependent variable is the semiconductor market which is measured by the U.S. index sector compromised in the Philadelphia Stock Exchange (SOX) [1]. The initial hit of COVID-19 is seen during the lockdowns in China, the egression of COVID-19 and its initial effect on society is thereby perceived as the first lockdown. According to Zhang (2021) study[2] the lockdowns move along the supply chain in a sector. Thus, an integrated variable representing COVID-19 lockdowns is

[1] See Appendix table 1.
[2] See Literature review 2.3.

decided to be added in our empirical assessment. To see the relation of SOX toward general markets and to fulfill the CAPM model the Standard & Poor's 500 (S&P 500) index is used. The scope of the study is from 01/01/2018 – 29/11/2021 to account for the ROI before and after the pandemic to determine the market behavior, the timeseries is chosen based on the availability of data. We conduct a time series using the linear regression of CAPM with robust standard errors and test of the results. Our primary variables and models selected are grounded in previous studies presented in the literature review and the theoretical framework with accordance to our research question.

1.4. Our Contribution

The measurement of risk perception through ROI can give answers to volatility spillovers between the S&P 500 and SOX. SOX is considered one of the most important industries in the world, and by seeing the effects a shock such as COVID-19 has on its market can give answer to how tolerant the industry is. To an extent, we also see that our contribution can give additional knowledge and direction if future shocks have the same characteristics as COVID-19. In summary the contribution is set out to benefit managerial analysis in the sector in conjunction with future research in the area to understand how a shock can affect the semiconductor market.

1.5. Disposition

The disposition is as follows; the first section **(1)** was an introduction to the world of semiconductors and its problems. The upcoming second section **(2)** reviews relevant literature in the field of semiconductors. The third section **(3)** focuses on the conceptual and theoretical framework. The fourth section **(4)** explains the methodology and applied model. Results and discussion are seen in section five **(5)** along with section six **(6)** followed up with section **(7)** where the paper is concluded.

2. Literature Review

This section begins with explaining the development of the field and then further explains how previous studies has been done during other shocks along with studies about COVID-19. The section ends with a summary of the literature review.

2.1. Development of the Field

The measurement of asset prices and their movement has been developed over a long time. The simplest asset price model is the CAPM, nowadays we see many extensions in the field (Perold, 2004). The extensions consist of heterogenous beliefs, The beliefs allow for measurement of ROI with additional variables rather than just the simple CAPM. However, the variables need to follow the basic assumptions[3] of the CAPM which are further validated with tests (Lintner, 1969). The test to confirm the assumptions are to control for linearity (Narayan, Phan & Liu. 2021). Further test can be done to assess the usage of variables, such as controlling the heteroskedasticity trough residuals. The heteroskedasticity can also be established by the Breusch pagan test that shows if there is variance in the regression. Finally, the arbitrage whites test then confirms if the value results are constant (Piao, Mei & Xue, 2016).

These types of tests and heterogenous beliefs led academia to focus more on empirical results then individuals investing decisions during a shock. By trying to linkage, the variables by estimating the exogenous event to the financial markets (Yan, Rebib, Woodard & Sornette, 2012), or linkage the endogenous macroeconomic effect to financial markets (Dellas & Hess, 2005). When sufficient computing power became available the empirical results were more accurate which is seen in studies by Harry Markowitz (1952, 1959) along with Fisher and Lorie (1964). The studies applied a more extensive theoretical framework which brought an insight to correlation between different assets and their volatility spillovers. The evidence shows that there is always risk in markets even if the investor tries to hedge their portfolio by diversifying investments, prices can still go lower which means nothing is a perfect protection against a downfall in markets (Perold, 2004).

[3] See Theoretical framework 3.1.

2.2. Previous Studies

2008 financial crisis, Ebola, Spanish flu shocks

Although shocks have volatility spillovers, less sensitive assets (i.e., established companies) is still common to have in portfolios as they give less risk during shocks and is still used as a hedge in most cases of anomalies (Perold, 2004).

The choosing of hedges during the shock can vary, dependent on the nature of the anomaly (Dure, 2020). However, shocks in the general view have similar characteristics in its effect on markets (Ahlstrom, Ciravegna, Michailova & Oh, 2021). During one of the most notable crashes, the 2008 financial crisis, the equity markets lost a lot of value. The endogenous event was a result from people being able to take more credit than they could afford from banks. This was caused by low supervision and regulation in the financial system according to most researchers (Merrouche & Nier, 2010). The following study on the event used market indexes and compared it to individual companies during the financial crisis, the results showed that investors ROI changes where negative whilst some investor had less negative ROI. This was because established companies were used amongst the less negative portfolios as a hedge (Johansson, Dimofte & Mazyancheryl, 2012).

Although the effect of shocks has the same characteristics, its effect on markets can vary. The observed effects are also dependent on the type of research conducted (Dure, 2020). A study about the Ebola epidemic which occurred between 2013 to 2016 in west Africa showed that companies near the area moved their businesses which was an endogenous effect on assets. The study on this effect shows that companies with more exposure to Ebola have lower ROI. The observation was conducted through a dummy variable to account for important closures in the area and how its correlated to ROI in S&P 500 (Ichev & Marinc, 2018). Compared to a study about the Spanish flu sector specific research was observed. The Spanish flu is an exogenous shock that occurred between 1918 to 1920 and killed 2% of the world's population, the disease led to endogenous policies such as closures in gathering places and consequently lead to a downfall in U.S. asset prices (Dure, 2020). The study concluded that less sensitive sectors is useful to invest in. The study variables consist of daily death rates along with closures of gathering places (i.e., lockdowns) in a time series regression (Angel, Fohlin & Widenmier, 2021).

COVID-19 shock

Observations on the COVID-19 shock and its effect in markets have been focused on calculating the ROI in assets along with the stringency index[4] to see the effects of lockdowns on assets (Baig, Butt, Haroon & Rizvi, 2021). The stringency index is concluded to be a sufficient estimate for asset returns. The following study looks at the G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom and United States) and their spread of COVID-19 independently. A time series regression is used to estimate the effectiveness of lockdowns. The research finds a positive linkage between lockdowns and stock market returns (Narayan et al., 2021). Zhang (2021) study also focuses on different countries, the conclusion is that the COVID-19 shock moves down in supply chains. However, the origin country (China) has the most negative effect compared to other countries. This is seen especially in sensitive sectors where technology is dominant. Zhang (2021) also mentions that the most accurate estimation on these types of shocks is through a baseline regression (i.e., CAPM) as a measurement of how the markets ROI have been in each sector.

2.3. Summary of literature Review

The simplest asset price model is the CAPM, extensions to the model can be used as long the model can follow the basic assumptions of CAPM and can pass suitable tests. When sufficient computing power became available studies in the CAPM field showed that when shocks happen it will affect the investor regardless of the choosing in investments. However, certain hedges can be used to have less loses during a shock, this is seen by previous studies in other shocks that has happened in markets. When conducting these studies ROI in a time series is a focus amongst the observations. Dependent on shock an additional variable is added as an extension, when looking at pandemic's lockdowns are used as a variable which is also seen in studies about COVID-19. The most useful measurement of lockdowns is the stringency index which can be used as a dummy variable. Zhang (2021) explains that shocks move down the supply chain and hence a dummy variable can be used to account for the closures in one place that affects another country. The easiest way to observe such an event is through a baseline regression such as the CAPM.

[4] See Methodology 4.2.

3. Theoretical framework

In the theoretical framework we first explain how the capital asset pricing model works related to the literature review. Then continue to unfold theories such as EMH, behavioral finance and business cycle theory. Lastly, the section is summarized.

3.1. Capital asset pricing Model

As mentioned, the CAPM can be applied with extensions. But like most models, the CAPM is based on certain assumptions (Perold, 2004). The three most important of these assumptions for the basic CAPM are the following: **(1)** investors hold portfolios that are individually optimized in risk and return. **(2)** In equilibrium, asset prices reflect the demand. **(3)** The choice of investment is based on the constraint in the individual's life. These notions measure a highly basic and idealized world but are applicable to find the fundamental problems of ROI. The assumption set the groundwork for the CAPM and was set as a standard of empirical measurement by Fama & MacBeth (1973) (Perold, 2004). The model has the following formula (Wahyuny & Gunarish, 2020).

$$R_{it} = \alpha + \beta_{it} R_{mt} \quad (1)$$

Where: R_{it} = The examined asset i returns R during the specific time t.

α = Is a constant with the null hypothesis of H_0 $a = 0$.

β_{it} = Is the coefficient and beta value of the asset.

R_{mt} = The general market returns.

To accept the regression, it needs to fail the rejection of H_0, a fail to reject means that there is a correlation between the variables. The variables correlation is built on linearity, the linearity is fulfilled when demand and supply reflect each other (i.e., equilibrium) which indicates that the asset follows the CAPM (Perold, 2004). To see if the CAPM fulfills this requirement a conduct of the security market line (SML) can be done, SML is derived from CAPM. The SML line shows the relationship between beta (β) and the expected return, the equilibrium is where the general market beta is which is always equal to 1 when conducting the SML. If the asset is deviating from the equilibrium and is either overvalued or undervalued (i.e., imbalanced) it will always go back to the equilibrium (Perold, 2004). The imbalanced asset is caused by risk in the investment which can be measured by the second derivation of the CAPM with an additional variable of standard deviation, it is called the capital market line (CML). CML shows the relationship between risk in the asset to the return through an efficient frontier. The efficient frontier is a line that explains how profitable an investment in the general market is in comparison to the imbalanced asset, the CML line is calculated with the following formula (Ganti, 2022).

$$R = \frac{R_{mt}}{\sigma_{mt}} = \sigma \quad (2)$$

Where: R = Is the return distribution in the examined asset and general market.

R_{mt} = The general market returns.

σ_{mt} = Is the standard deviation of the general market return.

σ = Is the standard deviation on the examined assets return.

3.2. Efficient Market Hypothesis and Behavioral finance

Regardless of the market being in equilibrium or if it is imbalanced, the EMH states that the movements on return along the profit-maximizing investor is based on new information coming into the markets. Markets then become efficient when the price fully reflects all available information, in practice markets cannot fully reflect all available information because of errors so this phrase is used as a benchmark. Furthermore, because the price reflects the information, an additional piece of information should make markets quickly go to the new equilibrium and cannot be predicted by past trends. According to EMH this means that the future period should be greater than the current one this is theorized to be a result of investors always being rational in the long term and overtake the irrational ones. This means when anomalies such as shocks happen prices will afterwards adjust to a higher price level but the anomalies whilst when the shock happen it is because of the information provided. EMH explains also that there are no trade patterns in markets because that will lead to abnormal returns. Trade patterns can be calculated by measuring the beta of assets using CAPM and decide the trajectory of investment thus making markets inefficient (Naseer & Tariq, 2016).

Behavioral finance continues the idea of EMH but contradicts some of the explanations as it does not look at the individual choices. According to behavioral finance when shocks happen the reaction is based on irrationality in the markets, where the factor for irrationality is the psyche of the investor. The psychological bias during the period the investment is made is divided into three parts: **(1)** The individuals do not have the same risk attitude in the markets, **(2)** the individual's investment is taken from a reference point which is decided by their current wealth, **(3)** losses have a larger effect than gains on the individual which makes the investment based on avoiding losses as much as possible (Kapoor & Prosad, 2017).

3.3. Business cycle theory

The aggregated movement explained by EMH, and the individual behavior explained by behavioral finance are branches of business cycle theory which combines these both mindsets. The evolution of the theory is described in three parts which are the pre-Keynesian business cycle, Keynesian general theory, and current modern business cycle theory. **(1)** The pre-Keynesian (sometimes called original business cycle) is based on aggregated variables in the economy, these theorists look if the variables undergo the same fluctuations (Lucas, 1977).

The theory does not have any model but instead is based on assumptions, which are that the country's sectors along with prices are moving together. The second assumptions are that the production is greater in durable goods indifferent to non-durable goods. The pre-Keynesian further developed the theory when the prominent scholar Keynes (1936) shifted the focus to determining each variable in a specific time. By determining each variable Keynes (1936) emphasized on the monetary and fiscal policy's importance and their relationship to models instead of solely assumptions. This change of mindset in business cycle theory created a shift to Keynes general theory. **(2)** The general theory states that business cycles fluctuate in high and low seasons, and that it is controlled with policies. Keynes (1936) states that when an anomaly such as a shock occurs it disturbs investment and leads to a general movement in prices but can also have a more permanent effect. This means that short term reaction can have a great movement in prices over a longer time which confuses the investor sentiment and can result in higher unemployment that evidently hurt the economy (Lucas, 1977)

(3) Modern business cycle theory has applied the Keynesian mindset of looking at specific variables along with new assumptions for markets. The first assumption is that an individual begins its period (i.e., before shock) with all their accumulated capital. The second assumption is during the shock, which says that the individual is faced with a choice in the financial and capital market to either make/keep investment or wait until the future. This decision is based on preferences that are constraint by labor left in the market, which means if the investor is younger, it tolerates more risky investments. The third and last assumption is that the investor needs a plan. The market perceives the plan before the shock as correct whilst when the shock happens the investor needs an explanation for the plan to justify if it is worthy of investing. These assumptions are only at the most formal level because the individual in the market needs to also formulate a subjective view of all the unknown variables through a probability distribution. If the investor knows the probability distribution, the risk the individual takes on is based on its own circumstances. Business cycle theorist explain this as a more philosophical question as the reality is complex and the choices are often not appropriate regarding the shock (Lucas, 1977).

3.4. Summary theoretical framework

The CAPM can be used to calculate market movements, the regression is accepted when H_0 cannot be rejected, this is seen through the SML and CML lines which explain the explain the linearity and risk. The deviation during a shock according to EMH is a collective movement and is always solved over a long period of time. Behavioural finance dives deeper into the individuals psychological bias during before and after a shock. These two mindsets are further established by the business cycle theorist, the evolution of business cycle theorist is dependent on assumptions and models. By looking at specific time periods and the individual’s choices in regard to aggregated movement the theory suggests that distributions in investments is dependent on circumstances which can have an effect on a long-term view in either direction.

4. Methodology

We begin with presenting the research method and explanation of the variables along with the data used. Lastly the specification of our model is presented

4.1. Research method

The research method follows the literature review and theoretical framework. Through extensions to the original CAPM allowed by Lintner (1969) additional variable is added to fit our research question which are later tested. The variables chosen in the research method are based on its association with our research question and is inspired from the literature review. The research method emanates from changes of ROI in a specific sector during a distinct time to account for changes in market behaviour under a shock. The exogenous event of COVID-19 has led to lockdowns which has affected the sensitive sector of IT (Zhang, 2021) which is part of the semiconductor industry and will be the dependent variable observed. To see how much the sector has been affected it is compared to a market index that represents the economy along with the endogenous variable caused by the shock (Angel et al., 2021). The endogenous variable is lockdowns which can be represented by the stringency index in a time series (Narayan et al., 2021) in our case the time series is from 01/01/2018 to 29/11/2021, as lockdowns move down the supply chain important countries in the sector are integrated in a single variable to account for the foreign effects (Zhang, 2021). This research method applies a quantitative method which is calculated by ROI with the following formula.

$$Return\,\% = \left(\frac{P_t - P_{t-1}}{P_{t-1}}\right) x\ 100 \qquad (3)$$

Where: P_t = Is the price at the specific time t

P_{t-1} = Is the price in the period before

The ROI during the time series is added to the CAPM (eq. 1) which is later derived to see the SML/CML. The variables of an asset return follow the assumptions of CAPM according to Perold (2004) which justifies the chosen factors. To understand the behaviour of the movement's the theoretical frameworks relevant theories are used to understand the collective movement, individual movement, and the underlying business cycle theory.

4.2. Variable Explanation and Data

SOX (Semiconductor sector) and S&P 500 (Market index)

To investigate the semiconductor industry equities representative data is collected from the country with largest market share, which is the U.S. (Semiconductor Industry association, n.d.). The sector is represented by the SOX index which is a sub-index in the S&P 500, this means that the S&P 500 also includes the SOX in its weighted average. For a company to be apart of the SOX it needs to be established so it can be listed, but it also needs have a market capitalization of $100 million (Downey, 2021). Moreover, the company business type needs to consist of fables design (chip creator), manufacturing (foundry), packaging and testng (P&T) and integrated design manufacturers (IDM) (Wang & Lin, 2021).

The CAPM independent variable needs to be a market index (Zhang, 2021), the appropriate market index is a large index, and because the SOX is a sub-index in the S&P 500 it can represent the entire U.S. market movement including the semiconductor industry. The S&P 500 consists of the 500 biggest companies which represent U.S. economy. If a certain company no longer represent its industry, it gets removed from the index (Chen, Noronha & Singal, 2005). Both indexes are collected over 985 days which accounts for the sample period in our research question (01/01/2018 to 29/11/2021). The source used is Investing.com (2021), the advantage of this database is the availability of free information and its strong establishment amongst investors for real-time updates of their assets.

Lockdowns (Stringency index)

The stringency index represents COVID-19 lockdowns and takes a value of 0 to 100 where 100 is complete lockdown. the source of the index is from established US universities such as Oxford university, and their standpoint is that stringency over 50 is a high stringency, 50 and below is a low stringency. Therefore, our critical value becomes 50. In accordance with Zhang (2021) study the variable is added as a integrated dummy variable that represents the supply chain, the chosen countries that has the largest market shares are, South Korea, China, Japan, and USA. Every time the stringency is over the critical value in one of the countries it takes the dummy of 1 or else 0. The data is collected from Our World in Data – OWID (Our world in data, 2021).

4.3. Model specification

The model used in this study describes how the dependent variable of semiconductor equity market SOX is affected by the independent variables of S&P 500 in the linear equation of CAPM:

$$R_{SOX,t} = \alpha + \beta_0 C19 + \beta_1 R_{S\&P500,t} + \beta_2 R_{S\&P500,t}\ X\ C19 \quad (4)$$

Table 3. explanation of the model specification

Variable(s)	Abbreviation	Indicator(s)	Measure(s)	Sign
Dependent				
Return SOX (%)	$R_{SOX,t}$	Return on Index	Semiconductor sector return	n/a
Independent				
Return S&P 500 (%)	$R_{S\&P500,t}$	Return on Index	Market return	+
alpha	α	Variable correlation	Null hypothesis	+
Integrated Dummy				
COVID-19	$C19$	Scale of lockdowns	Stringency index	+

This type of model specification is partly seen in previous studies. However, all variables are not added as it is adapted to our research question. The SOX has not been observed independently before but sector specific studies has been done, for example in Angel et al., (2021) study. The S&P 500 market index has been used previously in Ichev & Marinc (2018) study. Lastly the integration of a dummy variable is useful when observing COVID-19 but has in other type of shocks been used as a independent variable to account for closures which is seen previous studies (eg., Angel et al., 2021; Ichev & Marinc, 2018; Narayan et al., 2021). These type of extension in the CAPM is further validated by Lucas (1977). The potential advantage of this model is that the variables has been used before, the disadvantage is that the extension can potentially not represent the true effects of COVID-19 on the semiconductor industry.

4.4. Empirical Operationalization

We begin the process by first observing descriptive statistics which will give evidence of any volatility spillovers (Perold, 2004). This is executed by looking at the price movements and the introduction of COVID-19 to the market. According to Johansson et al., (2012) The ROI also needs to be examined which is graphically presented during the sample period, from 01/01/2018 to 29/11/2021. The conclusion of the ROI is further established by summary statistics which is controlled by data skewness through histograms[5].

Subsequently empirical results are presented to establish the previous arguments. The empirical evidence is graphically seen by plots[6]. The plots distribution in relation to the line of best fit is also observed and compared to the correlation matrix[7] between the variables used. The correlation matrix is colour coded, where blue is positive correlation, red is negative correlation and white is neutral. The resulting empirical evidence is thereafter assessed with the risk and valuation of the SOX and S&P 500 by the SML/CML[8] derivations of CAPM. To confirm the usage of variables in the thesis, an heteroskedasticity test is presented along with tests of the error term. The test consists of Breusch pagan and arbitrage white's test. Lastly we control for linearity between the variables to understand the robustness of the results.

[5] See Appendix figure 1
[6] See Appendix figure 2
[7] See Appendix Table 2
[8] See Appendix figure 3

5. Results

The result section shows what the descriptive results from the variables and proceed to see the empirical evidence which are lastly controlled with tests.

5.1. Descriptive results

Below is a presentation of the market over the time sample period 01/01/2018 to 29/11/2021.

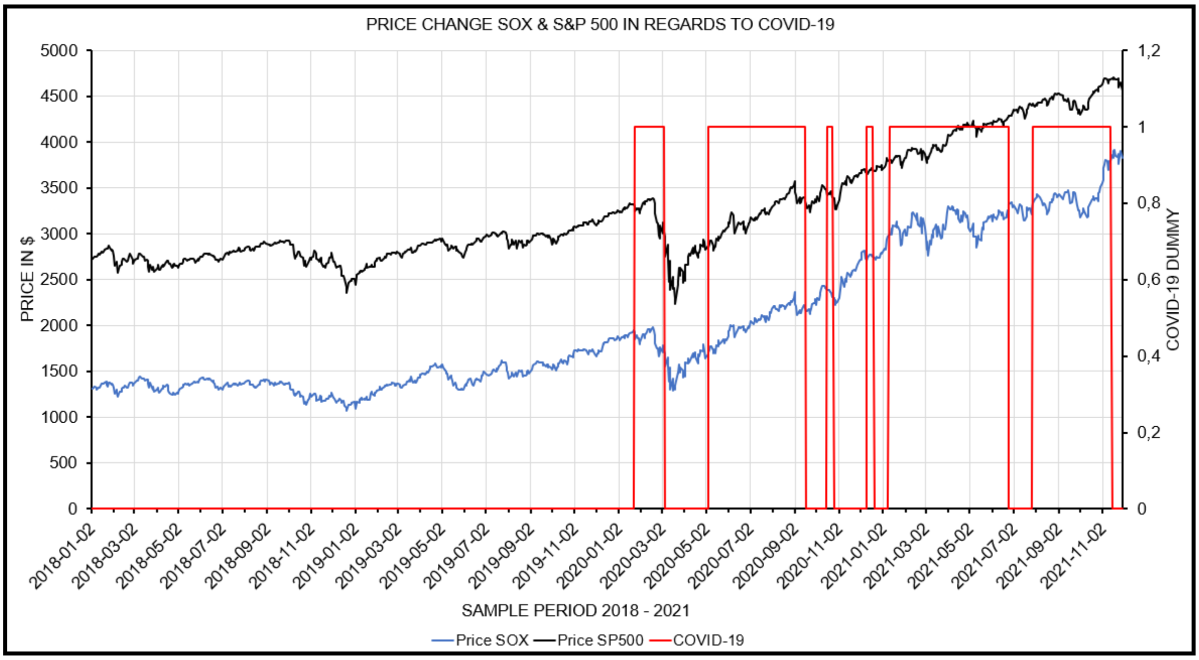

Figure 4. Price change in relation to the dummy variable COVID-19

The initial period before COVID-19 (i.e., 2018-2020) there is minimal volatility and a rather calm growth, in addition the volatility spillovers is perceived as calm between the indexes. This changes when the first hit of COVID-19 is seen, which is the Chinese lockdowns. The C19 variable goes over the critical point and becomes 1 but markets initially do not make a significant movement, but after approximately one month of lockdowns the price is seen to have significantly moved lower. When the C19 variable lockdowns are seized approx. 02/02/2020 an even further downfall is seen amongst the S&P 500 and SOX. This downfall ends in March of 2020 and is opposed with higher prices without any lockdowns and is followed by the C19 variable getting imposed again making assets go higher over a long period of time. However, long periods of lockdowns lead to short term downfalls in assets, but when lockdowns are short it also leads to downfalls which is seen in figure 4.

The market behavior in relationship to ROI and is changes is presented with the following graph.

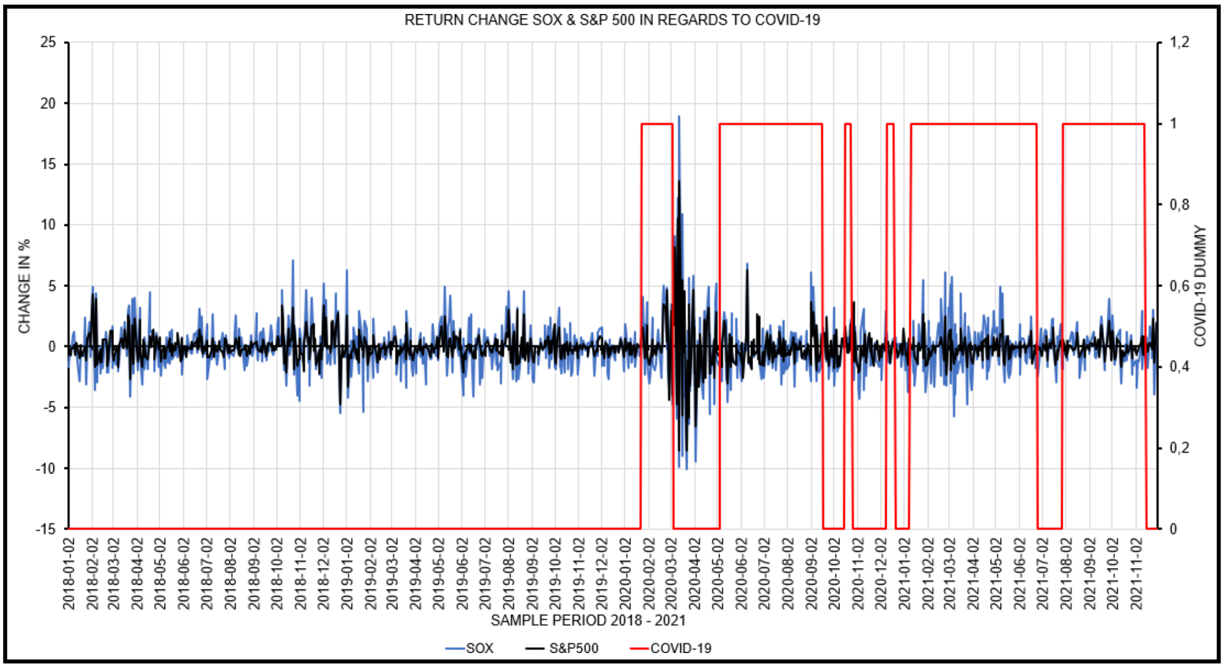

Figure 5. ROI in relation to the dummy variable COVID-19

The ROI is seen to be more volatile in the SOX compared to the S&P 500, and is explained by the indexes listing, as the S&P 500 is broader the movements are less rigid. The ROI from 2018-2020 is seen to be higher in the SOX over S&P 500 in all periods, but as COVID-19 lockdowns are introduced the ROI is relatively the same. The ROI is seen to be the most aggressive after the first lockdown with the biggest losses/gains. The following lockdown also give evidence of more volatility amongst ROI, but as more time goes the S&P 500 becomes calmer whilst the SOX is still highly volatile. When we see calmer ROI, it is comparably alike to the period before the C19 variable got introduced and has relatively the same amount of distribution between positive and negative returns. This conclusion can be further established by summary statistics shown in the following table.

Table 3. Summary statistics, SOX, S&P 500 and COVID-19

	SOX return %	*S&P500 return %*	*C19*	*C19 X S&P 500*	*Price SOX*	*Price SP500*
Mean	-0,0941	-0,0435	0,3330	-0,0201	2003,3758	3257,8113
Standard Deviation	2,1655	1,3621	0,4715	0,6464	775,2277	609,8224
Skewness	0,9935	1,4519	0,7098	1,5297	0,8074	0,8990
Minimum	-10,0523	-8,5779	0	-4,4013	1069,40	2237,40
Maximum	18,8971	13,6158	1	6,2636	3912,00	4706,64
No. Obs	985	985	985	985	985	985

The summary statistics show that the return mean is at -9,4% in the SOX index while the S&P 500 has -4,3% which is almost half of the semiconductor industry return indicating more profitability in the S&P 500. This is further established by the standard deviation being larger in the SOX which means there is more risk in the SOX compared to the S&P 500. However, the skewness of histograms during this period are positive indicating that both investments are positive in the full period of the time series. But this also requires a correct plan, when looking at the min and max we see that the SOX during the sample period gives higher returns when executing the investment correctly to maximize profits. The execution of investment in S&P 500 is although less important during the sample period as we see that the price mean is closer to the max. When observing the C19 variable we see that the mean is below the critical level but is positively skewed indicating many lockdowns being implemented during the period. When looking at the lockdowns effect on the market we see that volatility decreases, making a positive relation between the variables.

5.2. Empirical results

The empirical evidence for the descriptive statistics is seen in the following regression table, where each independent variable is added to the regression to account for changes in the coefficient of the SOX.

Table 4. Regression during the sample period (2018-2021)

Variables	(1)	(2)	(3)
S&P 500	1,345059*** (0,027053)	1,345194*** (0,027064)	1,326313*** (0,030721)
C19		0,040308 (0,078163)	0,045066 (0,078222)
S&P 500 X C19			0,084123 (0,064846)
Constants	-0,03451 (0,036841)	-0,04792 (0,045112)	-0,04859 (0,045099)
Regression statistics			
R^2	0,715491	0,715568	0,716055
Adjusted R^2	0,715201	0,714988	0,715186
No. Observations	985	985	985
***p<0,001 (Robust standard error)			

The regression columns show the number of regressions done. In all the columns the S&P 500 is highly significant and is justified as the SOX index moves with the market index. The standard error in the variables and the constant in all columns shows a low spread. The sample mean is also close to the population mean which is conversely seen in the adjusted R squared with about ≈ 71,5% accuracy. The constant is not significant in any of the regression which means our null hypothesis is met. The pandemic and the general market have a significant effect on the SOX where one unit change in both the independent variables moves the ROI in the SOX by 4,8%. When constructing the CML line the risk rate is ≈ 0,9. This means that the risk between S&P 500 and SOX is approx. 10%. The valuation of SOX is also seen with the SML, the alpha shows no significance which means markets are valuating correctly in relationship to S&P 500. The graphical results for the indexes plots are sporadic along with their correlation matrix being low. This is caused by the shock of lockdown and is seen by the effect of S&P 500 on the SOX in its high inflection on the semiconductor industry with 4,8% movements. This can also suggest that COVID-19 is not the only variable to explain market movements in the SOX.

5.3. Tests of the results

We control for heteroskedasticity in our model through squaring the residuals[9] and measure the predicted value of SOX. The results show a presence of heteroskedasticity. To control for a wrong error term, we use the Breusch pagan test. The results from the test showed a significant F of 0,943. This means we cannot reject the null hypothesis and that the error term is specified correctly. To further confirm this, we use the abridged whites test that gave a significance F of 0,410, making the results robust. The next test consists of controlling for linearity[10] in the model. We omit the C19 squared for the account of multicollinearity as it only has two points and is linear. The test uses six regressions to assess linearity, the added variables are squared, and a second estimate of beta is presented. The results show that the model still holds, we can conclude that the results are linear. This is evidently seen in the accuracy of adjusted R squared and that no new variable shows a significance.

[9] See appendix: Figure 6. Residual control for heteroskedasticity
[10] See appendix: Table 5. Non- linearity test of the regression

6. Discussion

We look at the meaning of our outcomes. We additionally feature the implications experienced and give suggestions on how to overcome them in future research

Outcomes

The result outcomes show that the aggregated movement is following EMH where the future period is greater than the current one because rational investors are overtaking the irrational ones. But EMH also states that this is caused by additional information to markets. Moreover, Behavioral finance according to Kapoor & Prosad (2017) explains that losses have a larger effect than gains which makes the individual wanting to have less risk and causes downfalls. Behavioral finance also states that any additional movement is caused by current wealth changing amongst the individual. Keynes (1936) clarifies the standpoint as the two theories emanate from the business cycle. By observing the ROI in the SOX, and its market behavior assumptions in the business cycle theory are met. Keynes (1936) explains that fluctuations where the investor begins its period with their accumulated capital is fulfilling their plan, whilst when the shock happens an explanation is needed. The explanation either leads to the investor keeping or leaving their asset.

The previous studies in the field of shocks are seen to being explainable through the other theories. Johansson et., al (2012) study on the 2008 financial crisis showed that some investor had less negative ROI, and this is because they had a plan according to Keynes (1936). However, when looking at Ichev & Marinc (2018) study on the Ebola pandemic we see that individual movements happen because of their current wealth. The outcome is therefore dependent on variables used in the model specification. Lastly Narayan et al., (2021) study on COVID-19 give implications of an aggregated movement in accordance with EMH as the study finds a general positive linkage between the variable of lockdown with G7 countries assets. This thesis on the semiconductor industry is sector specific to its equity markets index, which is large enough to deviate from individual choices, but the SOX is not weighted as a countries index.

Implications and future research

The implication of this is that the research question on U.S semiconductor market behavior before and after the shock of COVID-19 and its lockdowns are viewed through a middle ground, which is represented by the business cycle theory. From a business cycle point of view, we see market behavior is deviating during the initial hit of COVID-19, this deviation is divided equally. However, it is marginally more positive during the shock then negative which indicates that the market accepts more of a positive plan in a Keynesian perspective. The periods before and after the initial hit of COVID-19 are periods of accumulating capital. However, the EMH and its assumption on additional information coming to markets is partly in our regression because lockdowns has evidently caused movement and from our point of view, lockdowns are considered additional information as it affects the sector. The individual's choice based on Behavioral finance is not presented but can be based on the derivations of the CAPM. For example, the SML and CML shows the risk and valuation of the asset which can make the investor base their investment on that information.

The discussion standpoint is that the initial hit of COVID-19 made investor decide if they wanted to leave the market or stay based on circumstances. The price movement is also seen after the initial shock being highly skewed showing evidence of profitability in investing and a bigger price swing in the period after COVID-19. This has led to the period before COVID-19 being perceived as calm but when looking at the ROI it is observed that the semiconductor industry always has been more volatile than the S&P 500. This is further confirmed by Zhang's (2021) study where he explains that sensitive industries such as the semiconductor have an amplitude of movements. The sensitivity is more exposed when COVID-19 started as it led prices to fall. The overall results show robustness but as there can be many extensions of the CAPM where different explanations can be extracted, and our model specification does not include factors such as the individual behavior along with the aggregated behavior, we can conclude that our results are not totally accurate.

7. Conclusion

In the final section, a brief recollection of the research question and results are brought forward along with the discussion. The second ends with suggestions for future research.

This research aimed to find out how the shocks of COVID-19 impacted the semiconductor index SOX relative to the market index S&P 500. Using sector level data and the stringency index in the period of 2018 to 2021 gave evidence of higher ROI after the shock. The model used was built on 985 data collections to understand how the U.S. semiconductor equity market behaved before and after the shock of COVID-19 along with lockdowns. The result is that the semiconductor equity market is sensitive, the SOX before COVID-19 behaved calm, but the initial shock of the pandemic lead to a downfall in markets. The lockdowns that got implemented has affected the markets, the affection has been relatively positive dependent on the time the lockdown was applied.

From the results we can conclude that the CAPM is lackluster of other variables make it a non-accurate estimate of the total reality. where there is no inclusion of factors that represent the entire market or the individual. On the other hand, the C19 variable used is relatively new. COVID-19 is also one of the most critical shocks seen in recent time which can over a longer time give more accurate movements as more data becomes available. We choose lockdown periods as an estimate of COVID-19 but what we have realized after doing the study is that there can be other factors that affect the volatility in markets. This contraption was something we was prepared for as this specific model has not been used before. The suggested future research is to include other factors that can either measure individual behavior to explain how markets perceives or the aggregated movement. This can be done through appropriate extension of CAPM to give a sufficient estimation of the reality.

Bibliography

Ahlstrom, D., Ciravegna, L., Michailova, S., Oh, C. (2021). MNE and exogenous shocks: Learning from pandemics and other major disruptions. *Journal of World Business*, p. 1–8.

Angel, M., Fohlin, C., Weidenmier, M. (2021). Do Global Pandemics Matter for Stock Prices? Lessons from the 1918 Spanish Flu. *National Bureau of Economic Research Working Paper Series,* No. 28356. p.1-23. Doi: 10.3386/w28356

Baig, A., Butt, H., Haroon, O., Rizvi, S. (2021). Deaths, panic, lockdowns and US equity markets: The case of COVID-19 pandemic. *Finance Research Letters*, (38), p. 1-9. Doi: https://doi.org/10.1016/j.frl.2020.101701

Batra, G., Nolde, K., Santhanam, N., Vrijen, R. (2018). Right product, right time, right location: Quantifying the semiconductor supply chain. *McKinsey & Company.* https://www.mckinsey.com/industries/semiconductors/our-insights/right-product-right-time-right-location-quantifying-the-semiconductor-supply-chain# [2021-12-01]

Chen, N., Roll, R., Ross, S. A. (1986). Economic Forces and the Stock Market*. The Journal of Business*, 59(3), p. 383–403. Doi: http://dx.doi.org/10.1086/296344

Dellas, H., Hess, M., (2005). Financial development and stock returns: A cross country analysis. *Journal of International Money and Finance,* 24(6), p. 891-912. Doi: https://doi.org/10.1016/j.jimonfin.2005.07.002

Delis, M. D., Savva, C. S., Theodossiou, P. (2020). The Impact of the Coronavirus Crisis on the Market Price of Risk. *Journal of financial stability*, (53), p. 1-38. Doi: http://dx.doi.org/10.2139/ssrn.3618827

Downey, L. (2021). PHLX Semiconductor Sector Index (SOX). *Investopedia.* https://www.investopedia.com/terms/s/soxx.asp [2022-01-15]

Dure, E. (2020). The history of Pandemics and Stock Markets. *Investopedia,* https://www.investopedia.com/the-history-of-pandemics-and-stock-markets-5093256 [2022-01-15]

Ganti, A. (2022). Capital Market Line (CML).*Investopedia*, https://www.investopedia.com/terms/c/cml.asp [2022-01-16]

Gosak, M., Duh, M., Markovic, R., Perc, M. (2021). Community lockdowns in social networks hardly mitigate epidemic spreading. *New journal of Physics*, (23), p.1-11. Doi: http://dx.doi.org/10.1088/1367-2630/abf459

Chen, H., Noronha, G., Singal, V. (2005). The Price Response to S&P 500 Index Additions and Deletions: Evidence of Asymmetry and a New Explanation. *The journal of Finance*, 59(4), p. 1901-1930. Doi: https://doi.org/10.1111/j.1540-6261.2004.00683.x

Ichev, R., Marinc, M., (2018). Stock prices and geographic proximity of Information: Evidence from the Ebola outbreak*. International Review of Financial Analysis*, (56), p.153-166. Doi: https://doi.org/10.1016/j.irfa.2017.12.004

Johansson, J., Dimofte, C., Mazvancheryl, S., (2012). The performance of global brands in the 2008 financial crisis: A test of two brand value measures. *International Journal of Research in Marketing,* 29(3), p 235-245. Doi: https://doi.org/10.1016/j.ijresmar.2012.01.002

Kapoor, S., Prosad, J. (2017) behavioral Finance: A review. *Procedia Computer Science,* (122), p. 50-54. Doi: https://doi.org/10.1016/j.procs.2017.11.340

Lucas, R. E. (1977). Understanding business cycles. *Carnegie Rochester conference series on public policy*, (5), p. 7-29.

Merrouche, O., Nier, E. (2010). What Caused the Global Financial Crisis: -Evidence on the Drivers of Financial Imbalances 1999- 2007. *International Monetary Fund*, p.4-20. Doi: http://dx.doi.org/10.2139/ssrn.1735474

Narayan, P., Phan, D., Liu, G. (2021). COVID-19 lockdowns, stimulus packages, travel bans, and stock returns. *Finance Research Letters,* (38), p. 1-7. Doi: https://doi.org/10.1016/j.frl.2020.101732

Naseer, M., Tariq, Y. (2015). The efficient market Hypothesis: A critical Review of the literature. *The IUP Journal of Financial Risk Management,* 12(4), p. 48-63.

Our World In Data (2021). *COVID-19 Stringency Index.* Our World In Data. *https://ourworldindata.org/grapher/covid-stringency-index* [2021-12-17]

Perold, A., (2004). The Capital Asset Pricing Model. *Journal of Economic Perspectives.* 18(3) p.3-24

Piao, X., Mei, B., Xue, Y. (2016). Comparing the financial performance of timber REITs and other REITs. *Forest Policy and Economics,* (72), p. 115-121. Doi: https://doi.org/10.1016/j.forpol.2016.06.022

Rumbaugh, C., Hrbek, J., Hickey, M., Markowitz, N., Howell, T., & Awwad, M. (2020). *Review of the Effect of COVID-19 on the American Semiconductor Industry Supply Chain.* Diss., California Polytechnic State University. California: Univ

Semiconductor Industry Association (n.d.). What is a semiconductor. SIA. https://www.semiconductors.org/semiconductors-101/what-is-a-semiconductor/ [2022-01-15]

Singh, A. (2020). COVID-19 and safer investment bets. *Financial research letters*, (36), p.1-7 Doi: https://doi.org/10.1016/j.frl.2020.101729

Wahyuny, T., Gunarish, T. (2020). Comparative analysis of accuracy between capital asset pricing model (CAPM) and arbitrage pricing theory (APT) in predicting stock return. *Journal of Applied Economics in Developing Countries*, 5(1), p. 23-30.

Wu, X., Zhang, C. & W., Du. (2021). An Analysis on the Crisis of "Chips shortage" in Automobile Industry - Based on the Double Influence of COVID-19 and Trade Friction. *Journal of physics: Conference series*, 1971(1), p.1-6. Doi: 10.1088/1742-6596/1971/1/012100

Yan, W., Rebib, R., Woodard, R., Sornette, D., (2012). Detection of crashes and rebounds in major equity markets. *International Journal of Portfolio Analysis and Management,* 1(1), p.59-79.

Zhang, S. (2021). Using equity market reactions and network analysis to infer global supply chain interdependencies in the context of COVID-19. *Journal of Economics and Business*, (115), p. 1-19. Doi: doi.org/10.1016/j.jeconbus.2020.105974

Appendix

Figures

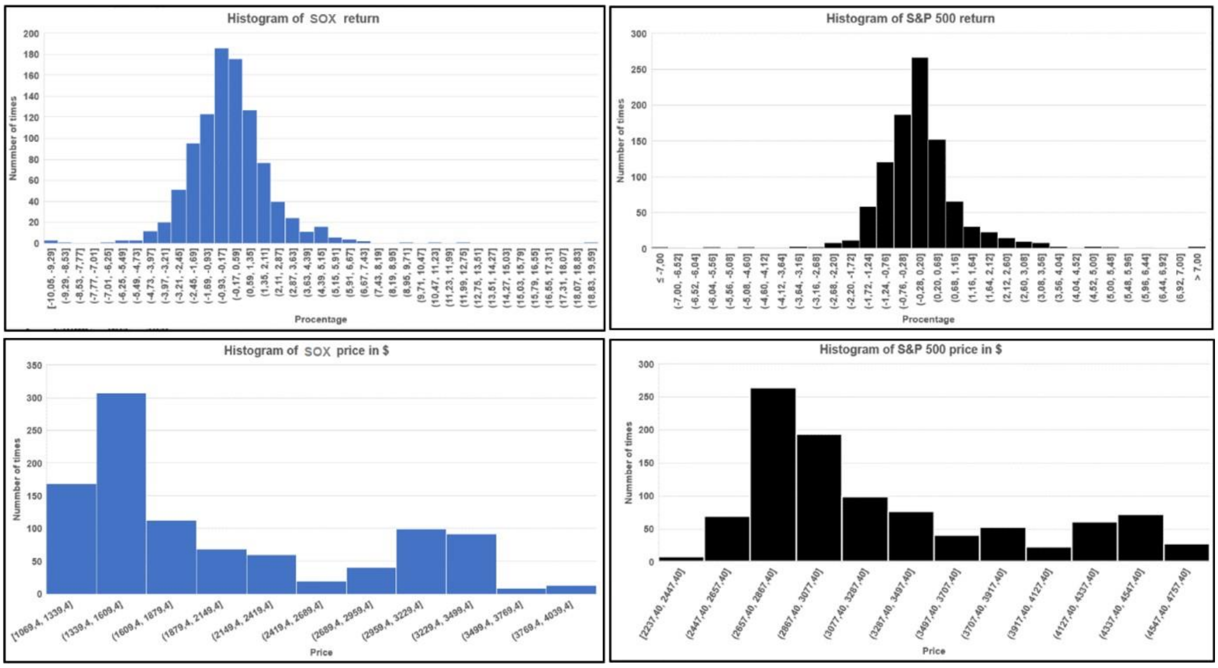

Figure 1. Percentage return and price histogram SOX versus S&P 500

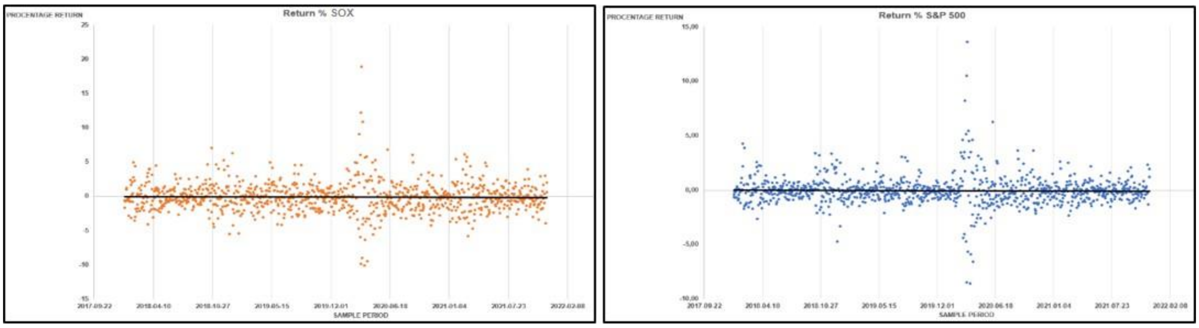

Figure 2. Scatterplots of return in the indexes with line of best fit

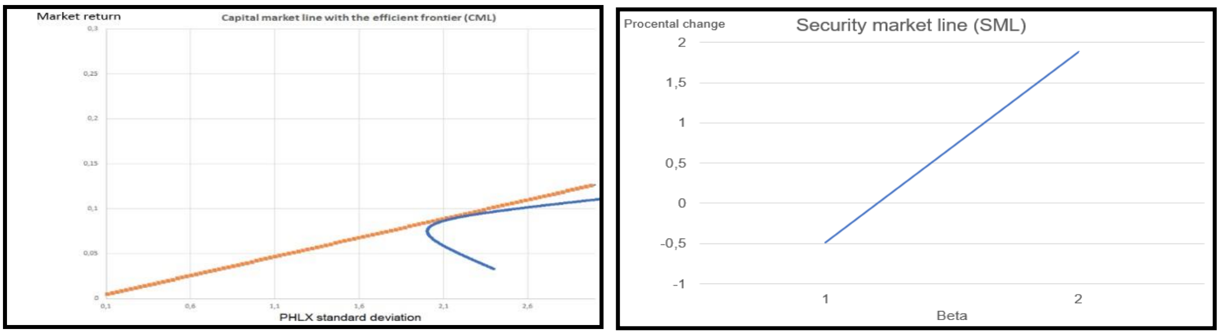

Figure 3. CML and SML of SOX

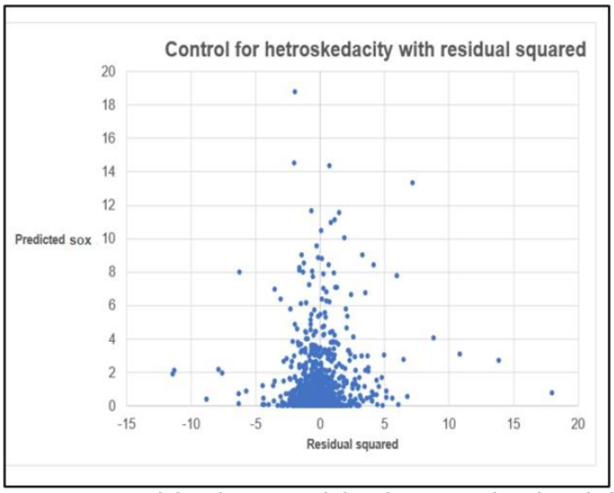

Figure 6. Residual control for heteroskedasticity

Tables

Table 1. SOX 30 companies

Symbol	Company Name	Symbol	Company Name	Symbol	Company Name
TXN	Texas Instruments Incorporated	QRVO	Qorvo, Inc.	MPWR	Monolithic Power Systems, Inc.
MRVL	Marvell Technology, Inc.	ON	ON Semiconductor Corporation	ADI	Analog Devices, Inc.
NVDA	NVIDIA Corporation	AMKR	Amkor Technology, Inc.	KLAC	KLA Corporation
LRCX	Lam Research Corporation	ASML	ASML Holding N.V.	TSM	Taiwan Semiconductor Manufacturing Company Limited
AVGO	Broadcom Inc.	POWI	Power Integrations, Inc.	AZTA	Azenta, Inc.
IIVI	II-VI Incorporated	IPGP	IPG Photonics Corporation	TER	Teradyne, Inc.
MCHP	Microchip Technology Incorporated	QCOM	QUALCOMM Incorporated	ENTG	Entegris, Inc.
NXPI	NXP Semiconductors N.V.	AMAT	Applied Materials, Inc.	MU	Micron Technology, Inc.
INTC	Intel Corporation	SWKS	Skyworks Solutions, Inc.	SLAB	Silicon Laboratories Inc.
LSCC	Lattice Semiconductor Corporation	AMD	Advanced Micro Devices, Inc.	WOLF	Wolfspeed, Inc.

Table 2. Correlation matrix

	SOX	S&P500	C19	C19 X S&P 500
SOX	1			
S&P500	0,845866806	1		
C19	0,000618981	-0,096834808	1	
C19 X S&P 500	0,419716664	0,47367126	-0,045863947	1

Table 5. Non-linearity test of the regression

Variables	(1)	(2)	(3)	(4)	(6)
S&P 500	1,345*** (0,0270)	1,345*** (0,0274)	1,326*** (0,0307)	1,325*** (0,0322)	1,323*** (0,0322)
C19		0,040308 (0,0781)	0,045066 (0,0782)	0,041595 (0,0784)	0,055149 (0,0812)
S&P 500 X C19			0,084123 (0,0648)	0,081941 (0,0650)	0,101426 (0,0687)
S&P 500^2				0,00039 (0,0044)	0,001274 (0,0046)
$(\text{S\&P 500 \& } C19)^2$					-0,01867 (0,0211)
Constants	-0,03451 (0,036)	-0,04792 (0,0451)	-0,04859 (0,0450)	-0,0494 (0,0462)	-0,05143 (0,0463)
Regression statistics					
R^2	0,71541	0,71558	0,71605	0,71577	0,71593
Adjusted R^2	0,71520	0,71498	0,71516	0,71457	0,71453
No. Observations	985	985	985	985	985
***p<0,001 (Robust standard error)					