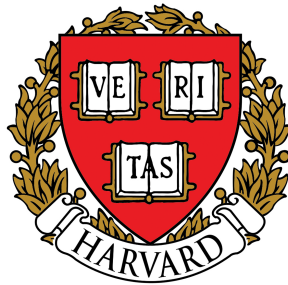


Forecasting Constituents of the MSCI Minimum Volatility Index Through Logistic
Regression

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John A. Gilheany

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Professor Michael Parzen

David Kane

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Abstract

The low-risk anomaly is the term in academic literature for the empirical regularity that low-volatility stocks perform as well or better than high-volatility stocks (Baker, Bradley, & Wurgler, 2011). The MSCI Minimum Volatility Index is designed to exploit this effect by holding a minimum variance portfolio of stocks. USMV is an exchange-traded fund that tracks the index. I used information from Wharton Research Data Services to calculate the trailing beta, trailing volatility, and price to book ratio for each stock. Using this data, I created a logistic regression model to calculate the probability of an individual stock being a member of the index at the next rebalance. It was found that stocks with lower beta and lower volatility are more likely to be in the index in the next period.

Chapter 1

Introduction

The iShares Edge MSCI USA Minimum Volatility (USMV) Exchange Traded Fund (ETF) is designed to track the investment results of the MSCI Minimum Volatility USA index, which is composed of stocks with a lower volatility than the general market. This can provide investors with exposure to a portfolio with low risk that has historically declined less in value than the broader market during economic downturns. The ETF is comprised of 189 holdings, and is rebalanced two times per year, with the intention of mirroring the changes made by the index. The purpose of this dissertation is to create a logistic regression model that will forecast which stocks will be added or removed from this ETF when it is rebalanced, and to understand what factors are significant. The model will take into account volatility attributes of each stock, as well as others potentially significant predictor variables from prior studies.

1.1 Low-Risk Anomaly

Several studies have shown that portfolios of low-risk stocks have higher risk-adjusted returns than portfolios of high-risk stocks (Baker et al., 2011). Low-risk stocks can be considered stocks with a low-beta and/or low-volatility. This anomaly exists for several reasons including the need for money managers to be compared to a benchmark and an increased focus on relative rather than absolute risk. The MSCI Minimum Volatility index helps investors take advantage of this anomaly.

1.2 MSCI Minimum Volatility Index

The MSCI Minimum Volatility USA index constituents come from the MSCI USA Index, which is roughly comprised of the top 600 US stocks by market cap. This minimum volatility index is intended to have a lower beta, lower volatility, lower cap bias, and contain more stocks with less risk than its parent index, which contains US mid-cap and large-cap stocks. On the last trading days of May and November, the index is rebalanced twice a year. The index typically has around 180 constituents, with an average of 20 new additions and 14 deletions every 6 months. Over the last five years, the number of additions has ranged from 12 to 25, while the deletions have

been between 10 and 19. Changes to the index are usually announced nine trading days before they are set to take place (BlackRock, 2017).

Using the Barra Open Optimizer, the Minimum Volatility Index creates a minimum variance portfolio of low-risk stocks as a subset from its parent index of US large-cap and mid-cap stock. Using an estimated security covariance matrix, the MSCI Minimum Volatility Index is the product of the lowest absolute volatility, considering the constraints (MSCI, 2013). Moreover, these additions are simply a relabeling of existing stocks in the parent index and do not include new additions to the parent index. The low-risk stocks chosen to be in the index are determined by a set of constraints, like maintaining a certain sector or country weight, relative to the parent index.

There are many specific constraints to the MSCI Minimum Volatility Index. One is that an individual stock cannot exceed 1.5%, or twenty times the weight of the stock in the parent index. The minimum weight of a security in the minimum volatility index is also capped at 0.05%. The index aims to keep the weight of specific countries within a 5% range of the weight in the parent index, or three times the weight of the country in the parent index. Sector weights cannot deviate more than 5% from the sector weights in the parent index. One-way turnover of the index is also maxed at 10%. Thus, taking into account these constraints, the Barra Open Optimizer creates the lowest absolute volatility portfolio possible (Wynne, 2016).

1.3 iShares MSCI Min Vol USA ETF

An Exchange Traded Fund (ETF) is a collection of stocks and/or bonds in a single portfolio that is traded on a major exchange (Hayes, 2017). As a result, the price of an ETF fluctuates on a regular basis. Exchange Traded Funds generally have more liquidity and lower fees when compared to other alternative instruments like mutual funds. Owning an ETF can allow investors to minimize risk, since owning an ETF is comparable to owning a portfolio of many different stocks. This diversification comes at lower costs and less effort for investors as well. ETFs can also track an index, commodity, bond, or basket of all of the above.

The iShares Edge MSCI Min Vol USA ETF (USMV) is a Blackrock-managed ETF that tracks the investment results of the MSCI Minimum Volatility USA index. Unlike an ETF, which is publicly traded, an index is not. The goal of the iShares MSCI Min Vol USA ETF (USMV) is to track the MSCI Minimum Volatility USA index, but this is more complicated than it seems. In addition to tracking stocks in this index, the ETF aims to mirror returns of the index. Any difference between the ETF return and actual index return is called tracking error. The tracking error is often very small and can typically be around a tenth of a percent. This error can come from indices being market capitalization weighted, meaning that price fluctuations of each stock lead to the weighting being changed by a ratio of its market cap against the market cap of all stocks in the index (Fontinelle, 2009). With these stock weightings in the index constantly changing and people buying in and out of ETFs constantly, it is hard to track performance completely accurately. However, ETFs very closely follow indices,

as their tracking errors are generally quite small. Thus, although ETF data is not the same as index data, the two are extremely comparable.

1.4 Regression Model

A logistic regression model will be created, which can be transformed to calculate a probability of a stock being a member of the Minimum Volatility Index. A logistic regression model will be used since the dependent variable is dichotomous. The predictor variables will include 52-week trailing volatility, 52-week trailing beta, price/book ratio, and whether or not the stock was in the index 6 months before, during the previous rebalancing. These attributes were chosen after looking at the historical literature and understanding of the minimum volatility index.

1.5 Significance

As mentioned, the purpose of this thesis is to create a logistic regression model to that will calculate the probability of a stock being in the Minimum Volatility Index. An accurate model will allow for a better understanding of a stock's volatility attributes, and can lead to an investment opportunity. There is substantial price movement whenever a stock is added or removed from a large ETF, like USMV. When a stock is added to the index, USMV will buy large amounts of that stock, increasing the demand, and consequently, the market price for that stock. If the stock is bought in advance of this large purchase, then an investor can enjoy quick price appreciation of the stock. Moreover, if a stock is removed from the Minimum Volatility Index, the ETF will sell all current holdings of the stock, which will increase the supply of the stock, driving down market price of the stock. If one were to short this stock before that happened, he/she can also profit from that event.

A phenomena known as ETF front-running occurs when traders buy or sell stocks in advance of ETF managers after they announce an exit or entrance of a position (MacDonald, 2009). There is typically a slight lag between an announcement of an ETF to add or remove a position and the actual purchase or sale of the stock. By acting quickly, traders can scalp profit by buying a stock before an ETF does, and selling it to them later at a slight profit, or short-selling a stock before an ETF exits the position, and then buying it back at the lower price. A model that can accurately calculate the probability of a stock being in the Minimum Volatility Index could be used to predict a stock's addition or deletion from the index before rebalancing. This can allow traders to similarly front-run USMV, but before the market is able to react, leading to larger profit opportunities.

Chapter 2

Literature Review

2.1 Measures of Risk

Assuming an efficient market, one of the most widely accepted tenets of investing is that one will be receiving higher reward for taking on more risk. Presumably, if this were not true, nobody would partake in higher risk investments. Some risks to consider when making an investment include those with respect to the market, liquidity, credit, inflation, and FX (Ontario, 2017). When quantifying risk for a company, one can look at the standard deviation of the stock price. By looking at the historical dispersion of data from the mean, or normal returns, one finds the stock's volatility. These calculations are based only on the price fluctuations of the stock and no other external factors (Investopedia, 2015). Volatility is also one of the best indicators of bankruptcy. The other common form of risk measurement in finance is beta, which measures the stock's price volatility compared to that of the stock market. The market is typically a benchmarked index relevant to the stock; for a large-cap US stock, the associated index could be the S&P 500. Beta is calculated by taking the covariance of the stock returns and the market returns, then dividing by the variance of the market. Shown below is the formula for beta, where R_s represents the return of the stock and R_m represents the return of the market:

$$\beta = \frac{Cov(R_s, R_m)}{Var(R_m)}$$

Figure 2.1: Beta

This yields a coefficient, which can be interpreted: a beta value of 1 indicates the stock price and market move together identically, a beta value of less than 1 indicates the stock is less volatile than the market, and a beta value of greater than 1 indicates the stock is more volatile than the market. Beta values can be negative as well, and hold the same interpretation as positive beta values, with the difference being that the stock price and market move in opposite directions. For example, a beta of -1 would mean the stock and market have the same volatility and changes in price, but that the performance is inversely related. Thus, the first sentence of this paragraph

can have many meanings, but can be interpreted as saying that stocks with higher beta or volatility will have higher expected return.

2.2 Overview of the Low-Risk Anomaly

The low-risk Anomaly stems from the observation that portfolios of low-risk stocks have higher risk-adjusted returns than portfolios of high-risk stocks. This idea challenges a widely regarded financial principle that investing in higher-risk stocks will generally result in higher expected return. In several studies, portfolios of high-risk stocks and low-risk stocks were constructed and rebalanced regularly to reflect these characteristics, and the low-risk portfolios outperformed the high-risk portfolios by a factor of several times, over long-periods of time including 1929-2015 (Vliet & Koning, 2016) and 1968-2008 (Baker et al., 2011).

One of the explanations is the need for money managers to be compared to a benchmark, such as an index like the S&P 500. This is reasonable, as many fund managers are charging fees to manage money, and need a way to prove themselves and their abilities. By outperforming an index, a fund manager is able to generate alpha, and presumably raise money money or change higher fees. By underperforming an index, the fund managers have a hard time justifying fee charges to clients, since they could just invest in the index passively for little to no fee. Thus, much of the risk for them is relative, coming from potentially underperforming on a benchmark. Moreover, with this doubling of assets under active management from 30% to 60% in 1968-2008, the low-risk anomaly intensified. Another metric of fund manager performance is through the “information ratio” (IR), or the expected return difference between the manager and the expected return of the S&P 500, divided by the volatility of this return difference (Goodwin, 1998). Shown below is the formula for IR, where R_p represents the return of the portfolio, R_i represents the return of the index, and σ_p represents the standard deviation of portfolio returns:

$$IR = \frac{(R_p - R_i)}{\sigma_p}$$

Figure 2.2: Information Ratio

The goal of an investment manager is to maximize this number, best as possible, through picking stocks that will outperform the market. These help to create a greater demand for higher-risk stocks while discouraging investments in low-beta, low-volatility stocks, and ultimately increases the market’s appetite for risky stocks with high reward potential, driving up price and driving down expected return.

In addition to the focus on relative rather than absolute risk, money managers also often focus on single period returns, often as short as a month, which aim to remove the effects of compounding. This helps differentiate each manager’s stock picking abilities, but ignores the real-world and significance of compounding. Humans also have a predisposition for the lottery effect, which is increased interest in stocks with

high skew - that is high upside potential. Risk can also be decomposed into macro and micro-effects - that is, looking for and comparing the risk-return characteristics of stocks with different risk profiles, but similar country and industry risks. It turned out that the micro-effects, those that were stock-specific, were statistically significant at generating alpha, while the macro-effects, those that were country and industry-specific was not. These literature reviews also examine both volatility and beta as a measure of risk and suggest that beta is not an adequate risk metric. In fact, though beta and volatility are obviously very correlated, beta appears to be more related to this low-risk anomaly than volatility. This can have significant implications on the significance of the predictor variables in the logistic regression model in this dissertation.

There are many real-world trading strategies that utilize this anomaly. One example includes betting against Beta (BaB), which is a strategy used by quantitative hedge funds like AQR. Betting against Correlation (BaC) is a similar strategy in that it decomposes the effects of beta into two separate factors for a more concentrated investment. Moreover, index additions and deletions have proven to be instrumental in influencing the price of affected stocks, indicating that if a model can predict these movements accurately beforehand, there is an additional considerable arbitrage opportunity.

2.3 Evidence of the Low-Risk Anomaly

2.3.1 1929-2015

Jan de Koning and Pim Van Vliet set out to investigate the question: *Do high-volatility stocks return more than low-volatility stocks?* by constructing high-volatility and low-volatility portfolios, and comparing the two over a 86-year time span, from 1929-2015. Over this period, low-volatility stocks outperformed high-volatility stocks by a factor of 18, excluding inflation and transaction costs. If both portfolios started off with \$100 in 1929, the low-volatility portfolio end value would be worth \$395,000, while the high-volatility portfolio would be worth just \$21,000. In reality, these values would both be much smaller if the costs of trading the stocks and inflation were considered, but excluding them is reasonable as the effect on both portfolios would be pretty similar. The low-volatility portfolio returned 10.2% annually whereas the high-volatility portfolio returned just 6.4% annually. This annual difference of 3.8% is striking, and when considering compounding over an 86-year period, helps explain why the low-volatility portfolio's value was over 18 times that of the high-volatility portfolio. In this study, the annualized volatility of the low-volatility portfolio was 13%, and the annualized volatility of the high-volatility portfolio was around 2.5 times that, at 36% (Vliet & Koning, 2016).

2.3.2 1968-2008

Baker et al. performed a study similar to that done by van Vliet and de Koning, but used 41 years of CRSP data, ranging from January 1968 – December 2008. It

is important to note the ranges of dates used; the Great Recession began in 2007 after the bursting of the subprime mortgage bubble, leading to the collapse of several large, investment banks, and the government bailout of many others. This caused market indices, like the Dow, to drop from a high in 2007 of 14,164.43 to 8,776.39 by December 2008, representing a decrease in over 38% during that period (Amadeo, 2017). Thus, just as van Vliet and De Koning started their sample right before the Great Depression to help amplify their results, Baker, Bradley, and Wurgler ended their sample after the Great Recession. Though this may help amplify the results, this does not take away from the significance of the findings (Baker et al., 2011).

Baker et al. constructed low-volatility, high-volatility, low-beta, and high-beta portfolios using the top 1,000 stocks by market capitalization and then calculated each stock's five-year trailing volatility or beta. A dollar investment in the low-volatility portfolio in 1968 appreciated to \$59.55 by 2008, or \$10.12 in real terms, when accounting for inflation. On the other hand, the highest-volatility portfolio went from a dollar in value to just 58 cents from 1968-2008, with a real value of around 10 cents, when considering inflation. Thus the low-volatility portfolio outperformed the high-volatility portfolio by over 100 times both in terms of nominal and real value. When using beta as a measure for risk, the finding was very similar. In the lowest-beta portfolio, a dollar grew to \$60.46 in nominal value throughout the 41-year period, or \$10.28 in real value after considering inflation. The highest-beta portfolio grew from a dollar to \$3.77 in nominal terms, or \$0.64 in real terms after accounting for the effects of inflation. Thus, the low-beta portfolio outperformed the high-beta portfolio by a factor of 16, in both nominal and real terms. One interesting observation here is though both the low-beta and low-volatility portfolios outperformed the high-beta and high-volatility portfolios, respectively, the discrepancy was far more pronounced in the case of the the volatility portfolios. Another significant observation was that investors who owned either the high-beta or high-volatility portfolio in 1968 would have lost money when accounting for the effects of inflation by 2008. It is also important to note that this was just the case for large-cap companies, as these portfolios were constructed from the top 1,000 stocks in terms of market capitalization. The fact that this anomaly was observed for large-cap companies is quite impressive, given there are generally a lesser degree of mispricing in that realm than with small-cap companies, because many small-cap stocks are not big enough for institutional investors to invest in. Thus, this anomaly would be larger if the study had been done for small-cap stocks instead. In addition, the portfolio end values assumed no transaction costs, which in reality would have been considered. The high-beta and high-volatility portfolios also cost more to rebalance on a monthly level, as was done in the paper, than the low-beta and low-volatility portfolios, indicating this anomaly is actually more pronounced than initially reported. Baker et al. noted that while high-beta portfolios outperformed the low-beta portfolios in up-markets and underperformed the low-risk portfolios in down-markets, that the low-beta anomaly persisted in both situations. On a market-adjusted basis, low-beta consistently generates high alpha (Baker et al., 2011). This was consistent with prior research (Pettengill, Sundaram, & Mathur, 1995).

2.3.3 Critique of the Capital Asset Pricing Model

These findings are not new or revolutionary and have been observed in many previous academic articles. Black, Jensen, and Scholes evaluated some of the assumptions and effectiveness of the Capital Asset Pricing Model (CAPM) (Jensen, Black, & Scholes, 1972). CAPM is a model that quantifies the relationship between risk and expected return for a stock, and considers that investors should be compensated for the time value of their money and risk they are taking. This is calculated as the risk free rate plus the beta times the difference between the risk free rate and expected market return (Brennan, 1989). Shown below is the calculation for the expected return on an asset, \bar{r}_a , where r_f represents the risk-free rate, β represents the stock's beta, and \bar{r}_m represents the expected market return:

$$\bar{r}_a = r_f + \beta(\bar{r}_m - r_f)$$

Figure 2.3: Capital Asset Pricing Model

This will give the expected return of the stock, and anything in excess of this will be considered alpha. Black, Jensen, and Scholes were able to find that expected excess return, alpha, was not strictly proportional to Beta, as it is mathematically in the CAPM. In 1975, Haugen and Heins similarly found that there was little support for the idea that risk premiums have manifested themselves in realized rates of return. In fact, they pointed out that the relationship between risk and return is much flatter than it is in the CAPM (Haugen & Heins, 1975). Twenty years later, Fama and French famously declared that beta was dead after finding a flat relationship between beta and stock returns (Fama & French, 1992). Many additional papers and researchers have added evidence for disproving the Capital Asset Pricing Model, and even suggest that beta may not be the correct measure of risk, meaning that the relationship between risk and return is not what many people believe it to be (Mullins, 1982). However, other models relating risk and return have had difficulty gaining acceptance and widespread usage in the finance industry.

2.4 Explanations for the Low-Risk Anomaly

2.4.1 Compounding

To fully grasp the low-risk anomaly, it is important to understand that a higher volatile stock or portfolio will move in greater magnitude than the underlying market. This holds true for both downside and upside scenarios. When the market increases in value, a high-volatility stock will increase in excess of this. For example, if the market increases by 20% in one year, a high-volatility portfolio would reasonably appreciate by more than 20% over the same period. However, when the market declines, a high-volatility portfolio would be expected to decrease in excess of this amount. For instance, if the market decreases by 20% in one year, a high-volatility portfolio would

reasonably depreciate by more than 20% over the same period. Lower-volatility portfolios would react in similar fashion, just with a lesser magnitude with respect to the market. With this in mind, one way the low-volatility portfolio is able to outperform the higher-volatility portfolio is by losing less during times of financial stress. Pim van Vliet and Jan De Koning conveniently started their analysis right at the beginning of the most severe economic depression in American history, the Great Depression (Vliet & Koning, 2016). The Great Depression began in 1929 and eroded away around 80% of the market's value by the time the recovery began in 1932 (History, 2010). With this in mind, by 1932 the high-volatility portfolio declined by over 80% while the low-volatility portfolio declined by less than 80%. More specifically, the high-volatility portfolio shrunk from \$100 in value to just \$5 while the low-volatility portfolio shrunk from \$100 in value to \$30. Thus, the results of this Vliet et al. could be taken with a grain of salt, since although the portfolios each started off with the same amount of money in 1929, the low-volatility portfolio was worth 6 times as much as the high-volatility portfolio just four years later. However, this is an expected consequence of the high-volatility portfolio, so these results should not be discredited. With this being said, since the low-volatility portfolio was able to lose less money during market downturns, it is able to grow, or compound, its capital more effectively than the high-volatility portfolio. To illustrate this, the portfolio values can be considered in 1932, when the high-volatility portfolio lost over 80% in value. As Benjamin Graham, a famous value investor, once noted the mathematical fact that "once you lose 95% of your money, you have to gain 1,900% just to get back where you started" (Graham, 1965). Similarly, since the high-volatility portfolio lost six times as much value as the low-volatility portfolio by 1932, it would have to outperform the low-volatility portfolio by significantly more than 600% in order to return to the same value.

2.4.2 Benchmarking

Thus, it seems very counterintuitive that fund managers and investors would not only invest in low-volatility stocks, as it appears that these stocks will outperform high-volatility stocks in the long-run. Part of understanding why this is not a commonplace investment strategy for many comes from interpreting what risk is defined as by the financial community. To investors, risk is not necessarily analogous to volatility, or even losing money. For many fund managers, risk comes from underperforming a benchmark. David Blitz, the head of quantitative equity research at Robeco, discussed the need for benchmarking the performance of investment managers (Vliet & Koning, 2016). Many managers, especially of actively managed funds, command handsome compensation in exchange for their investment acumen and diligence. Many hedge funds have a "Two and Twenty" compensation structure, where the managers charge a 2% fee on total assets under management and take an additional 20% of profits (Investopedia, 2017). Given the large amount of fees clients are paying, it is reasonable to believe that they expect to receive a greater return than if they had invested in a passive, market tracking ETF. These investment professionals need to prove to their bosses and clients that they are above average at their job. For example, if a hedge

fund manager returns 10% in one year, but the market returns 10% that same year, the client will be upset, as they are now receiving a smaller return, given the hefty fees. In this case, a \$100 investment in a market tracking index would return approximately \$10 pre-tax, given there are little to no management fees. However, \$100 invested in a hedge fund with a “Two and Twenty” structure would yield the same initial \$10 pre-tax return, but the client would pay 2% of \$100 (\$2) in management fees, and 20% of the \$10 profits (\$2) in additional compensation. This would leave the client with a total of \$6 return, or 6%, after all of the fees are paid out, and around half as much as if they had invested in a market tracking ETF. As a result, given the fee structure and client demands, active money managers are often compared to a market benchmark like the S&P 500; more importantly, they are expected to outperform these benchmarks substantially. Benchmarking also helps add perspective to a manager’s returns. If a manager returns 20% in one year when the market returns 10%, he/she will have many happy clients. However, if the manager returns 20% in the same year that the market returns 30%, clients will not be as pleased. This is a concept known as “relative” risk.

Some investors, like individuals saving for retirement, primarily care about absolute risk, which is the total amount of money that is gained or lost due to overall stock movements, with regard to the starting amount of money invested. They will check their portfolio’s total performance without much concern for the exact market return. If their portfolio gains 20% in one year, they will be content, even if the market increases 30% in the same period. For these investors, the horizon is long-term, so the short-term performance isn’t as important for them as it is for fund managers who may be trying to raise more capital or justify high fees from clients. Volatility, in itself, captures these changes in the price of a stock, and is an absolute risk measurement. Many institutional investors do not look at risk on an absolute level, as a retiree or mom-and-pop investor may, but instead look at the risk of a portfolio with respect to the stock market or some other widely accepted benchmark. For these investors, the risk is not so much about losing money, rather it is more centered around lagging the market or their peers. Investing is very much a relative game. To further illustrate this idea, in relation to a fund manager, if a portfolio drops 20% while the market drops 40%, this is seen as a much better outcome than if a portfolio goes up 20% while the market goes up 40%. In the former, the manager lost money, but outperformed the market by 20%. In the latter, the manager made money but lagged the market by 20%. This concept can be hard to fully grasp due to the natural bias towards focus on absolute risk. Many have tried to explain this seemingly misunderstood phenomena, including Jason Karceski, who noted that an extrapolation bias could cause mutual fund managers to care more about outperforming in a bull market, than underperforming in a bear market (Karceski, 2002).

In fact, in 1968, institutional investors managed 30% of all money, but by 2008, the final year of the Baker et al. study, this figure increased to 60% (Baker et al., 2011). With this doubling of assets under active management, the low-risk anomaly intensified. In addition to being directly benchmarked against an index like the S&P 500, fund managers can also be compared using the “information ratio” (IR) which is the expected return difference between the manager and the expected return

of the S&P 500, divided by the volatility of this return difference (tracking error) (Goodwin, 1998). The goal of an investment manager is to maximize this number, as best possible, through picking stocks. In fact, over 61% of U.S. mutual fund managers are benchmarked against the S&P 500, while over 94% are benchmarked to some U.S. index benchmark (Sensoy, 2009). Moreover, SEC rules require mutual funds to compare their performance to some benchmark (SEC, 2017). This intuitively makes sense, as it allows investors to assess the skill and ability of managers in an unbiased way, and also allows fund managers a chance to differentiate themselves. However, this makes institutional investors, who are managing the majority of the money in the United States, less likely to buy low-volatility stocks, leading to higher prices and lower expected returns for the high-volatility stocks and further exacerbating the low-risk anomaly.

Going back to Baker's findings, it is very hard for fund managers to attain a high IR with a low-risk portfolio. Part of this stems from the need for investment managers without leverage to find mispriced stocks with a beta very close to market risk (beta of 1), overweighting positive-alpha stocks while underweighting negative-alpha stocks. When comparing the Sharpe ratio of large cap stocks for a low-volatility portfolio, it was found to be quite high at 0.38. However, the Information Ratio was a very low 0.08, showing that this would be very tough for a fund manager to have. To provide a comparison, during 1968-2008, the top value strategy portfolios had an IR of 0.51, and top momentum strategy portfolios had an IR of 0.64. This is extremely high compared to the IR of low-volatility stocks in this period, which ranged from 0.08 to 0.17, showing these constructed low-beta portfolios would be unlikely to be used by any fund manager. While beta and volatility are undoubtedly very correlated, this shows that beta is more related to the anomaly than volatility, especially with large cap stocks, which is what most fund managers disproportionately focus their investments in (Baker et al., 2011).

2.4.3 Single-Period Returns

Another explanation of the low-volatility anomaly is an increased focus on returns over short-term periods by many researchers and investors. By focusing on "single period returns," which in most academic studies is just a one-month period, the significance of compounding is removed. This is more of an arithmetic way to calculate returns, where each month's return can be averaged, for example. Mathematically, this is not the correct way to calculate a return since it does remove the effect of compounding, but is a common way to compare fund managers. Moreover, when done over very short time periods (like a year), the effect of compounding is not as significant as it is for very long-term periods. To illustrate this, the following scenario can be considered: in one month a portfolio worth \$100 drops 50% to \$50, then the next month increases 50% to \$75. The investment return is dependent on how one divides the time period. Looking at it on a monthly basis, even though the portfolio lost \$25 in value, the net return would be $-50\% + 50\%$, or 0% (with focus on single period returns, not accounting for compounding). However, looking at it on a longer-term basis, the net return was -25%, as the \$100 portfolio ended up losing \$25 in value. By not fully

including the magic “return upon return” effect of compounding, the high-volatility portfolio discussed earlier performed more than 6% better per year (Vliet & Koning, 2016).

Psychological and Behavioral Factors

In addition to the reasons mentioned, there are several psychological reasons why some investors are not attracted to low-risk stocks. Eric Falkenstein, a renowned author in the low-volatility investing realm, wrote that “envy is at the root of the investment paradox” (Falkenstein, 2012). Some investors simply don’t recognize the significance of compounding returns. Many others do but are unable to utilize the paradox due to relative risk and career pressures. Analysts who choose big winners are more likely to get recognized and promoted than those who pick safer stocks with lower upside potential; funds that pick the right high-risk stocks that turn out to be major home-runs will see more reward as an increase in AUM, and consequently an uptick in management fees. Moreover, some people do not invest in low-risk stocks because they have less of an appeal than high-risk stocks, where investors think they can make a lot of money easily and quickly. Even the news will have a bias towards reporting about and covering stocks that have become big winners. One famous big winner is Amazon: a \$5,000 investment in 1997 would be worth \$2,400,000 today, or an increase 49,000% (Berger, 2017). With all the excitement and reporting to this day on big winners like Amazon, many people forget about the number of similar technology companies that failed during the dot-com bubble and are worth nothing today. Thus, these high-risk stocks are more “sexy” and have a “lottery ticket” element that tempts investors with the appeal of a big payday.

Many investors have a natural preference for lotteries, even though there is a general aversion towards loss. If a stock has a positive skew, which is defined as a larger probability of a large positive payoff than probability of a small payoff, investors typically are very interested (Baker et al., 2011). Though skew is not the same as volatility, through their research, Boyer, Mitton, and Vorkink made a strong case for how expected skewness is a proxy for volatility through their findings that expected skewness assisted in explaining the observation that stocks with high idiosyncratic volatility have low expected returns (Boyer, Mitton, & Vorkink, 2009).

Another idea is representativeness, or that Bayes’ rule and probability theory are often not natural to people, even in the most seasoned investment professionals. One example of this is selectively looking at a few speculative investments that have turned out to be massive successes without considering the numerous failures. As mentioned earlier, the news will focus on Amazon’s great success over the past twenty years, but will not focus as much on all of the tech stocks that became worthless after the bubble burst. By not separating and considering all winners and losers, the average investor may be inclined to overpay for a riskier stock (Baker et al., 2011).

Overconfidence has also been tied to a preference for volatile stocks; optimists are generally more aggressive than pessimists. In a study, people were asked questions on how certain they were of their responses and it appeared many did not have an understanding of probability. Estimating the heat of a candle flame is very difficult, so

for someone to say they are 80% sure of their answer is impressive, yet hard to believe. This can apply when people are asked for a confidence interval of the population of a city. In many instances, the person would be confident and give a very narrow range of people (Fischhoff, Slovic, & Lichtenstein, 1977). This same concept applies when valuing stocks and evaluating certain investment opportunities.

Overall, irrational investor preference for lotteries and high-volatility stocks, as well as investment managers' focus on benchmarks and IR, flatten and eventually invert the relationship between risk and return in the long-run. Moreover, it has been shown by Baker et al., and prior observations that the anomaly intensified with the increase in assets under active management of fund managers in the U.S. These reasons together have led to the findings that low-beta and low-volatility stocks have outperformed high-beta, high-volatility stocks from 1968-2008, in part due to combining great returns with low downturns. Investor preference for "lotteries" and a bias of overconfidence creates a higher demand for higher-volatility securities, and the need to benchmark creates a greater demand for higher risk stocks, while discouraging investments in low-beta, low-volatility stocks. This understandably, increases the market's appetite for risky stocks with high reward potential, driving up price and driving down expected return. These reasons appear perennial, so the anomaly is unlikely to cease to exist in the near future.

2.4.4 Profitability

Defensive equity strategies generally aim at constructing a portfolio comprised of more low-risk stocks. This strategy has been becoming very popular as of late, in part due to equity markets that have suffered two recent, severe downturns, negative nominal returns in the first decade of 2000, and literature proving a weak or negative relationship between risk and return (Novy-Marx, 2014). Prior literature has looked at the relationship of performance relative to size and value, but many studies have not done a deeper dive into the effect of specific factors, such as profitability (Chan, Hamao, & Lakonishok, 1991). In fact, it has been shown that high profitability is the most significant predictor of low-volatility, inherently causing these defensive equity strategies to indirectly tilt towards profitability, in addition to the more known factors, like size and value. Size is very important, as small growth stocks are typically underweight in these strategies, while large value stocks are overweight. Likewise, value stocks are typically overweight, while growth stocks are underweight. Thus, the performance of defensive equity strategies can be explained by accounting for size, value, and profitability (Novy-Marx, 2014).

In terms of performance, defensive equity strategies, which are defined as low-volatility or low-beta in nature, have outperformed more aggressive strategies. This was already shown between 1929-2008 (Vliet & Koning, 2016) and in a separate study from 1968-2015 (Baker et al., 2011), but Novy-Marx analyzes a different timeframe. He looks at the characteristics of these low-risk portfolios in more detail by analyzing log-likelihood ratios that a stock selected at random is of a given style, like size or value, relative to the unconditional probability of being that style (Novy-Marx, 2014). The findings were very telling: on average, low-volatility stocks were 30 times larger than

high-volatility stocks. As a result, though the high-volatility names made up half the total number of stocks, they contributed to just 9% of the total market capitalization when compared with low-volatility stocks. Moreover, when looking at the average returns across the portfolios of various volatilities, there seemed to be a relatively flat, slightly increased return with increasing volatility. The high-volatility/high-beta portfolio had a significant negative alpha, while the low-volatility/low-beta portfolio had a significant positive alpha (Novy-Marx, 2014).

Many of the volatile stocks tended to be small, unprofitable growth stocks which can help explain the relationship of the defensive strategy performance to size, value, and profitability. In fact, since 1968-2015, the portfolio of high-volatility stocks almost mirrored the performance of the portfolio of unprofitable, small growth stocks. Thus, the outperformance of defensive stocks from 1968-2015 have delivered significant alpha and can be explained when accounting for size, value, and profitability. In fact, profitability itself is so significant, that the case can be made that this alpha may come in large part from excluding unprofitable, small growth stocks (Novy-Marx, 2014).

2.5 Decomposition of the Low-Risk Anomaly into Micro and Macro Effects

The low-beta anomaly can be further broken up into micro and macro effects. The micro effects can be observed through picking low-beta stocks, and keeping country and industry risk the same, while the macro effects can be isolated by picking low-beta countries or industries, while keeping stock-specific risk the same. Baker et al. generates observable micro effects by creating portfolios of equity longs and shorts, holding forecasted country and industry risk constant. The macro effects were observed by constructing long-short portfolios of various countries and industries, holding forecasted stock-specific risk constant. Studying a number of stocks within 29 industries and 31 different developed countries, the macro and micro effects were observed and, both together, were shown to play an important role in explaining the low-risk anomaly (Baker, Bradley, & Taliaferro, 2014).

Looking at 31 developed countries including Canada, France, Germany, Japan, and Singapore, Baker et al. worked to decompose the low-risk anomaly into country and stock specific effects. Similar to the industry findings, country-beta was able to predict stock betas to a certain extent, but not as well as historical stock betas were. Looking only at country betas yielded around half the risk reduction and two-thirds the risk-adjusted return improvement, as compared to stock betas. This study implied that predicting risk of individual stocks is in itself very hard when only given data on country or industry risk, but when given all the data can have much more predictive power (Baker et al., 2014).

It was found that using industry beta to predict future stock betas was possible, but not as effective as just using historical stock betas. Industry beta information without stock information does improve risk-adjusted returns, just not to the same extent as stock information does. Baker et al. go into detail trying to isolate pure-industry

effects and pure-stock effects. Pure-industry effects are the average differences between high and low-beta industries, while holding constant stock risk. Pure-stock risk is the opposite of that, calculating the average difference between high-beta and low-beta stocks, keeping industry risk constant. In the end, finding low-risk portfolios using selection of low-risk stocks and keeping industry constant was around four times more effective than using low-risk industries and keeping stock risk constant. However, once again, using the historical betas of both together, has more predictive power than either one alone (Baker et al., 2014).

Micro-selection of stocks, holding country and industry risks constant, was shown to significantly reduce risk without a significant decrease in return. In some cases, high-risk stocks within particular industries were able to be distinctly identified, and they typically had similar returns when compared to low-risk stocks in the same industry and country. Macro-selection, which involved holding stock-specific risks constant, was shown to lead to increases in return with small differences in risk, especially with regards to the country chosen. Stocks in high-risk countries were found to have distinctly lower returns than low-risk countries. These findings hold significant investment opportunity, due to the implication that people seeking arbitrage opportunities through mispricing of macro-effects like industry and sector, or through ETFs might not be as successful as exploiting the risk reduction opportunities stemming from micro-effects. While both the micro and macro-effects led to higher CAPM alpha by reducing risk and increasing returns, only the micro-effects were found to be statistically significant, whereas the macro-effects of country selection and industry selection were not found to be statistically significant. Thus, there is more of an arbitrage opportunity exploiting the micro-effects of individual stock selection than the macro-effects like country to industry. Even though the macro-effects have many limitations in practice, micro-effects are also limited due to leverage restrictions and benchmark mandates.

2.6 Applications of the Low-Risk Anomaly

2.6.1 Betting Against Beta (BaB)

Prior studies suggest that beta is not a great measure of risk and is more related to the anomaly than volatility is. AQR, a successful quantitative-focused hedge fund, employs a strategy called Betting Against Beta (BaB), which is a simple method of statistical arbitrage generated by shorting high-beta stocks and longing low-beta stocks (Investopedia, 2015). As discussed in some of the works previously, the premise behind this arbitrage opportunity is that high-beta stocks are overpriced while low-beta stocks are underpriced. The theory is that the stocks will eventually return to this equilibrium point, called the security market line (SML). While the prices approach this median, the investor can capture this spread as an arbitrage opportunity (Investopedia, 2015).

The Capital Asset Pricing Model calculates the expected equity return given certain levels of risk. Any excess above this risk-adjusted return is the Sharpe Ratio, or alpha that is generated by the stock. The Sharpe Ratio is calculated by taking the

mean portfolio return and subtracting the risk free rate, then dividing by the standard deviation of portfolio returns (Investopedia, 2017). Shown below is the formula for the Sharpe Ratio, where \bar{r}_p represents the expected return of the portfolio, r_f represents the risk-free rate, and σ_p represents standard deviation of portfolio returns:

$$SR = \frac{\bar{r}_p - r_f}{\sigma_p}$$

Figure 2.4: Sharpe Ratio

Investors try to maximize this number, and one way to do it is by leveraging up, or using borrowed capital to invest. By paying a fixed interest rate on the borrowed capital, assuming the return is more than the interest rate, an investor can increase the return on their invested equity. As one may imagine, this is more risky, as returns in both the upward and downward direction are magnified. As a result, many investment managers, like mutual funds, are legally constrained on the amount of leverage they can apply to a portfolio. Due to this, many fund managers must overweight high-beta stocks to improve overall returns. This leads to a tilting towards beta, and a flattening of this SML in relation to CAPM. This leads to a pricing anomaly which firms like AQR can take advantage of. By creating a market neutral strategy, and shorting high-beta stocks while longing low-beta stocks, they can capture this opportunity.

Andrea Frazzini and Lasse Heje Pedersen of AQR describe this strategy through a model in one of their studies (Frazzini & Pedersen, 2014). In this paper, a real-world resembling model is created with leverage and margin constraints in 55,600 stocks from 20 global stock, bond, credit, and future markets. Some agents in this model cannot use any leverage, and some have limited margin constraints, much like many investors and fund managers. As mentioned, many mutual funds, pension funds, and individual investors are constrained by the amount of leverage they can take on, such that instead of investing in a portfolio yielding the highest Sharpe Ratio, they are forced to overweight portfolios with riskier stocks. This suggests fund managers hold high-beta stocks to a lower risk adjusted return standard than low-beta stocks, which would require leverage. Thus, if someone cannot leverage or has significant leverage constraints, then they will overweight riskier securities. The model in this paper was able to empirically show this in the equities, bonds, and futures markets. This was done by sorting portfolios by betas, and realizing alphas and Sharpe Ratios declined with increases in portfolio-beta (Frazzini & Pedersen, 2014).

Presumably, if one could lever up without constraint, the investor would underweight high-beta assets and overweight low-beta assets. BaB factors help explain this. A BaB factor is a portfolio longing low-beta securities (leveraged to a beta of 1), shorting high-beta assets (deleveraged to a beta of 1), that is market neutral. Frazzini's model predicts that this portfolio will have a positive return that increases with the spread in the betas and tightness of leverage constraints. Thus, being long low-beta stocks and short high-beta stocks yields significant, and positive risk-adjusted returns. This was observed in the model by looking at U.S., developing, and international equity markets and noting that the BaB factor yielded a Sharpe ratio that was double

its value effect, and 40% greater than momentum. The BaB factor had very high risk-adjusted returns, and during four twenty-year periods between 1926 and 2012, produced significant positive returns. This generally held across other asset classes, too, including credit and treasury bond markets (Frazzini & Pedersen, 2014).

When a leverage constraint was met or surpassed, and the agent needs to deleverage, the BaB factor portfolio experiences negative returns, but its expected future returns still increased. This was once again shown with a time series with spreads of various funding constraints. Another central idea of the model was that increased funding liquidity risk compresses betas toward one. Frazzini et al. proved this by looking at the volatility of funding constraints as funding liquidity risk; the end finding was that the dispersion of betas when funding liquidity risk is high, and was much lower than when funding liquidity risk is low. In other words, tightening of funding constraints leads to a lower BaB factor (Frazzini & Pedersen, 2014).

Finally, the model showed that investors who are more leverage-constrained are forced to overweight riskier securities, while investors without such constraints could overweight low-risk securities. Observing a number of stock portfolios from constrained investors showed most fund managers and individual investors' portfolios have a beta greater than one. However, many private equity firms that perform leveraged buyouts are traditionally able to purchase firms with a beta below one and apply leverage, allowing them to utilize this anomaly due to the fact that they have lower leverage constraints than their public market counterparts. Famed investor Warren Buffett even bets against beta, as many of his investments are leveraged, low-beta stocks. By having these constraints, though, the typical public markets investor is forced to hold on to riskier, high-beta stocks, leading to effectiveness of the BaB factor (Frazzini & Pedersen, 2014).

2.6.2 Betting Against Correlation (BaC)

In trying to understand the low-risk anomaly and how it could be applied, Asness et al. considered two possible explanations. The first looked at whether it was caused by leverage constraints, or measurement using systematic risk. The second focused on the behavioral effects, or idiosyncratic risks. One of the main issues with prior research is that many low-risk factors are correlated and interrelated, making it hard to completely isolate certain factors or effects. Adrian et al. showed a link between return of the BaB factor and financial intermediary leverage (Adrian, Etula, & Muir, 2014). Many of these factors, including BaB, generally exhibited the "low-risk effect" and were consequently very difficult to completely distinguish from one another.

Asness et al. attempted to clarify this by introducing a couple new factors meant to control for existing factors (Asness, Frazzini, Gormsen, & Pedersen, 2016). They broke down BaB into two separate factors: betting against correlation (BaC) and betting against volatility (BAV). This was done because beta itself is calculated by taking the stock's correlation with the market times its own volatility and dividing by the market's overall volatility. BaC is accomplished through longing stocks with a low correlation to the market, and shorting those with a high correlation to the market, while trying to match the volatilities of both the long and short portfolios. BAV is

achieved in a similar manner, except through longing stocks with low-volatility and shorting high-volatility stocks while keeping correlation constant.

To address the behavioral explanation, Asness et al. looked at some prior factors from observations made by Ang et al. (Ang, Hodrick, Xing, & Zhang, 2006). They found that stocks with low idiosyncratic volatility (IVOL) had a greater risk-adjusted return, and in 2009 added to this by finding that a low maximum return (LMAX), a measure of idiosyncratic skewness, is associated with greater risk-adjusted returns (Ang, Hodrick, Xing, & Zhang, 2009). Asness et al. kept the focus on the LMAX and IVOL, but added another factor, scaled MAX (SMAX), which longs stocks with a low MAX return divided by ex-ante volatility, and consequently shorts stocks with a high MAX return divided by ex-ante volatility (Asness et al., 2016). This allows focus on the lottery demand, holding volatility relatively constant and only focusing on the distribution of the returns. Margin debt held by investors and investor sentiment were also noted.

Overall, 58,415 stocks from the MSCI World Index from 24 different countries between January 1926 and December 2015 were covered (Asness et al., 2016). BAV and BaC were found to be very successful in controlling for the other factors that could influence the “low-risk effect.” The BAV findings are in line with prior findings, and can be explained through behavioral effects like the lottery preference and leverage aversion. For all stocks, the BaC factor produced a significant six-factor alpha that was nearly independent of the other low-risk factors studied. This was partially due to the leverage aversion, which indicates correlation changes in beta should be priced in. In terms of explaining the behavioral side with factors, SMAX was the only truly great, resilient measure used. The rest generally had higher turnover, and were consequently very susceptible to microstructure noise. SMAX attained positive risk-adjusted returns in the U.S. but negative risk-adjusted returns globally, which was seen with some other idiosyncratic risk factors. Asness et al. showed that systemic low-risk factors generally tended to outperform behavioral risk factors, especially when considering turnover and time period length. All in all, the low-risk effect was believed to be driven by multiple factor effects, meaning both leverage constraints and lottery demand could play a role in influencing this. However, leverage constraint effects were a bit stronger, especially internationally. By cleaning up these factors, clearer explanations for previously observed results were provided (Asness et al., 2016).

2.6.3 Stock Price Response to Index Rebalancing

One of the driving fundamental assumptions of finance is a flat demand curve for stocks, where risk is the main driver and each stock has a perfect substitute. However, this concept has been questioned for the past few years, with literature picking up on stocks showing supply shocks and quantifying how this affects their market price. Literature has shown several instances where large block sales of stock has negatively affected its price (Harris & Gurel, 1986). This was often due to information contamination, which is new, significant information about the company in the market. This information often reflects fundamental changes in the company, and, if it is negative, will understandably trigger block sales. Thus, the price change could be less

due to the supply shock, and caused more by fundamental changes in the company's value, such as a scandal or earnings report release.

However, interesting patterns that have not yet been fully explained emerge from observations regarding S&P 500 company addition and deletions. When companies are added or removed from the index, it is often purely mechanical and usually not due to some drastic fundamental change in the company. Assuming the market is efficient, the demand for stocks should not change due to being added or removed from an index, but several studies have shown that it does (Shleifer, 1986). The studies agree that new additions to the S&P come with higher than normal returns for that company (Beneish & Whaley, 1996). Though they agree on the price movement, the studies tend to disagree on the precise reason for this price movement; some possible explanations include: compensation for providing liquidity, better monitoring for investors when a company is added to a reputable and large index, and higher analyst coverage leading to more information and analysis available on the company (Chen, Noronha, & Singal, 2004). One primary concern is whether or not index reshuffling is an information-free event - that is, whether a company being added or removed adds information about the company to the market.

Others looked at factor index rebalancing for an information-free event (Huij & Kyosev, 2016). Factor indices are part of a parent index of many other stocks and are constructed in a mechanical way that is publicly available and usually based on ranking stocks off a particular ratio of characteristic. The authors looked at one example, the MSCI Minimum Volatility index, and recorded returns for the stocks that had been added or dropped. It was found that the cumulative return from announcement to the effective day was 1.07% for stocks added with a significant t-statistic of 7.16, with 62% of the stocks exhibiting a positive cumulative abnormal return. Of the 1.07% increase, 0.63% of it was gained the following day, indicating that a large part of the increase was due to greater demand from index funds. 0.31% of the return was lost five days after the rebalancing, but generally the price tended to stabilize after around ten days. Thus, 68% of the price increase was long lasting while the other 32% was temporary and lost after a few days. This can be due to a liquidity premium charged by the stock's owner or arbitrage activity. Average trading volume was also significantly higher for stocks that were recently added to the index. For the days between the announcement and actual addition of the stock, the average trading volume was 30% higher than normal, with a significant t-statistic of 3.81. Moreover, there was a 74% increase in volume for the day prior to the actual addition of the security. A very similar phenomena occurs with stocks set to be dropped from the USMV Index; from the announcement of a stock being dropped to the day before it is actually deleted from the index, the total cumulative abnormal return was -0.91%, and a total of -0.57% came the day before. After the stocks were deleted, 64% had a negative return the following day, and only 0.49% of the -0.91% was regained after three weeks. Trading volume also spiked 46% on the day prior to removal from the index. After three weeks, it returned back to within 1% of the normal trading volume (Huij & Kyosev, 2016).

These findings imply that once a security is added to a factor index, the demand curve shifts to the right, moving the equilibrium. The trading volume change is

likely due to index funds buying or selling massive amounts of the stocks that will be added or removed. Moreover, it was found that the amount of the return is also directly related to the weighting of the volume of stocks entering or leaving the factor index. All in all, these findings suggest an index arbitrage opportunity exists if index additions or deletions can be accurately predicted.

Chapter 3

Data Gathering Process

3.1 Data Aggregation

Data was collected for the iShares MSCI USA Equal Weighted ETF (EUSA), which tracks the parent index of the minimum volatility index, and iShares Edge MSCI Min Vol USA ETF (USMV), which tracks the minimum volatility index, from Oct 31, 2011 to December 31, 2016 (BlackRock, 2017). The iShares data contained this information for the two ETFs of interest for each constituent on the last trading day of every month. This included characteristics of each stock, such as: ticker, company name, asset class, weight of the stock relative to the entire index, price per share, number of shares, market value of the position, notional value of the position, sector, sedol number, isin number, exchange that the stock is listed on, and the month end date for the data. Each month-end dataset was individually downloaded, then aggregated to create the two separate raw data sets - one for EUSA and one for USMV. The data was then cleaned and stored in R (RStudio Team, 2015).

3.2 Data Cleaning

After having a quick overview of the data, there were many issues with each respective dataset that needed to be fixed before the analysis could occur. Since USMV is a subset of EUSA, the issues were very similar, and those that existed in USMV, generally existed in EUSA as well. The issues could be broken down into 3 main types: erroneous listed stock exchanges, problematic listed tickers, and price discrepancies due to issues like stock splits. Moreover, cash and cash related assets were removed from the data, as this dissertation focuses only on the stocks.

3.2.1 Non-US Exchanges

Looking at the unique exchanges of the data, it was observed that there were several foreign exchanges like the Swiss Exchange and the Mexican Stock Exchange. Some of the stock exchanges from the data set are shown below:

- [1] New York Stock Exchange Inc.
- [2] NASDAQ
- [3] Bolsa Mexicana De Valores (Mexican Stock Exchange)
- [4] Nyse Euronext - Euronext Paris
- [5] Boerse Berlin
- [6] Tokyo Stock Exchange
- 17 Levels: Boerse Berlin Boerse Duesseldorf ... Tokyo Stock Exchange

This did not make sense, given the ETF constituents are supposed to be US-focused, meaning they should be listed on US-based exchanges. Of the non-US exchange errors, they can be further broken up into two subgroups: companies that were incorrectly listed overseas and are actually listed on US exchanges, and companies that also are actually listed on US exchanges but instead had their overseas exchange tickers listed.

Mislabeled Exchanges

The first type of error involved companies that are actually listed on either the NYSE and NASDAQ, but were listed on a foreign exchange in the data and still had their US ticker used. One example was BAC (Bank of America) which is listed on the NYSE, but was listed on the Swiss Stock Exchange in the dataset:

	ticker	name	weight	price	exchange	date
1	BAC	BANK OF AMERICA CORP	0.5812	6.83	Swiss Exchange	2011-10-31
2	BAC	BANK OF AMERICA CORP	0.4643	5.44	Swiss Exchange	2011-11-30
3	BAC	BANK OF AMERICA CORP	0.4732	5.56	Swiss Exchange	2011-12-30
4	BAC	BANK OF AMERICA CORP	0.5823	7.13	Swiss Exchange	2012-01-31
5	BAC	BANK OF AMERICA CORP	0.6235	7.97	Swiss Exchange	2012-02-29
6	BAC	BANK OF AMERICA CORP	0.7375	9.57	Swiss Exchange	2012-03-30

The price for BAC in the data set corresponded to the price of BAC in the NYSE, even though it was listed on the Swiss Exchange; BAC also did not corresponded to Bank of America on the Swiss Exchange. Thus, after several checks, it could be concluded that BAC in the data set was incorrectly listed on the Swiss Exchange, and should have been listed on the NYSE instead. Since the ticker was still correct and would be read in properly in the later stages of this paper, these cases were left as is and no changes were made.

Mislabeled Tickers

The second type of error stemmed from companies listed on foreign exchanges that are also listed on a US exchange in reality, but had their non-US ticker used in the data set. One example of this was Aflac, Inc. which was listed by its ticker “8686” on the Tokyo stock exchange:

	ticker	name	weight	price	exchange	date
1	8686	AFLAC INC.	0.1779	45.09	Tokyo Stock Exchange	2011-10-31
2	8686	AFLAC INC.	0.1719	43.44	Tokyo Stock Exchange	2011-11-30

```

3  8686 AFLAC INC. 0.1699 43.26 Tokyo Stock Exchange 2011-12-30
4  8686 AFLAC INC. 0.1810 48.23 Tokyo Stock Exchange 2012-01-31
5  8686 AFLAC INC. 0.1698 47.25 Tokyo Stock Exchange 2012-02-29
6  8686 AFLAC INC. 0.1646 45.99 Tokyo Stock Exchange 2012-03-30

```

This immediately raised a red flag due to the numbers in the ticker. This numeric ticker corresponded to Aflac, Inc. on the Tokyo exchange, but when checking the recorded price of the stock for corresponding dates, it matched up with the Aflac, Inc. stock on the NYSE, with ticker “AFL”. Thus, when this happened, each company was treated on a case-by-case basis. In this case, since the stock price corresponded to AFL, the ticker name was changed from “8686” to “AFL”.

3.2.2 Unrecognized Tickers

The final general type of error in the data occurred when the ticker incorrectly recorded in the data set. This was evaluated, once again, on a case-by-case basis, by observing which tickers were not recognize, and looking at the company name to understand why. Sometimes, the issue was very obvious. One example of a clear discrepancy was when the ticker had an asterisk at the end of it. After careful digging, the asterisk did not seem to mean anything, and it is unclear why some tickers contained it. One ticker was “AAPL*”:

```

      ticker      name weight  price      date
1  AAPL* APPLE INC 3.1640 404.78 2011-10-31
2  AAPL* APPLE INC 2.9821 382.20 2011-11-30
3  AAPL* APPLE INC 3.1623 405.00 2011-12-30
4  AAPL* APPLE INC 3.4130 456.48 2012-01-31
5  AAPL* APPLE INC 3.8840 542.44 2012-02-29
6  AAPL* APPLE INC 4.2291 599.47 2012-03-30

```

This would cause future issues when reading the data in, because that ticker was not read in as “AAPL” due to the asterisk. This was fixed by simply removing the asterisk from the ticker name.

Another example of the ticker not being read in properly was when it contained numbers. Allflac was an example that was mentioned previously, but another one that applied here was “AG4” which was the ticker for Allergan. Since NYSE and NASDAQ tickers do not contain numbers, this was a clear issue:

```

      ticker      name weight  exchange price      date
1    AG4 ALLERGAN 0.2160 Boerse Berlin 84.12 2011-10-31
2    AG4 ALLERGAN 0.2157 Boerse Berlin 83.72 2011-11-30
3    AG4 ALLERGAN 0.2275 Boerse Berlin 87.74 2011-12-30
4    AG4 ALLERGAN 0.2178 Boerse Berlin 87.91 2012-01-31
5    AG4 ALLERGAN 0.2126 Boerse Berlin 89.59 2012-02-29
6    AG4 ALLERGAN 0.2204 Boerse Berlin 95.43 2012-03-30

```

After some research, it found that AG4 is the ticker for Allergan on the Deutsche Boerse AG Stock Exchange, but the prices corresponded to that of Allergan's on the NYSE. Thus, the AG4 ticker was changed to the ticker used for Allergan on the NYSE - AGN. Overall, though each category is unique, there has been a lot of overlap, and often times correcting one type of error would fix other errors too. For example here, many tickers that include numbers would lead to obvious errors, and this was often times because the ticker corresponded with the right company, just on a foreign exchange.

3.2.3 Price Discrepancies

The general methodology to ensure a change in ticker was appropriate was to check the price of the stock at a specific date, in the USA data set, and then compare it to the new ticker being assigned. If the price matched, the change was made. If the price did not match up, and was very different, research was performed to see if a stock-split might be the cause of this. If there was no evidence of a stock-split, then the stock further analyzed to see what the issue was. In addition to looking at when prices did not match up with tickers and companies for certain dates, monthly returns were calculated for each stock during the times they were in the index, and any abnormal returns (magnitude greater than 30% in one month) were look at manually. One example of this was Netflix's stock 7:1 stock split in 2015. The monthly data showed drastic fall in price from 656.94 on 2015-05-29 to a 114.31 on 2015-07-31, in just one month. This amounts to recorded loss of 82.5%:

	ticker	name	weight	exchange	price	date
1	NFLX	NETFLIX INC	0.1840	NASDAQ	624.06	2015-05-29
2	NFLX	NETFLIX INC	0.1945	NASDAQ	656.94	2015-06-30
3	NFLX	NETFLIX INC	0.2329	NASDAQ	114.31	2015-07-31
4	NFLX	NETFLIX INC	0.1693	NASDAQ	115.03	2015-08-31
5	NFLX	NETFLIX INC	0.1588	NASDAQ	103.26	2015-09-30

Since this surpassed the threshold set, it was look at in more detail. After some research, it was shown there was in fact a 7:1 stock split, so the price of the stock on 2015-07-31 was adjusted to 800.17, and the appropriate calculations were done. Thus, in this case, the ticker was left alone, but just the price was adjusted.

Tickers and stock names that could not be determined were removed. In the end, "1015736" and "Orchard Supply Hardware Stores" were removed from the data set. These together accounted for less than 0.2% of the data for a given month-end date.

3.3 Data Overview

To get a sense of the cleaned EUSA data, an overview is shown below:

	ticker	name	asset.class	weight	price	shares
1	A	AGILENT TECHNOLOGIES INC	Equity	0.1090	37.07	79

2	AA	ALCOA INC	Equity	0.0981	10.76	245
3	AAP	ADVANCE AUTO PARTS INC	Equity	0.0388	65.07	16
4	AAPL	APPLE INC	Equity	3.1640	404.78	210
5	ABC	AMERISOURCEBERGEN CORP	Equity	0.0942	40.80	62
6	ABT	ABBOTT LABORATORIES	Equity	0.7018	53.87	350
	market.value	notional.value	sector	sedol		isin
1	2929000	NA	Health Care	2520153	US00846U	1016
2	2636000	NA	Materials	2021805	US013817	1014
3	1041000	NA	Consumer Discretionary	2822019	US00751Y	1064
4	85004000	NA	Information Technology	B011001	US037833	1005
5	2530000	NA	Health Care	2795393	US03073E	1055
6	18855000	NA	Health Care	2002305	US002824	1000
			exchange			date
1			New York Stock Exchange Inc.			2011-10-31
2			New York Stock Exchange Inc.			2011-10-31
3			New York Stock Exchange Inc.			2011-10-31
4			Bolsa Mexicana De Valores (Mexican Stock Exchange)			2011-10-31
5			New York Stock Exchange Inc.			2011-10-31
6			New York Stock Exchange Inc.			2011-10-31

Shown below are summary statistics for EUSA. Each name is represented 63 times, which indicates no name is overrepresented in the dataset. Moreover, every row is an equity, which makes sense considering cash and cash assets were removed from the dataset at the beginning of the cleaning process. The weights of each stock in the EUSA ETF are also all between 0 and 4.6773%. There are no negative values and no stocks that appear to be incorrectly overweight. Moreover, each sector appears to be reasonably distributed, and the dates correctly range from 10-31-2011 to 12-30-2016.

	name	asset.class	weight
3M CO	: 63	Cash : 0	Min. :0.0000
ABBOTT LABORATORIES	: 63	Equity :38598	1st Qu.:0.0536
ACCENTURE PLC	: 63	Money Market: 0	Median :0.1208
ACTIVISION BLIZZARD INC:	63		Mean :0.1629
ADOBE SYSTEM INC	: 63		3rd Qu.:0.1636
ADVANCE AUTO PARTS INC :	63		Max. :4.6773
(Other)	:38220		
	sector	date	
Financials	:6825	Min. :2011-10-31	
Consumer Discretionary:	6595	1st Qu.:2013-02-28	
Information Technology:	5487	Median :2014-06-30	
Industrials	:4687	Mean :2014-06-12	
Health Care	:4067	3rd Qu.:2015-09-30	
Energy	:3208	Max. :2016-12-30	
(Other)	:7729		

To get a sense of the cleaned USMV, an overview is shown below:

	ticker	name	asset.class	weight	price	shares
1	AAP	ADVANCE AUTO PARTS INC	Equity	0.7986	65.07	316
2	AAPL	APPLE INC	Equity	0.0943	404.78	6
3	ABC	AMERISOURCEBERGEN CORP	Equity	0.7479	40.80	472
4	ABT	ABBOTT LABORATORIES	Equity	1.5544	53.87	743
5	ACGL	ARCH CAPITAL GROUP LTD	Equity	0.7767	35.97	556
6	ACN	ACCENTURE PLC	Equity	1.6452	60.26	703

	market.value	notional.value	sector	sedol	isin
1	20562	NA	Consumer Discretionary	2822019	US00751Y1064
2	2429	NA	Information Technology	B011001	US0378331005
3	19258	NA	Health Care	2795393	US03073E1055
4	40025	NA	Health Care	2002305	US0028241000
5	19999	NA	Financials	2740542	BMG0450A1053
6	42363	NA	Information Technology	B4BNMY3	IE00B4BNMY34

	exchange	date
1	New York Stock Exchange Inc.	2011-10-31
2	Bolsa Mexicana De Valores (Mexican Stock Exchange)	2011-10-31
3	New York Stock Exchange Inc.	2011-10-31
4	New York Stock Exchange Inc.	2011-10-31
5	NASDAQ	2011-10-31
6	New York Stock Exchange Inc.	2011-10-31

Shown below are summary statistics for USMV. Each name is represented 63 times, which indicates no name is overrepresented in the dataset. Moreover, every row is an equity, which makes sense considering cash and cash assets were removed from the dataset at the beginning of the cleaning process. The weights of each stock in the USMV ETF are between 0.0002 and 2.8287%. There are no negative values and no stocks appear to be incorrectly overweight. Moreover, sectors appear reasonably distributed, and the dates correctly range from 10-31-2011 to 12-30-2016.

	name	asset.class	weight
ABBOTT LABORATORIES	: 63	Cash	: 0
ALTRIA GROUP INC	: 63	Equity	:9229
ARCH CAPITAL GROUP LTD	: 63	Money Market:	0
AT&T INC	: 63		
AUTOMATIC DATA PROCESSING INC:	63		
AUTOZONE INC	: 63		
(Other)	:8851		

	sector	date
Health Care	:1631	Min. :2011-10-31
Financials	:1548	1st Qu.:2013-04-30
Information Technology:	1482	Median :2014-09-30
Consumer Staples	:1222	Mean :2014-08-13
Consumer Discretionary:	1053	3rd Qu.:2015-11-30
Utilities	: 616	Max. :2016-12-30
(Other)	:1677	

3.4 Data Check

In addition to the basic checks above, further tests were performed to check how accurate and complete the data was. This was accomplished by comparing the weighted-returns from the indices constructed from ETF data to the actual ETF returns on a monthly basis.

3.4.1 Weights

Total weights of the constructed US Equal Weight and Minimum Volatility indices were calculated by adding up each constituent's weight on a monthly basis. If the data were perfect, these should add up to 1 for each month. However, given some tickers and cash were removed, and given tracking error between the ETF and index, this was not expected.

The monthly change in weights for the constructed US Equal Weight Index is shown below in Figure 3.1. The weights of the constructed index are very close to 100%, with just two months exceeding that value. The minimum weight is 99.54%, while the largest weight is 100.21%. The mean weight is 99.79%.

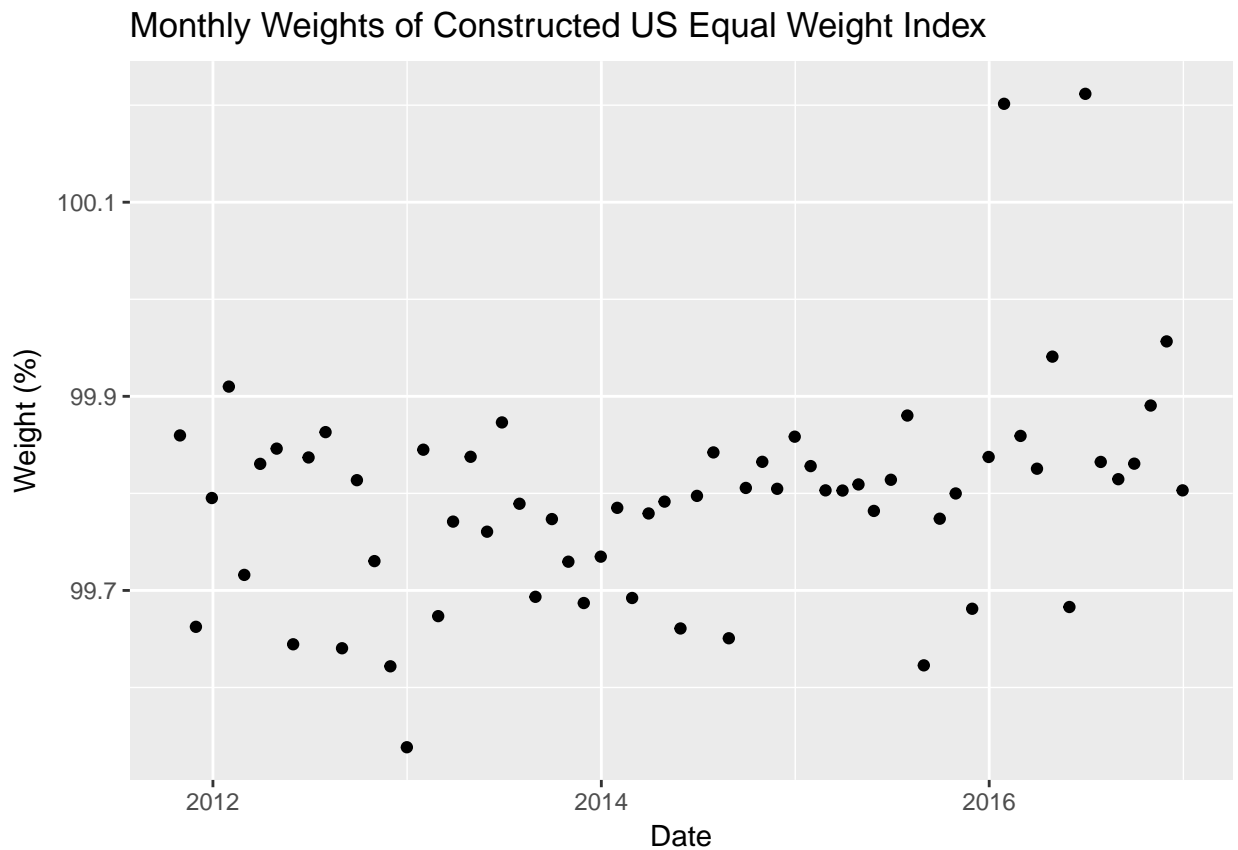


Figure 3.1: Weights of the constructed US Equal Weight Index by month

The monthly change in weights for the constructed Minimum Volatility Index is shown below in Figure 3.2. The weights of the constructed index are very close to 100%, but with no value exceeding that. The minimum weight is 99.58%, while the largest weight is 99.99%. The mean weight is 99.76%.

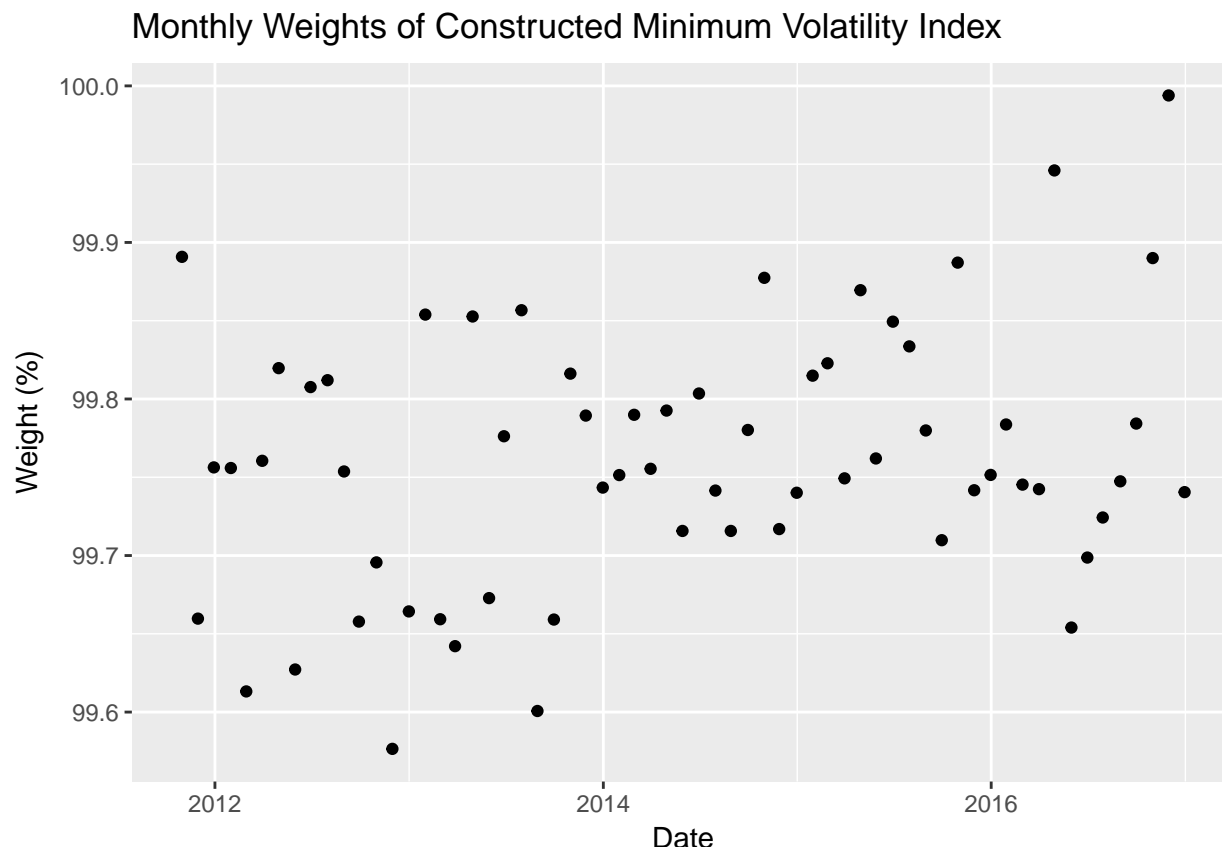


Figure 3.2: Weights of the constructed Minimum Volatility Index by month

3.4.2 Comparing ETF returns to Constructed Index returns

Given the weights were very close to 100% for both constructed indices on a monthly basis, an additional check was performed by comparing the weighted returns of the constructed indices to the actual ETFs that mirror them. The ETFs are traded in the stock market, so daily price information on each was widely available. Thus, this provided a way to check how the constructed weighted returns compared to the ETF returns for both the constructed US Equal Weight Index and Minimum Volatility Index. Correlations were calculated between the performance of the constructed index and its ETF, and plotted over time. As shown in Figure 3.3, the overall correlation between the constructed US Equal Weight Index monthly returns and EUSA ETF monthly returns was 98.06%. As shown in Figure 3.4, the overall correlation between the constructed Minimum Volatility Index monthly returns and USMV ETF monthly returns is 99.07%.

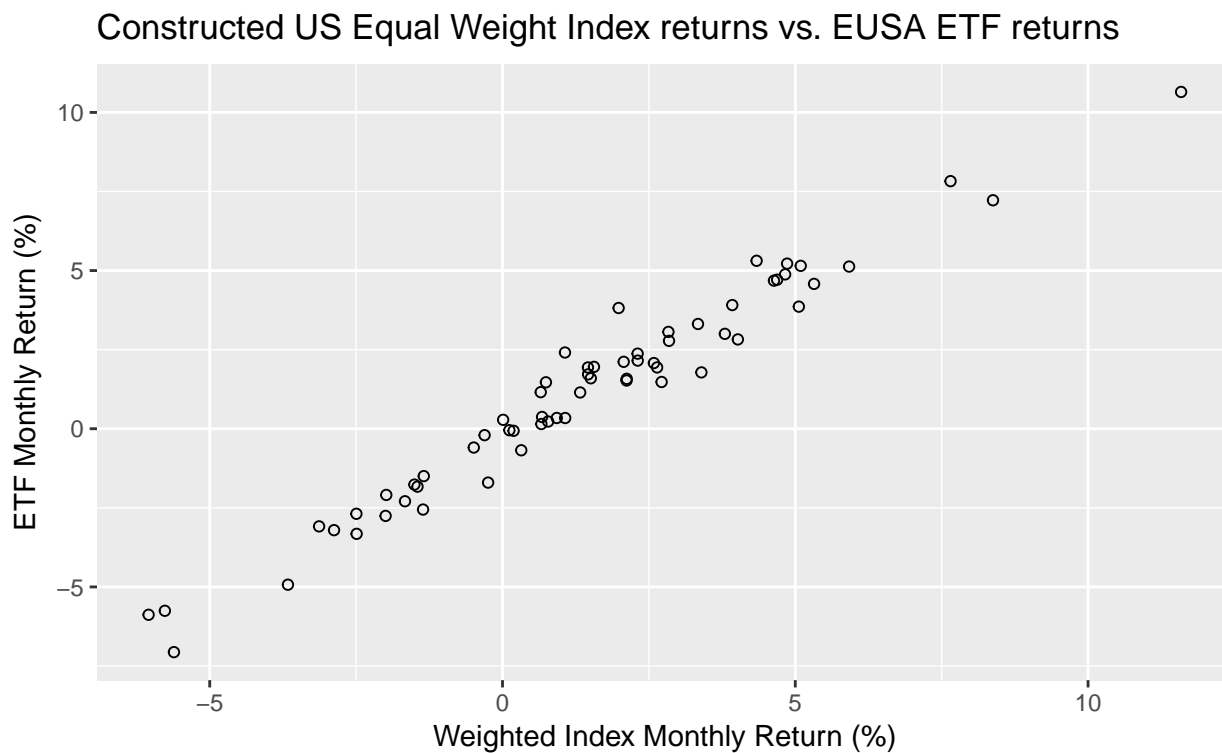


Figure 3.3: Correlations between constructed US Equal Weight Index monthly returns and EUSA ETF monthly returns

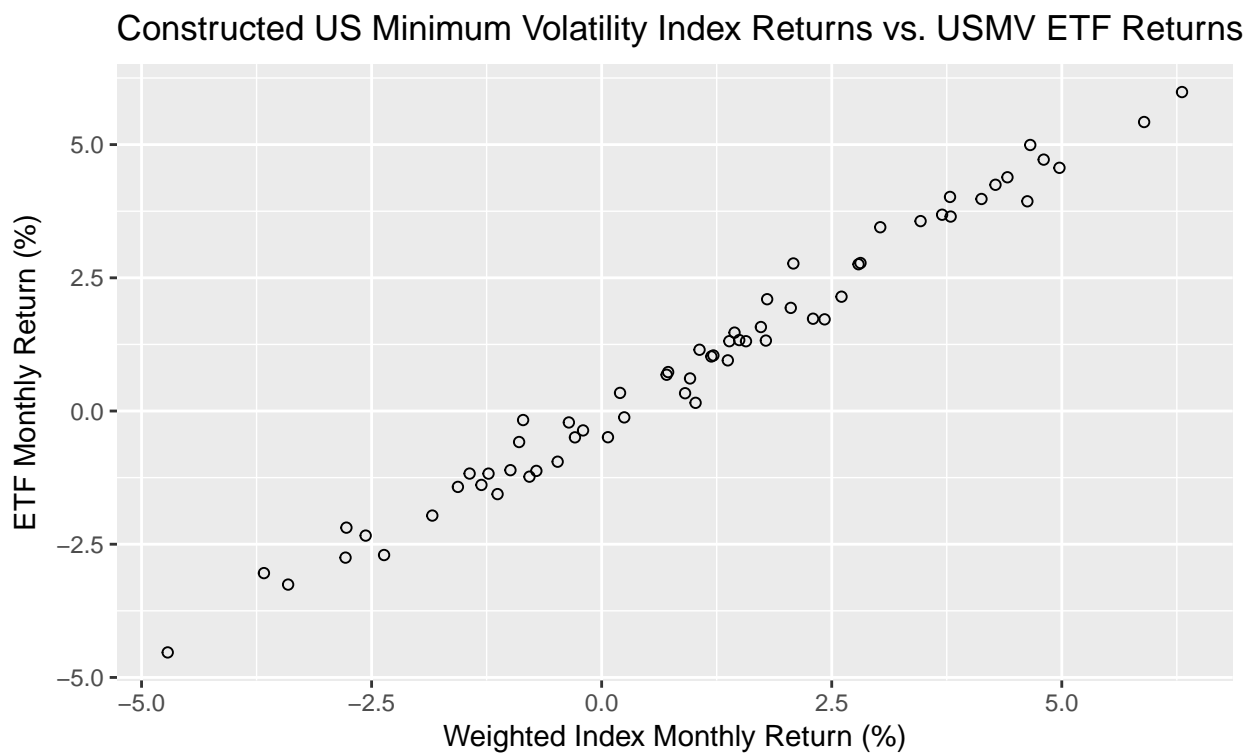


Figure 3.4: Correlations between constructed Minimum Volatility Index monthly returns and USMV ETF monthly returns

Chapter 4

Data Analysis

4.1 Change in Largest Holdings Over Time

The top 5 largest holdings in the US Equal Weight Index by average weight are Apple (AAPL), Exxon Mobil (XOM), Microsoft (MSFT), General Electric (GE), and Johnson & Johnson (JNJ). Each stock's average weight is shown below in Table 4.1.

Table 4.1: Average Weight of Top 5 Holdings in the US Equal Weight Index

Rank	Ticker	Average Weight (%)
1	AAPL	2.542271
2	XOM	1.946284
3	MSFT	1.315786
4	GE	1.157559
5	JNJ	1.135282

The top 5 largest holdings in the Minimum Volatility Index by average weight are Verizon (VZ), AT&T (T), Automatic Data Processing (ADP), Johnson & Johnson (JNJ), and McDonald's (MCD). Each stock's average weight is shown below in Table 4.2.

Table 4.2: Average Weight of Top 5 Holdings in the Minimum Volatility Index

Rank	Ticker	Average Weight (%)
1	VZ	1.508046
2	T	1.493976
3	ADP	1.479657
4	JNJ	1.470513
5	MCD	1.458286

The 5 largest holdings in the US Equal Weight index are AAPL, XOM, MSFT, GE, and JNJ. As shown in Figure 4.1, the weights of the 5 companies start off very high, each comprising a few percent of the overall index, then suddenly all drop significantly to a fraction of a percent after 2015-08-31. After verifying this with iShares and MSCI, it was discovered that this was due to change in the weighting mechanism.

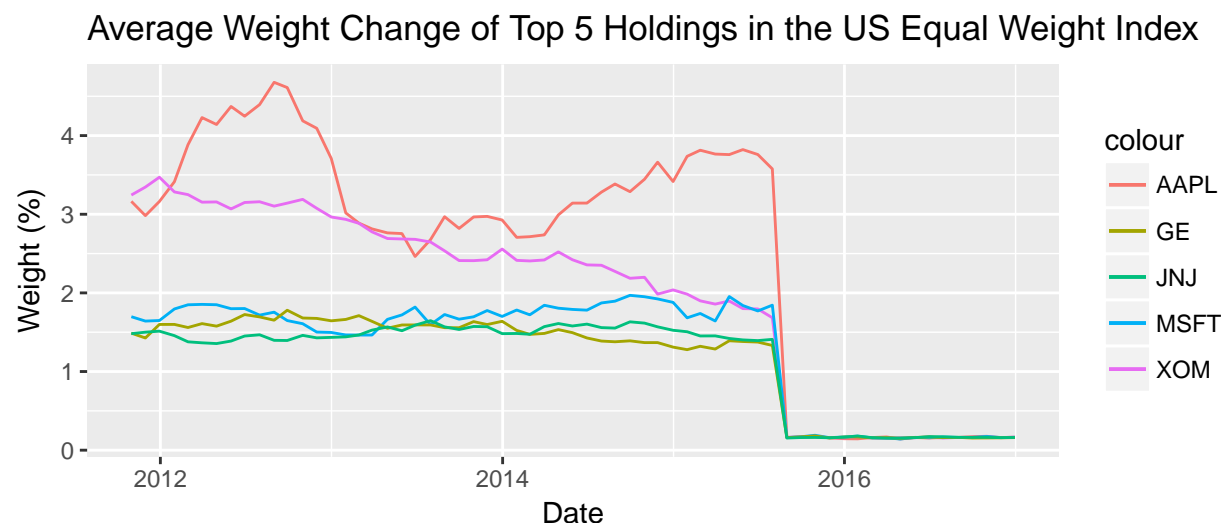


Figure 4.1: Change in weight for the top 5 holdings in the US Equal Weight index over time

The 5 largest holdings of the Minimum Volatility index are VZ, T, ADP, JNJ, and MCD. As shown in Figure 4.2, since the index's inception these stocks have generally oscillated between a weight of 1.3% and 1.7% of the overall portfolio, with the exception of Verizon which reached around 2% in 2014.

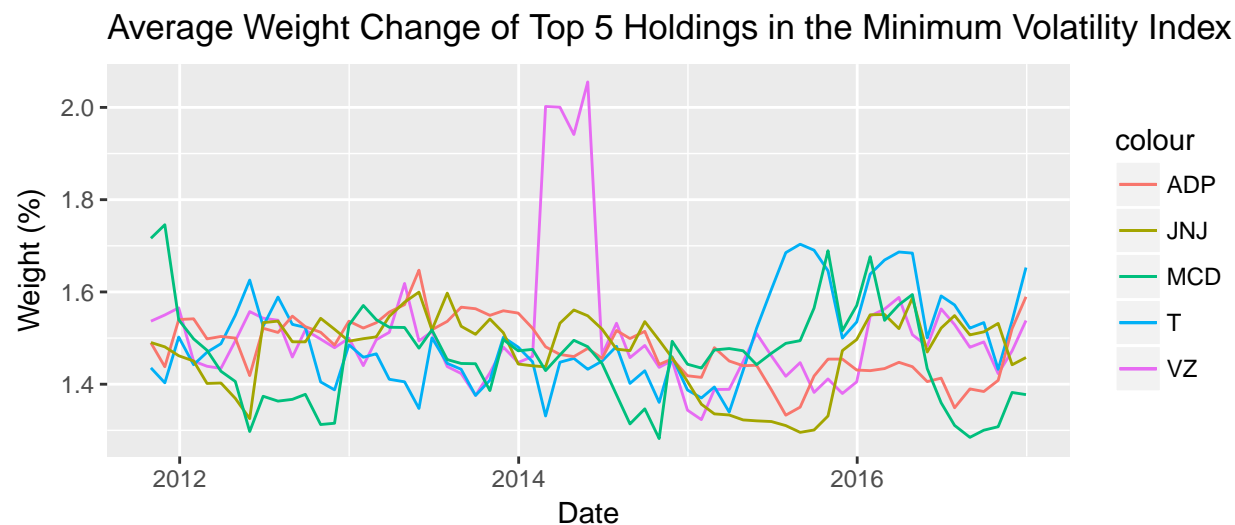


Figure 4.2: Change in weight for the top 5 holdings in the Minimum Volatility index over time

4.2 Change in Sector Weights Over Time

Sector weights were calculated over time for both the US Equal Weight and the Minimum Volatility Index by dividing the number of holdings for each industry by the total number of holdings in the portfolio. This was done to get a sense of what industries may be inherently more “low-risk” or “high-risk.” Moreover, this could help verify the accuracy of the data, as each sector weighting in the Minimum Volatility index should be within 5% of each sector weighting in the US Equal Weight Index, as specified by the Barra Open Optimizer (MSCI, 2013).

Shown below in Figure 4.3 are the sector weights over time for energy stocks in both indices. The weighting of energy stocks in the US Equal Weight Index is consistently greater than the weighting of energy stocks in the Minimum Volatility Index. This could imply that by nature, energy stocks are more volatile than stocks in other industries.



Figure 4.3: Weight of energy stocks by index over time

Shown below in Figure 4.4 are the sector weights over time for financial stocks in both indices. The weighting of financial stocks in the US Equal Weight Index is fairly consistent, until a significant drop towards the latter half of 2016. This timing coincides with the Federal Reserve's decision to hike rates for just the second time in a decade, amid positive economic signs (Cox, 2016). In the Minimum Volatility Index, the weighting of financials fluctuate quite a bit, and experience a similar drop in weight at that same point in time.

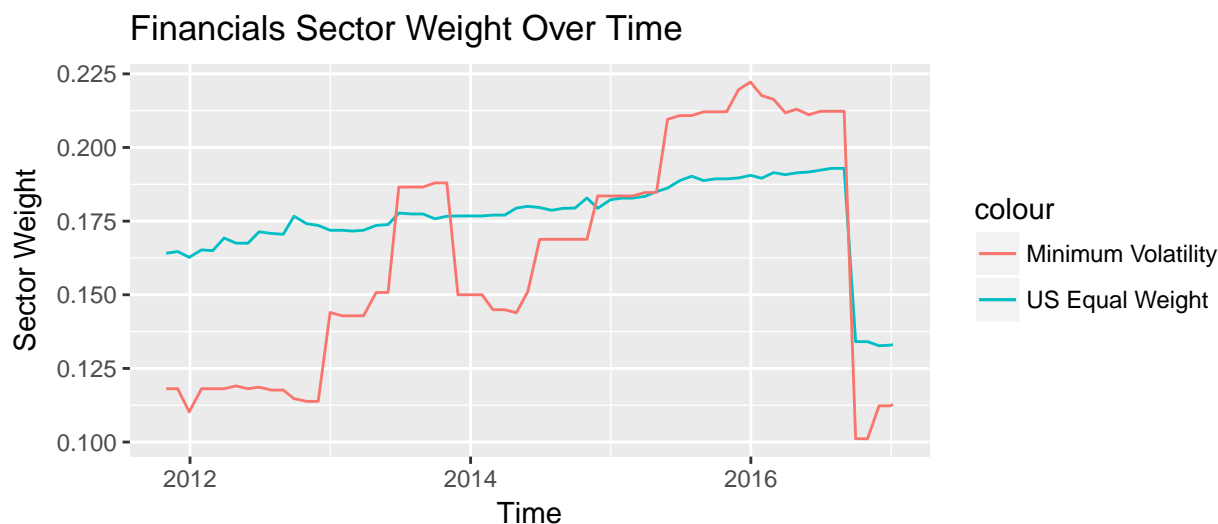


Figure 4.4: Weight of financial stocks by index over time

Shown below in Figure 4.5 are the sector weights over time for consumer staple stocks in both indices. The weighting of consumer staples in the US Equal Weight Index is consistently lower than the weighting of consumer staples in the Minimum Volatility Index. This could imply that consumer staple stocks are less volatile than stocks in other industries.

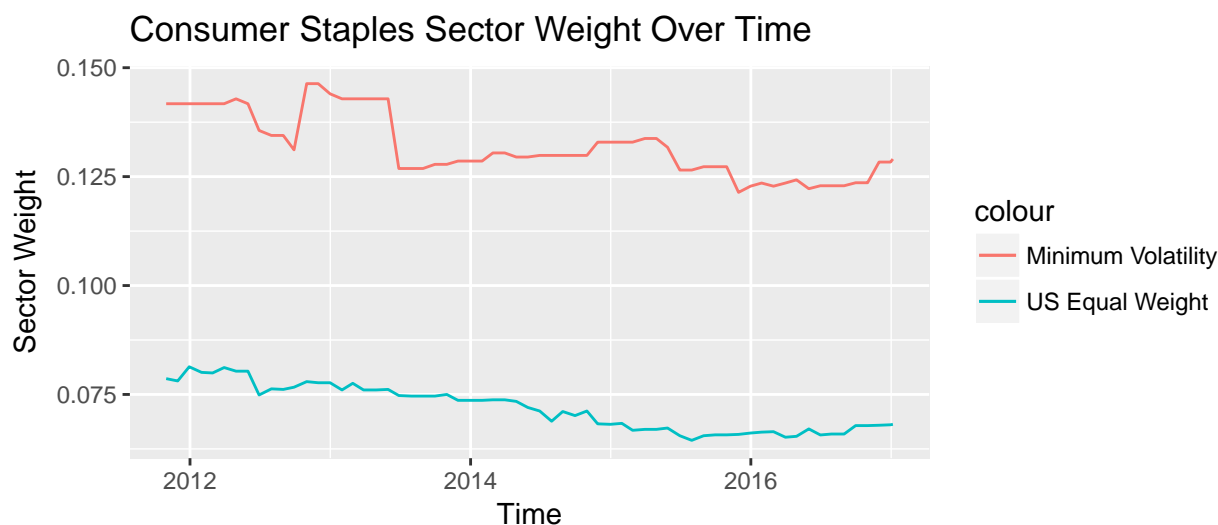


Figure 4.5: Weight of consumer staple stocks by index over time

Shown below in Figure 4.6 are the sector weights over time for consumer discretionary stocks in both indices. The weight of consumer discretionary stocks is consistently greater in the US Equal Weight Index than in the Minimum Volatility Index. This could imply that consumer staple stocks are more volatile than stocks in other industries.

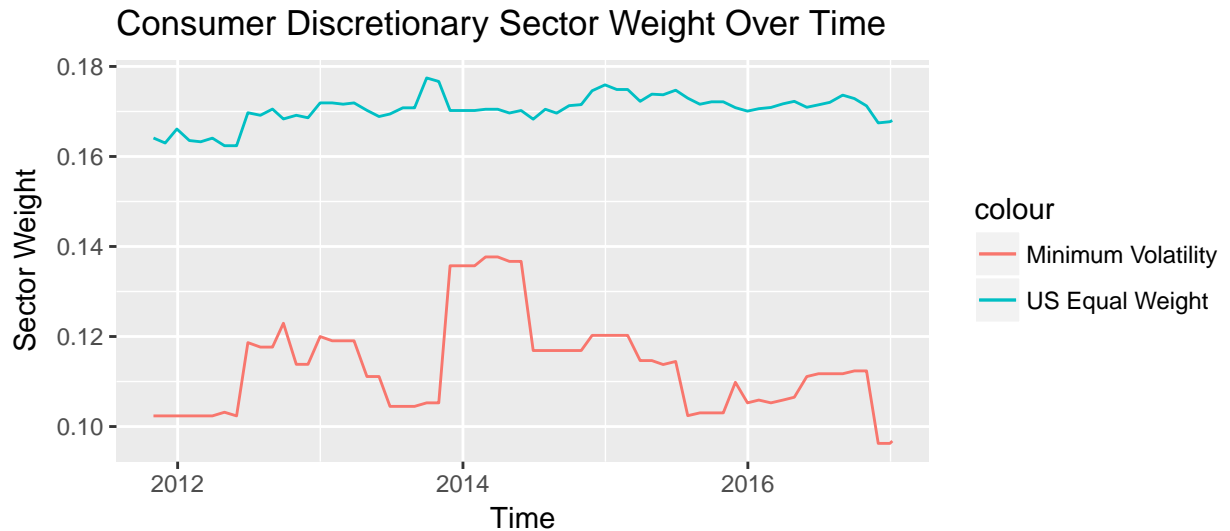


Figure 4.6: Weight of consumer discretionary stocks by index over time

Shown below in Figure 4.7 are the sector weights over time for healthcare stocks in both indices. The weight of healthcare stocks is consistently higher over time in the Minimum Volatility Index than in the US Equal Weight Index. This could imply that consumer staple stocks are less volatile than stocks in other industries.

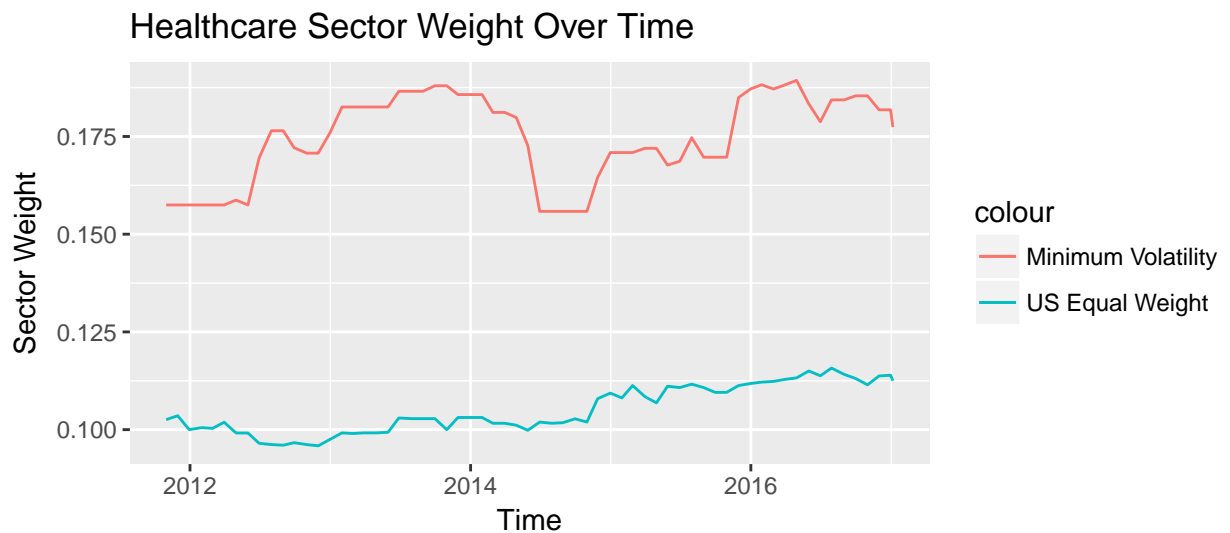


Figure 4.7: Weight of healthcare stocks by index over time

Shown below in Figure 4.8 are the sector weights over time for industrial stocks in both indices. The weight of industrials is consistently higher over time in the US Equal Weight Index than in the Minimum Volatility Index. This could imply that industrial stocks are more volatile than stocks in other industries.

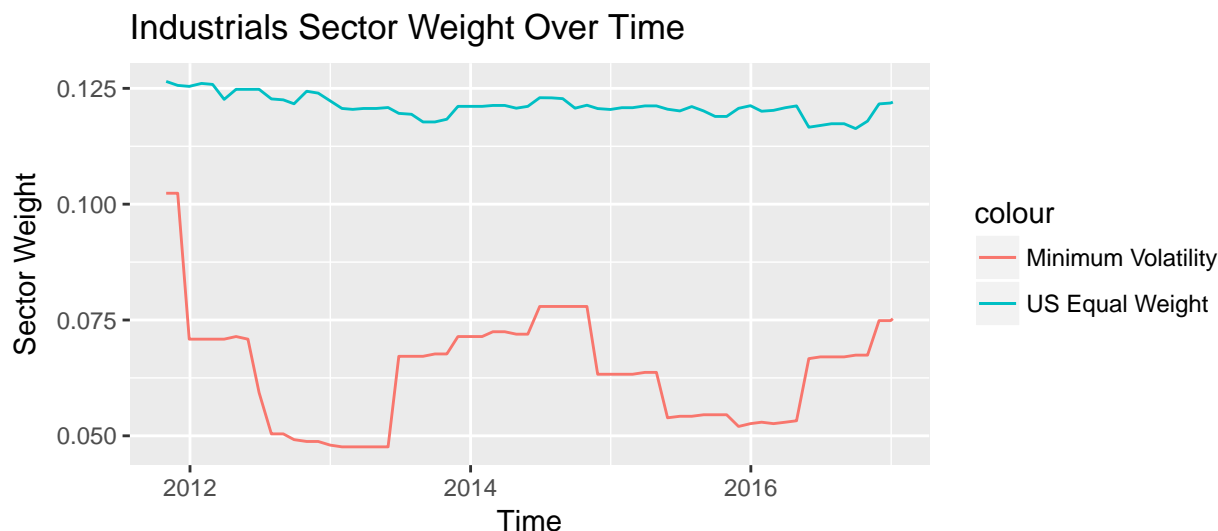


Figure 4.8: Weight of industrials stocks by index over time

Shown below in Figure 4.9 are the sector weights over time for information technology stocks in both indices. The weight of information technology stocks between 2012 and 2013 was significantly greater in the Minimum Volatility Index than in the US Equal Weight Index. However, since 2014, the weights of IT in both indices have converged, implying the industry may have become more volatile over the last few years.

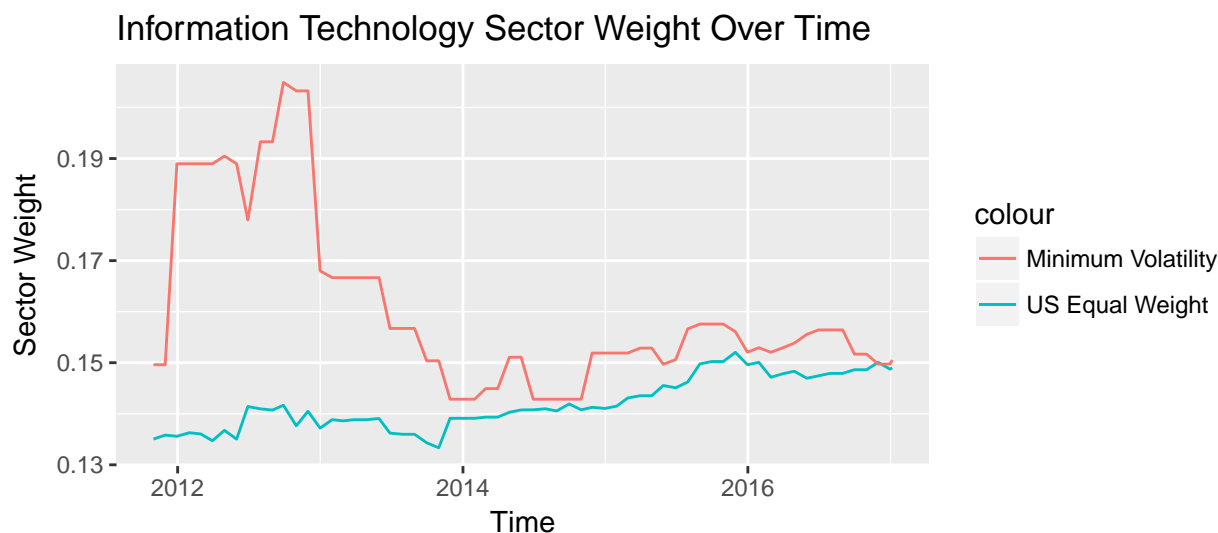


Figure 4.9: Weight of information technology stocks by index over time

Shown below in Figure 4.10 are the sector weights over time for materials stocks in both indices. The weight of materials is consistently higher over time in the US Equal Weight Index than in the Minimum Volatility Index. This could imply that materials companies may be more volatile than companies in other sectors.

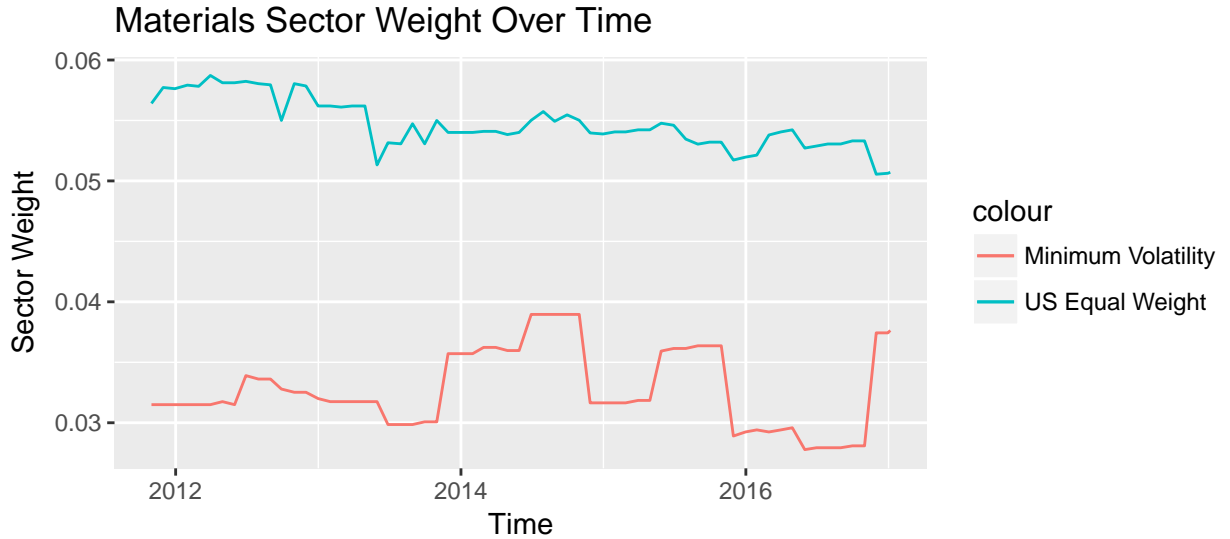


Figure 4.10: Weight of materials stocks by index over time

Shown below in Figure 4.11 are the sector weights over time for utilities stocks in both indices. The weight of utilities stocks is higher over time in the Minimum Volatility Index than in the US Equal Weight Index. This could imply that the utilities sector may not be as volatile as other sectors.

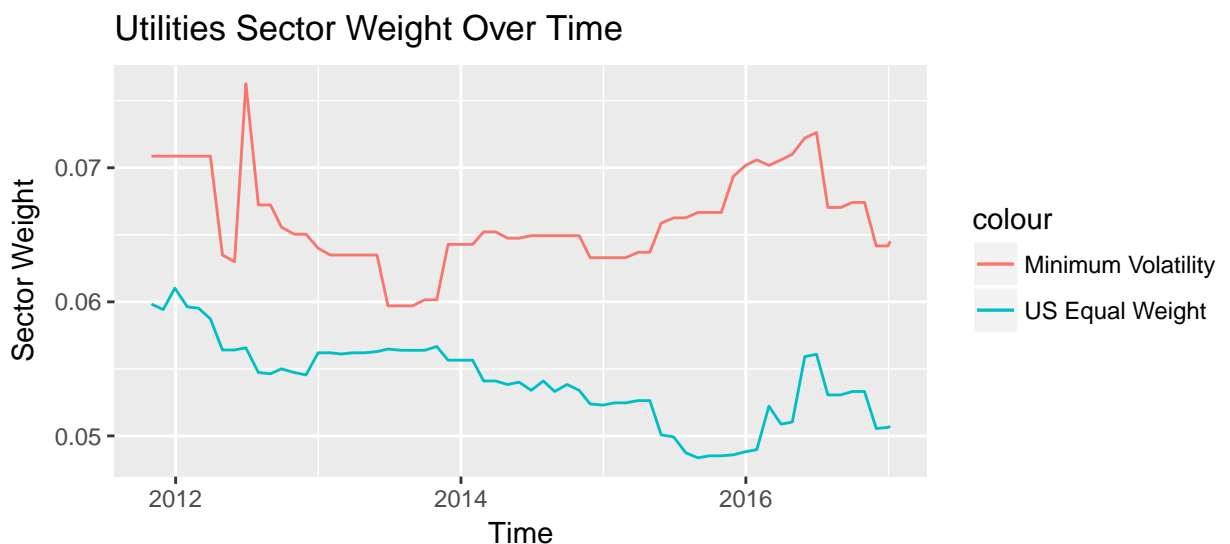


Figure 4.11: Weight of utilities stocks by index over time

Shown below in Figure 4.12 are the sector weights over time for telecommunications stocks in both indices. The weight of telecommunications stocks is higher over time in the Minimum Volatility Index than in the US Equal Weight Index. However, over time the weight of telecommunications has consistently decreased, which would imply the industry has gotten more volatile over the past few years.

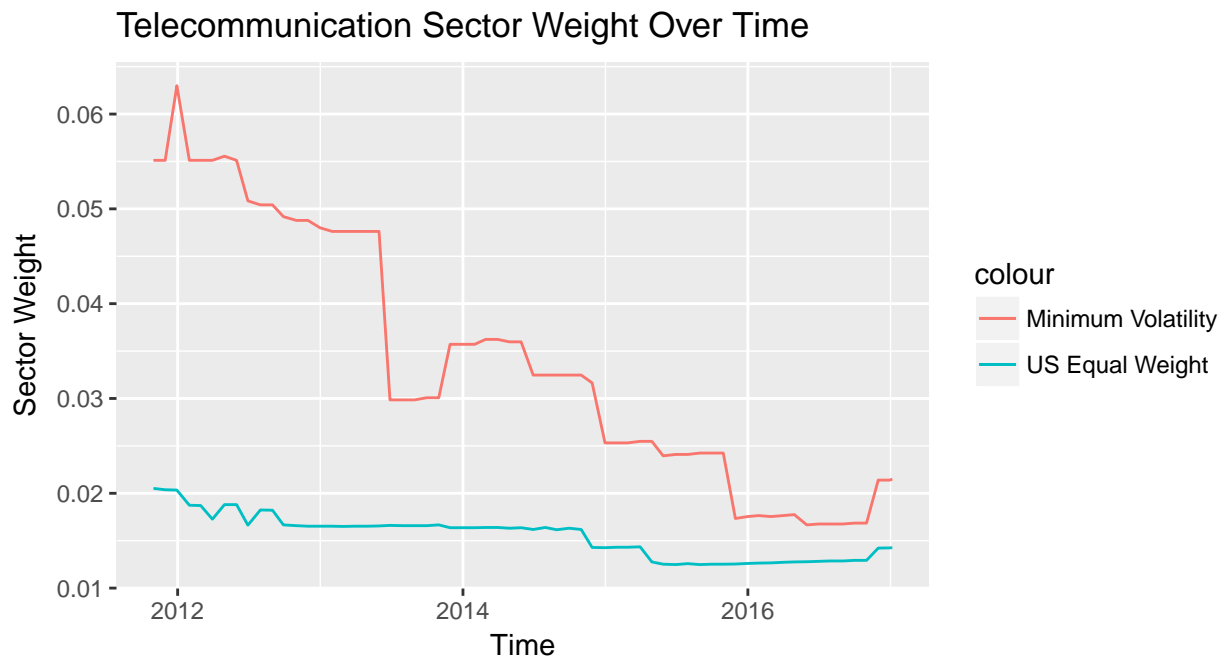


Figure 4.12: Weight of telecommunications stocks by index over time

4.3 Trailing Volatility

Data was collected from 10/31/2010 to 12/30/2016, from Wharton Research Data Services (WRDS) for the 908 historical constituents of the USA Equal Weight (EUSA) ETF, of which the Minimum Volatility Index is derived (Wharton Research Data Services, 2017). Each stock's 252-day (annual) trailing volatility was calculated, and a month end spaghetti plot was produced for stocks in the Minimum Volatility Index, and the remainder of the stock comprising the US Equal Weight Index, to get a relative sense of each group's volatility attributes. The stocks comprising the Minimum Volatility Index generally had a lower volatility than those in the US Equal Weight Index. Shown below in Figure 4.13 are the 52-week trailing volatilities for stocks in the US Equal Weight Index ranged from 0.00492 to 87.37030, with a mean value of 1.44738.

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.00492	0.50030	0.87466	1.44738	1.56562	87.37030

52-Week Trailing Volatility for Stocks in the US Equal Weight Index

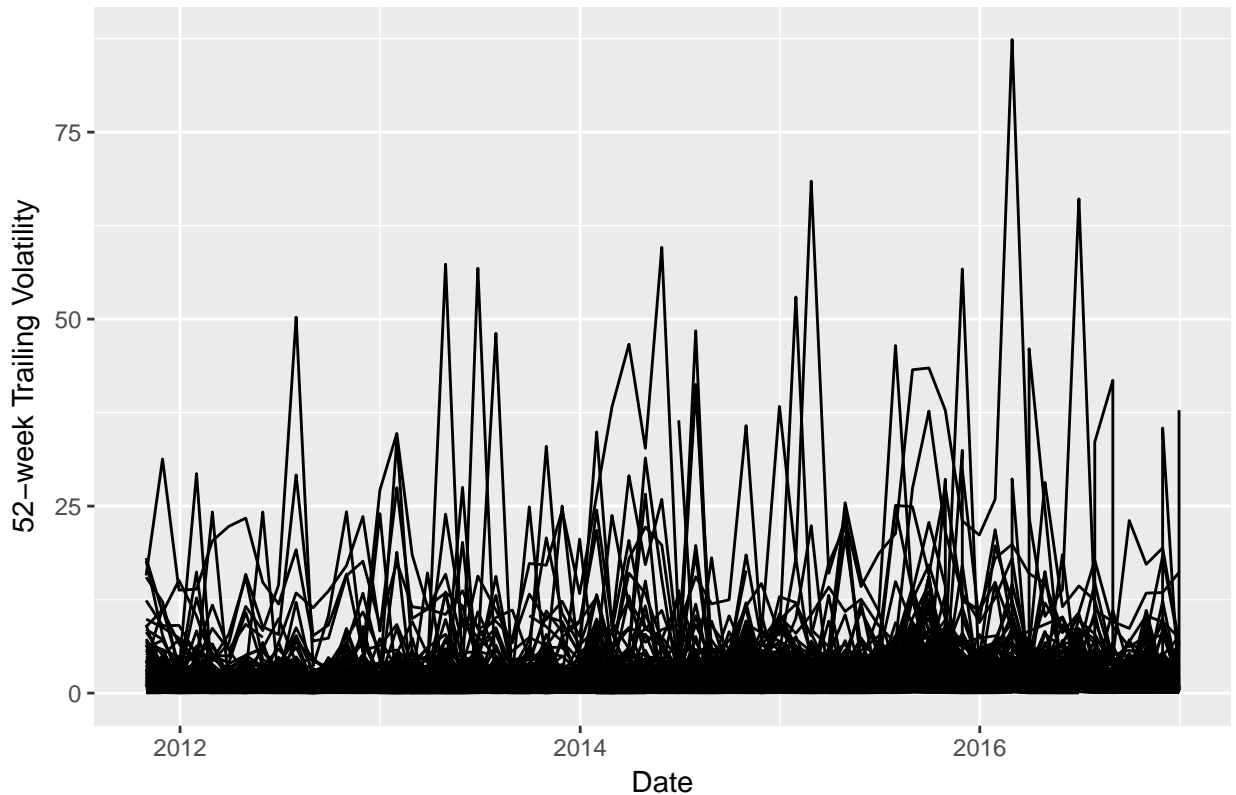


Figure 4.13: 52-week trailing volatility for stocks in the US Equal Weight Index

Shown below in Figure 4.14 are the 52-week trailing volatilities for stocks in the Minimum Volatility Index ranged from 0.03085 to 34.20974, with a mean value of 1.40784.

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.03085	0.54767	0.91226	1.40784	1.51399	34.20974

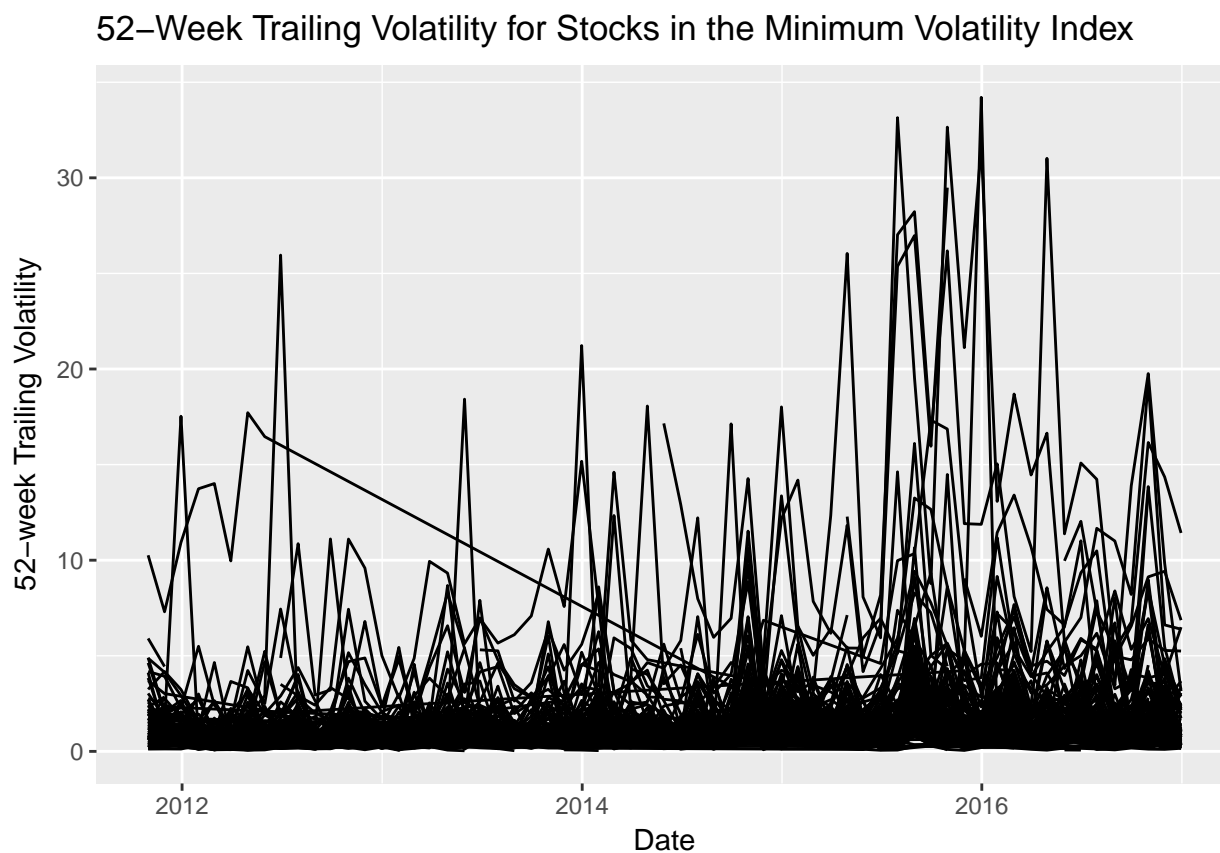


Figure 4.14: 52-week trailing volatility for stocks in the Minimum Volatility Index

4.4 Trailing Beta

Data was collected from 10/31/2010 to 12/30/2016, from Wharton Research Data Services (WRDS) for the 908 historical constituents of the USA Equal Weight (EUSA) ETF, of which the Minimum Volatility Index is derived (Wharton Research Data Services, 2017). Each stock's 252-day (annual) trailing beta was calculated, and a month end spaghetti plot was produced for stocks in the Minimum Volatility Index, and the remainder of the stock comprising the US Equal Weight Index, to get a relative sense of each group's volatility attributes. Generally, the stocks comprising the Minimum Volatility Index had a lower beta than those in the US Equal Weight Index. Shown below in Figure 4.15, the 52-week trailing beta for stocks in the US Equal Weight Index ranged from -4.9037 to 6.4952, with a mean value of 1.1505.

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
-4.9037	0.9316	1.1250	1.1505	1.3512	6.4952

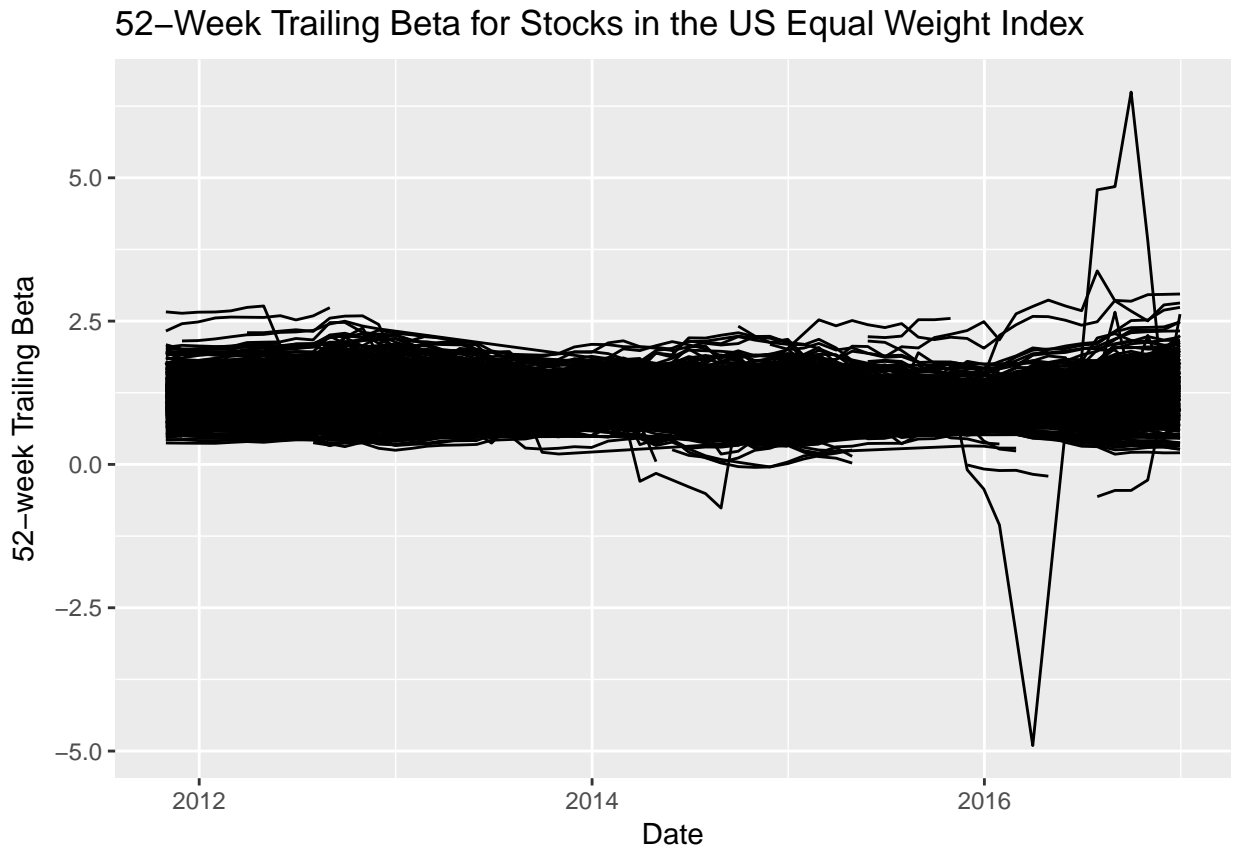


Figure 4.15: 52-week trailing beta for stocks in the US Equal Weight Index

Shown below in Figure 4.16, the 52-week trailing beta for stocks in the Minimum Volatility Index ranged from -0.2473 to 3.2021, with a mean value of 0.7856.

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
-0.2473	0.6319	0.7912	0.7856	0.9330	3.2021

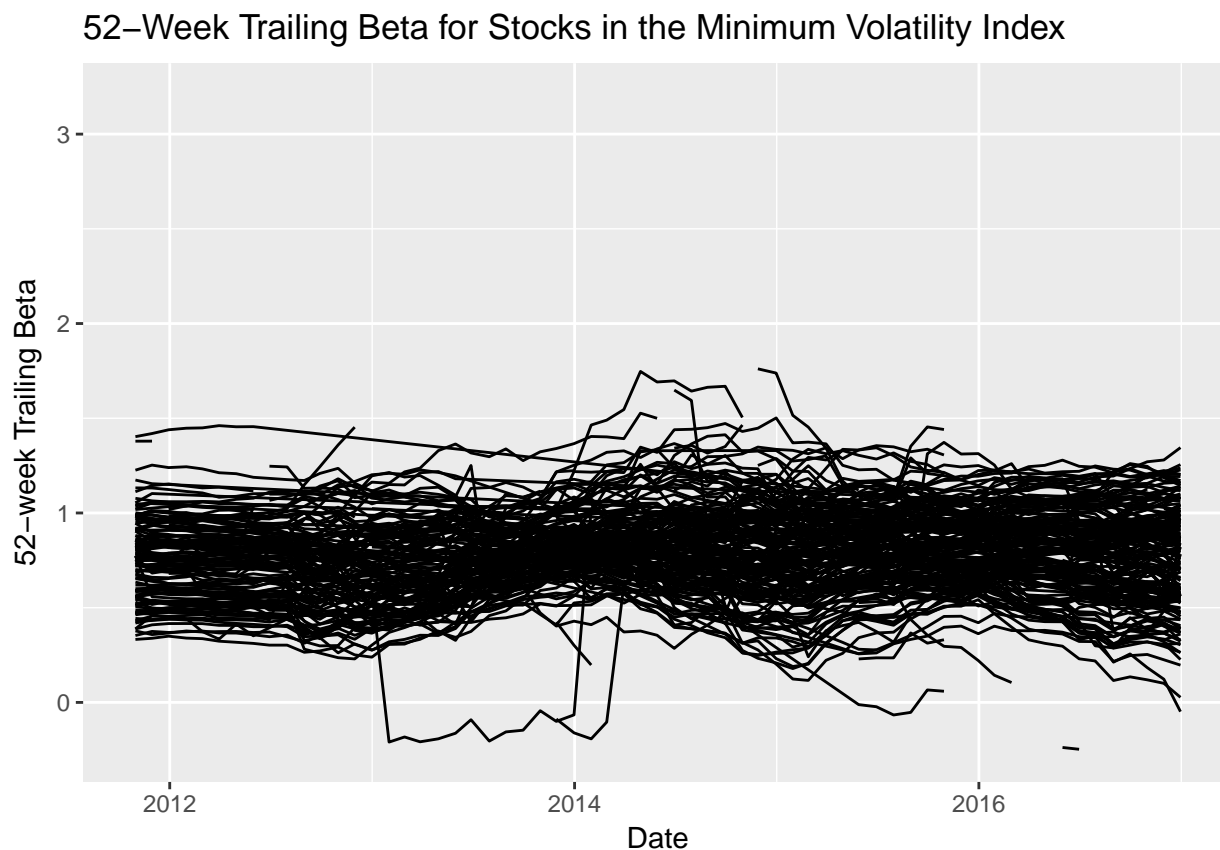


Figure 4.16: 52-week trailing beta for stocks in the Minimum Volatility Index

Chapter 5

Logistic Regression Model

Once the final data set was created and cleaned, with a number of response variables including trailing beta, trailing volatility, price to book ratio, and the whether or not a stock was in the Minimum Volatility index or not (1 if in, 0 if not in). Given the nature of the data, a logistic regression was run. Looking at all of the historical data and stock various characteristics, this modeled the log odds of a stock being in the minimum volatility index as a combination of the linear predictors mentioned. Since the index is rebalanced twice a year, it makes sense to look at a model including the data for both of these months.

5.1 Data Cleaning

5.1.1 Removing Class Bias

Ideally, the proportion of stocks in and out of the Minimum Volatility index should approximately be the same. However, after checking this, it is clear that this is not the case, as there were 4182 observations for stocks not in the index, and just 1385 observations for stocks in the index. Since just around 25% of the data was from stocks that are currently in the index, there is class bias. As a result, observations were sampled in equal proportions to get a better model.

5.1.2 Creating Development and Test Samples

One way to address the problem of class bias is to draw the 0's and 1's for the development sample in equal proportions for a majority of the observations. In doing so, the remaining data will not included for the model, but will be used as the validation sample to evaluate and test the model. Class bias was removed, as the sample is now evenly weighted, with each outcome being represented by 969 observations. The remainder of the data was placed in the validation sample.

5.2 Logistic Regression Model

Call:

```
glm(formula = index_now ~ volatility + beta + price_to_book +
     index_before, family = binomial(link = "logit"), data = trainingData)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-3.4421	-0.3205	0.0156	0.2131	3.3425

Coefficients:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	1.858e+00	3.623e-01	5.128	2.93e-07 ***
volatility	-3.976e-02	4.072e-02	-0.977	0.329
beta	-4.193e+00	3.933e-01	-10.661	< 2e-16 ***
price_to_book	5.059e-05	1.775e-02	0.003	0.998
index_before1	5.432e+00	2.382e-01	22.802	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 2686.64 on 1937 degrees of freedom
 Residual deviance: 745.23 on 1933 degrees of freedom
 AIC: 755.23

Number of Fisher Scoring iterations: 6

To calculate the log odds of a stock being an index constituent:

$$\text{logit}(p) = \log(\text{odds}) = 1.858 - 0.03976 \times \text{Volatlity} - 4.193 \times \text{Beta} + 0.00005059 \times \frac{\text{price}}{\text{book}} + 5.432 \times \text{index}$$

Figure 5.1: Log Odds Equation

To calculate the odds of a stock being an index constituent:

$$\text{odds} = e^{1.858 - 0.03976 \times \text{Volatlity} - 4.193 \times \text{Beta} + 0.00005059 \times \frac{\text{price}}{\text{book}} + 5.432 \times \text{index}}$$

Figure 5.2: Odds Equation

To calculate the probability of a stock being an index constituent:

$$p = \frac{odds}{1 + odds} = \frac{e^{1.858 - 0.03976 \times Volatility - 4.193 \times Beta + 0.00005059 \times \frac{price}{book} + 5.432 \times index}}{1 + e^{1.858 - 0.03976 \times Volatility - 4.193 \times Beta + 0.00005059 \times \frac{price}{book} + 5.432 \times index}}$$

Figure 5.3: Probability Equation

5.2.1 Coefficient Interpretation

The coefficients can be interpreted as:

- Volatility: For a one unit increase in volatility, the log odds of a stock being an index constituent change by -0.3976
- Beta: For a one unit increase in beta, the log odds of a stock being an index constituent change by -4.193
- Price to Book: For a one unit change in price to book ratio, the log odds of a stock being an index constituent increase by 0.00005059
- Index before: For a one unit change in previous index membership, the log odds of a stock being an index constituent increase by 5.432

5.3 Diagnostic Testing

To test the quality of the model, several diagnostic tests were performed:

Variance Inflation Factors

Variance inflation factors (VIF) are used in regressions to check for multicollinearity, which occurs when one predictor variable can be predicted from the others with a high degree of accuracy. An example of this includes a person's height and weight, as these two variables are very closely related. VIFs measure how much the variance of the estimated regression coefficients in the model are inflated, compared to a case when the predictor variables are linearly unrelated. The general rule of thumb is that predictor variables with a VIF over 4 should be further inspected, and variables with a VIF above 10 require correction. As shown below, all the predictor variables in the model have VIFs well below 4, indicating that multicollinearity is not a concern:

volatility	beta	price_to_book	index_before
1.018738	1.053972	1.020580	1.065880

Optimal Cutoff

To get a sense of the model's predictive power, it is important to first tune the optimal cutoff to improve the model by reducing misclassification error. The default cutoff is often 0.5, but by tuning the probability cutoff, the ability of the model to correctly predict 0's and 1's greatly improves. In this model, that cutoff was found to be 0.86.

Concordant and Discordant Pairs

To calculate the number of concordant and discordant pairs, all the possible pairs of 0's and 1's will be considered - that is, all the pairs of observations for stocks not in the index, and stocks in the index. In this data set, a total of 1,336,608 pairs were considered, and the probability values for 0 and 1 were calculated for each. Thus, considering each pair, which can be represented as (1,0), ranges for cutoff values were determined based off of the probability of each observed 0 and 1. Concordant pairs were noted when the cutoff value for the 1 was higher than the cutoff value of the 0. Discordant pairs were noted when this was not the case, and this was equivalent to the case where the probability of the event was lower than the probability of a non-event. These instances are contrary to the definition of the event and non-event based off of the cutoff value calculated. In a perfect model, 100% of the pairs would be concordant. In this model, 96.8% of the pairs were concordant and 3.2% of the pairs were discordant.

Misclassification Error

Misclassification error measures the accuracy of the model by determining what the percent mismatch is of the predicted outcomes compared to the actual outcomes. By looking at the test data, this quantifies how accurate the model was at predicting which stocks were in the index and what stocks were not in the index, given their predictor variable values. Better models will have lower misclassification errors. In this logistic regression model, the misclassification error was 4.02%.

Sensitivity and Specificity

Sensitivity, also called the true positive rate, is the proportion of stocks in the minimum volatility index that were correctly predicted by the model. In the logistic regression model, the sensitivity was found to be 86.29%. Specificity, also called the true negative rate, is the proportion of stocks not in the minimum volatility index that were correctly predicted by the model, and can be calculated as $1 - \text{False Positive Rate}$. In the logistic regression model, the specificity was found to be 98.19%.

Confusion Matrix

The confusion matrix is a table showing the total number of true positives, true negatives, false positives, and false negatives from the test data to evaluate the performance of a model. In this logistic regression model, there were a total of 359 true positives, 3155 true negatives, 58 false negatives, and 57 false positives. Shown below, the columns are actuals outcomes, while the rows are predicted outcomes:

Table 5.1: Regression Model Confusion Matrix

	0	1
0	3155	57
1	58	359

Receiver Operating Characteristics Curve

The Receiver Operating Characteristics (ROC) Curve plots the true positive rate (sensitivity) against the false positive rate (1-specificity) for all different possible cutoffs. The area under the curve is a measure of the accuracy of the model in distinguishing between stocks in the index and stocks not in the index. A perfect model would yield a ROC curve passing through the top left corner, representing a sensitivity of 100% and a specificity of 100%, with an area under the curve of 100%. The area under the ROC curve for the logistic regression model in this study is 96.77%:

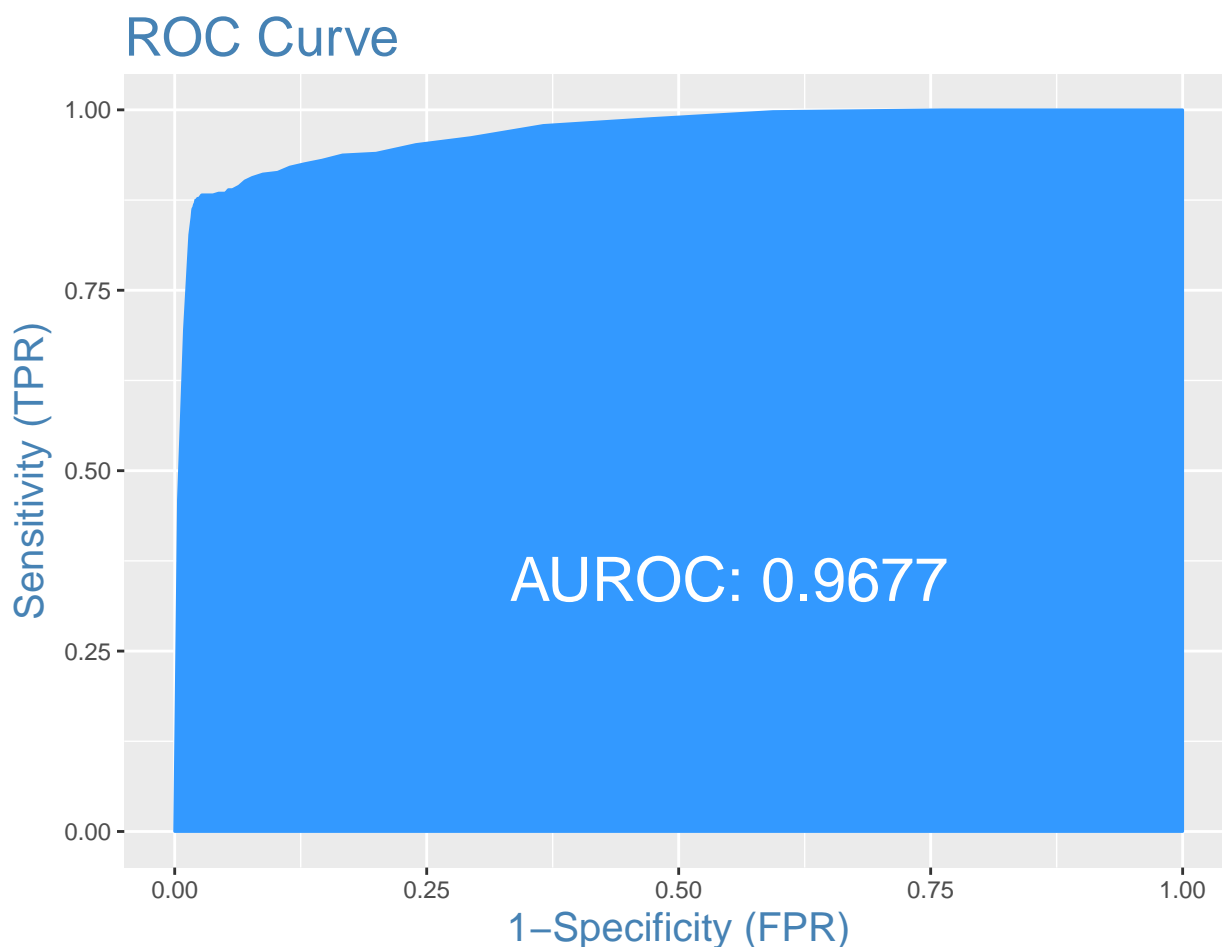


Figure 5.4: ROC Curve for Logistic Regression Model

Chapter 6

Conclusions and Future Work

The logistic regression model was statistically resilient and had strong predictive power. Based off of historical data, it was able to correctly predict 86.29% of stocks that were in the minimum volatility index, and 98.19% of the stocks that were not members of the minimum volatility index, using the optimal cut off. Overall, the logistic regression model had a 96.77% accuracy in distinguishing between stocks that were members of the index, and stocks that were not members of the index. The model can also be easily transformed to calculate the probability of a stock being a member of the minimum volatility index based off of its trailing beta, trailing volatility, price to book ratio, and prior index membership.

6.1 Understanding of Relationships

The model can help build on previous understanding of what traits of a stock are important in its membership in the minimum volatility index. The relationship between trailing volatility and current membership in the index was unsurprisingly negative; the larger a stock's volatility, the less likely it is to be in the index. To be specific, the odds of being in the index is 0.96 less with a one unit increase in a stock's volatility. This makes sense, given the Barra Open Optimizer works to create a minimum variance portfolio. The relationship between beta and membership in the minimum volatility index was also negative; the larger the magnitude of a stock's beta is, the less likely it is to be in the index. To be specific, a one unit increase in a stock's beta makes it 0.015 times as likely to be in the index. This makes sense given that beta is a measure of a stock's volatility as well. However, the regression coefficient for beta was much stronger than the coefficient for volatility, which at first glance appears puzzling, given that this is a minimum volatility index. However, considering the units of each variable can alleviate this concern; a one unit increase in volatility is much less than a one unit increase in beta. For example, it would be extremely very hard for a stock's beta to jump from 0.7 to 1.7 over a short period of time, and would represent a massive change in a stock, even though it is just one unit. This can help explain this coefficient discrepancy, but it is important to note that both volatility and beta are negatively related to index membership.

The relationship between price to book ratio and current membership in the minimum volatility index was nonexistent in this model. In fact, with a one unit increase in price to book ratio for a stock did not affect a stock's odds of being a member of the index. This is an interesting finding, in that it might imply a stock's value is unrelated to its volatility, especially in relation to the importance of profitability in defensive equity strategies (Novy-Marx, 2014). The relationship between prior index membership and current membership in the minimum volatility index was by far the most powerful. A stock was over 228 times more likely to a member of the index if it was a member six months ago. This is logical, considering a vast majority of the stocks in the index remain. There are approximately 180 stocks in the index, and during each rebalance only around 14 are removed (BlackRock, 2017).

6.2 Sector-Specific Risk

Some sectors were overweight or underweight in the minimum volatility Index, which would imply something about sector-specific risk. Macro-effects, like industry specific effects, have been shown to be important in affecting risk and return of a portfolio (Baker et al., 2014). Based off of the findings in this paper, energy, consumer discretionary, industrials, and materials were shown to be consistently underweight in the minimum volatility index when compared to the parent index. This could mean these sectors are inherently more volatile than other sectors. Moreover, consumer staples, healthcare, and utilities were consistently overweight in the minimum volatility index when compared to the parent index. This could imply that these sectors are inherently less volatile than other sectors.

6.3 Future Models

The logistic regression model took into account all of the data from the months when rebalances took place. However, more specific models could have been made to increase predictive power. Models could have been made by using data by sector. As shown in the analysis, some sectors are more volatile and risky than others, so using stocks without regard to sector might lead to a less accurate model. Sector could also have been used as a categorical predictor variable.

Seeing how significant of a predictor variable previous index membership was in the regression model, it could make sense to create two separate models: one for stocks currently in the minimum volatility index, and one for stocks that are not. This could also help for investment applications, as there will be one model used for short-selling stocks, and one for deciding which stocks to purchase. Finally, creating models by month could be telling too. By combining the May and November rebalancing data, the current model does not take into account specific factors that might be unique to rebalancing that occurs in either period.

6.4 Investment Implications

Given the accuracy and predictive power of the logistic regression model, there are many ways it could be applied and used as an investment opportunity. If the model can accurately forecast index membership in advance of its rebalancing, investors could long stocks that are predicted to be added to the index, and short the stocks that are expected to be removed from the index. Given that approximately 20 stocks are added and 14 stocks are removed during each rebalancing (BlackRock, 2017), it could make sense to purchase stock in the top 5 companies that are currently not in the minimum volatility index but have a high probability of being added, and short-sell stocks that are currently in the minimum volatility but have a low probability of remaining. When the iShares MSCI Minimum Volatility ETF is rebalanced, stocks that were added enjoyed an average 0.63% increase in price the day after the announcement, and stocks that were removed lost 0.57% of value after the announcement. Though the values are small by themselves, on an annualized basis, an accurate model could lead to a very lucrative investment strategy.

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