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Risk and return characteristics of the swap spread arbitrage strategy

Navn: Kjetil Engelsgjerd, Adrian Gullvåg Tabbech

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by

Kjetil Engelsgjerd and Adrian Tabbech

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ABSTRACT

We conduct a study on the risk and return characteristics of the swap spread arbitrage strategy. Specifically, we investigate the two-year, three-year, five-year, seven-year, ten-year, and an equally-weighted swap spread strategy in the US, the UK, and Japan. We find that there is very little "arbitrage" in this fixed income trading strategy. Furthermore, our findings suggest that the less liquid markets offer better risk and return characteristics than the more liquid markets.

Acknowledgements: We are grateful to our supervisor Professor Sven Klingler for directing us in the fixed income space, and for suggestions and comments. We also thank our family, friends and fellow students for moral support.

Contents

1. Introduction

In this master thesis, we investigate the risk and return characteristics of the swap spread arbitrage strategy. An important note is that we do not consider arbitrage in the textbook sense, i.e., that arbitrage is a free lunch, rather we consider an arbitrage strategy a strategy that tries to exploit relative mispricing's between securities. These kinds of strategies are not required to be costless to instigate, nor are they required to be risk-free, the strategies are, however, supposed to be market neutral. More commonly and accurately, trading on these strategies is often referenced to as relative value trading or convergence trading. The strategies are profitable when the relative positions converge towards one another, and of course, unprofitable if they diverge.

Financial player's that are exploiting these mispricing's, primarily hedge funds, are theoretically making the market more efficient by pushing the prices of the underpriced and overpriced securities towards more fundamental values, in addition to providing more liquidity to the market. Hedge funds have throughout the years been accused of manipulating asset prices, building up financial bubbles and deepening recessions.[1] As convergence trading strategies rely on prices moving towards fundamental values, neither manipulation of prices nor enforcing financial bubbles should be attributed to these strategies. These strategies may indeed deepen crises or burst bubbles as the relative positions should push overpriced securities downwards. As these strategies often entail holding positions in several securities, the arbitrageurs are affecting several markets which can deepen recessions further when trades are going sour, and fire sales occur, and especially so if the arbitrageurs are heavily levered.

Long Term Capital Management (LTCM) experienced its convergence trades go from bad to worse, while being substantially levered, and was bailed out after Russia defaulted on its debt in 1998 to avoid destabilization of the financial system. LTCM was primarily conducting what is known as fixed income arbitrage, i.e., relative value trading strategies concerning securities based on interest rates. LTCM went from an annual return of over 40% in the first years of the 1990s to a

[1] Stromqvist (2009) discusses the role of hedge funds in financial crisis and argues that the IT bubble is the only crisis, of the one she discusses, that hedge funds can be accused of contributing to creating a bubble, and she further states that, generally, arbitrage strategies counteracts the development of financial bubbles.

sudden loss of 4.6 billion and an effective debt-to-equity ratio of 250 to 1.[2] This raised the question of whether these strategies were only offering nickels in front of a steamroller. Were the colossal losses due to abundant leverage, or are they an inherent characteristic of the fundamental nature of these strategies?

Inspired by the article "Risk and return in fixed income arbitrage: Nickels in front of a steamroller?" by Duarte, Longstaff, and Yu (2007), we investigate the swap spread strategy, using a similar methodology. Duarte et al. (2007) investigated five different fixed income strategies, namely the swap spread, volatility, yield curve, capital structure, and mortgage arbitrage. They found that most strategies had positive average excess returns with positive skewness, which contradicts the common notion that these strategies only offer nickels in front of a steamroller, i.e., that these strategies offer small returns most of the time and occasionally huge losses. In fact, the finding of the positive skewness implies that even though there might be large losses, some of the time, there are even larger offsetting gains. Specifically, the swap spread strategy was conducted on two-, three-, five- and ten-year maturities, and they found positive average excess returns for all strategies and positive skewness for three of them. These findings lead us to our research question:

What are the risk and return characteristics of the swap spread arbitrage strategy in the post-crisis environment in the US, the UK, and Japan? Can the strategy be considered an "arbitrage" strategy or is the strategy merely "picking up nickels in front of a steamroller"?

Specifically, we hypothesize that the event of the financial crisis of 2008 had major effects on the skewness of the distribution of the monthly excess returns on the strategy. Secondly, we hypothesize that less liquid markets offer better risk and return characteristics. Thirdly, we hypothesize that there are diversification benefits of conducting the strategy across countries.

We find that the financial crisis of 2008 had a massive effect on the risk and return characteristics of the strategies implemented in the US. All, but one strategy, have a negative skewness of their distribution of monthly excess returns, the average excess returns are substantially lower, and the risk-adjusted returns are all

[2] John Meriwether, the founder of LTCM, later launched another hedge fund called JMW Partners which reportedly lost 44% on its "relative value opportunity II fund", between September 2007 and February 2009, using the same investment strategies as LTCM.

negative, although only the equally-weighted strategy is significant at the five percent level while ten-year strategy is statistically significant at the ten percent level. The risk and return characteristics of the strategies implemented in the UK are better, with all strategies considered offering larger average excess returns, although only two strategies, as well as the equally-weighted strategy, have a positive skewness of their distribution of monthly excess returns, all risk-adjusted returns are negative, and none are statistically significant. The risk and return characteristics of the strategies in Japan are even better, with the strategies generally offering larger average excess returns, all strategies provide positively skewed distributions, and only two risk-adjusted returns are negative while the rest are positive, although none are statistically significant.

The rest of the thesis is structured as follows. Section 2 reviews previous literature that surrounds our topic of study. Section 3 briefly describes the swap spread strategy. Section 4 describes the data employed in our study and our methodology of how we implement the strategy, construct our return indices, and develop our multifactor regressions to control for market risks. Section 5 presents our results and analysis. Finally, in section 6, we conclude our investigation.

2. Literature review

In this section, we review previous literature related to risk and return characteristics of fixed income arbitrage, where specifically the swap spread strategy is of interest. There seems to be somewhat limited research on this subject. However, we found some literature that relates to our field of study.

Shleifer and Vishny (1997) explain a more realistic view of arbitrage as opposed to the classical textbook arbitrage. They show that so-called specialized arbitrageurs, typically hedge funds, raise outside capital from investors and does not fully bring prices to fundamental values, in contrast to the view of the classical role of an arbitrageur. The main empirical finding suggests that "real world" arbitrage require capital and is risky in reality.

Xiong (2001) studied convergence traders with logarithmic utility in a continuous-time equilibrium model, and found that although convergence traders reduce volatility in asset prices and provide liquidity by taking risky positions against noise traders, when unfavorable shocks occur causing capital losses, the risk-bearing capacity diminishes which causes the convergence traders to liquidate their positions and thus amplifying the original shock. The diminished wealth of the traders, function as an amplification mechanism on the original market event or shock. The author found that this amplification mechanism can explain excess volatility and stochastic volatility and that in extreme circumstances, the convergence traders are destabilizing by trading in the same direction as noise traders.

Another paper that addresses the real-world role of arbitrageurs is the paper by Mitchell and Pulvino (2012). Specifically, the authors investigated the reasons behind the high level of relative mispricing of assets for several months during the financial crisis in 2008. They found that severe negative market shocks affect debt financing for arbitrage hedge funds, leading the hedge funds to liquidate their positions. This, in turn, makes the mispricings diverge even further, and it lasted for months due to opportunistic capital constraints. Gromb and Vayanos (2010) reviewed the whole literature on the limits of arbitrage and summed up prior papers concerning the costs experienced by arbitrageurs. Arbitrageurs in the textbook sense are known to eliminate mispricings and provide liquidity to outside investors. However, costs can prevent it from happening, such as risks, short-selling costs, leverage, and margin constraints, as well as equity capital constraints.

Partially related to our study is the literature on hedge fund return characteristics. Hedge funds widely use the swap spread arbitrage strategy, and our results of the risk-adjusted returns can, therefore, be compared to hedge funds' excess returns. Studies conducted on hedge funds alpha's that can be mentioned are Berk and Green (2004), Fung, Hsieh, Naik, and Ramadorai (2008), and Cai and Liang (2012). These studies found that there is a negative trend of the alpha and that capital inflow also affects the generated alpha.

Agarwal, Fung, and Loon (2011) contributed to the literature by identifying risk factors that drive hedge fund strategies' returns. Specifically, they found that the supply of convertible bonds affects convertible arbitrage hedge funds' performance. Also, they found that funds short stocks for risk management purposes and not for speculative purposes. They found evidence of Sharpe ratios ranging from 0.30 to 0.62.

There have been several studies regarding the market-neutrality of these trading strategies. An early study by Liang (1999) investigated hedge fund performance and risk, where they found empirical evidence that hedge funds have lower market risk and higher abnormal returns than mutual funds. A later study conducted by Patton (2009) found significant evidence against the market-neutrality and that many hedge funds indeed are exposed to market risks.

Duarte et al. (2007) took it a step further by investigating five of the most widely used fixed income arbitrage strategies through time to study the risk and return characteristics of these strategies. Specifically, they investigated the swap spread, yield curve, capital structure, volatility, and mortgage arbitrage strategies. They found that all strategies considered yield positive average excess returns. They also found that most strategies offered positive skewness, except volatility arbitrage which offered negative skewness for all maturities on the caps they considered. They found that most strategies are sensitive to various equity and bond market factors and that the three strategies that required the most "intellectual capital" to implement offered positive excess returns even after controlling for market risks, transaction costs, and fund fees. Turning to the swap spread strategy, specifically, they found that their strategies on two-, three-, five- and ten-year maturities all offered positive average excess returns ranging from 0.313% to 0.546%. The swap spread strategy using two-, three- and ten-year maturities additionally all had a positive skewness of the distributions, but the strategy using five-year maturities as well as the equally weighted strategy had a negative skewness of their distributions.

Even though we are focusing on fixed income arbitrage, there is a wide literature on returns to arbitrage strategies in general. A study conducted by Mitchell and Pulvino (2001), focused on the risk and return characteristics of another classical hedge fund arbitrage strategy, called merger arbitrage. The paper analyzed the investment strategy of merger arbitrage by attempting to profit on the spread between the target company stock price and the offer price. They found that the merger arbitrage returns are similar to those returns obtained from writing out of the money put options. The authors postulated that the excess return reflects a premium paid to the risk arbitrageurs for providing liquidity.

Yu (2006) examines the risk and return characteristics of capital structure arbitrage, which is a strategy that exploits mispricing between the value of debt and equity of a company. Specifically, the strategy consists of entering a credit default swap (CDS) position when there is a divergence of the actual CDS market spread and the modeled CDS spread, in addition to an equity position to hedge against market movements. The core finding of the study is that individual trades can be risky due to unexpected credit events or economic shocks that widens the CDS spread. However, the author also found evidence of attractive Sharpe ratios, ranging from 0.39 to 0.80, when aggregating the individual trades into a portfolio.

Gatev, Goetzmann, and Rouwenhorst (2006) studied risk and return characteristics on a relative-price arbitrage trading strategy, commonly called statistical arbitrage, with daily data over the period 1962-2002. The strategy consists of finding two stocks that have moved together historically, buying the winner and shorting the looser, when the spread between them widens. The authors found that top pairs portfolios yield an annualized average excess return of 11%, and they interpreted the results from the research in favor of profitable arbitrage. They argue that the arbitrageurs are compensated for enforcing the Law of One Price. Avellaneda and Lee (2010) also investigate pairs trading or statistical arbitrage strategies in US equities. They generate trading signals by using Principal Component Analysis (PCA) and ETFs. The authors found empirical evidence of attractive Sharpe ratios of 1.44 and 1.1 in the period 1997-2007. Also, the authors improved the signals by including daily trading volumes, increasing the Sharpe ratio for ETF-based strategies to 1.51 in the period 2003-2007.

3. Trading strategy

The swap spread arbitrage strategy consists of two legs. The first leg is to enter a plain vanilla swap, where one receives a fixed rate (CMS) and pays a floating LIBOR rate (L). The second leg consists of shorting a Treasury with the same maturity as the swap, which is traded at par, such that we pay a fixed rate (CMT), and then we invest the proceeds in a margin account earning the repo rate (r). There is then a fixed annuity consisting of the difference between the fixed coupon on the swap and the Treasury bond, and a floating cash flow consisting of the difference between the repo rate and the LIBOR rate. The strategy is thus a bet that the swap spread received (size of the fixed annuity) will remain larger than the floating spread paid. If the floating spread (FS) is larger than the swap spread (SS), one will take on the opposite positions.[3]

The positions are held until convergence of the spreads or until maturity.

$$Swap\ spread\ (fixed\ annuity): \quad SS = CMS - CMT$$
$$Floating\ spread: \quad FS = L - r$$

Similarly, to Duarte et al. (2007), we choose a position to hold each month depending on the trigger at +/- 10 basis points, where the trigger is SS minus FS, and we either hold until maturity or until convergence. If the trigger is above +10 basis points we take a “long” position on the strategy, meaning that we short the Treasury and so forth. If the trigger is below -10 basis points we take a “short” position, meaning that we buy the Treasury and so forth. We also use the same transaction costs to make our risk and return properties as comparable as possible. The transactions costs of the other currencies considered are also assumed to be the same as for the US. We assume this to be able to compare the strategy across currencies without having to consider differences in frictions and its effect on the strategy. By assuming this, we know that the risk and return characteristics of less liquid markets are skewed towards better results (as less liquid markets generally have larger bid-ask spreads). We prefer this bias over using different assumptions for different countries, as we then cannot be sure to which way the results are skewed in relation to the US “benchmark” and each other. This would make the

[3] When swap rates are negative, there is a theoretical arbitrage opportunity in the textbook sense. The interested reader is referred to Klingler and Sundaresan (2018), which provide an explanation for the persistence of the negative 30-year swap spread.

precision of our assumptions of transaction costs a key component of the analysis, which we want to avoid. Specifically, bid-ask spreads on Treasuries are assumed to be 1/32, 1 basis points on swaps and 10 basis points on the repo rates. Furthermore, we assume that there are no haircuts on the financing of this strategy.

As mentioned, the strategy is not considered an arbitrage strategy in the textbook sense as the trader is subject to changes in the floating spread, specifically the LIBOR is subject to the indirect default risk of the banks quoting the LIBOR rate. Additionally, there is the mark-to-market risk, i.e., the risk of changes in the value of the relative positions on the swap and the bond, where margin calls can potentially force an arbitrageur to liquidate at unfavorable moments if capital is insufficient. We, however, assume that the arbitrageur conducting the strategy is always able to meet margin calls and that there are no counterparty credit risks.

What has historically made this strategy attractive is that the floating spread has generally been quite stable. Duarte et al. (2007) found an average of 27.3 basis points with a standard deviation of 13.4 on the floating spread with their data from December of 1988 to December 2004. Whereas we, with our data from the end of June 1996 to the end of December 2018, found an average of 18.5 with a standard deviation of 23.8 basis points. Unsurprisingly, given the inclusion of the financial crisis of 2008, the standard deviation of our sample is larger than the sample used by Duarte et al. (2007). While for the UK and Japan, with data from July 1996 to December 2018, the average is 33.4 and 15.9 with standard deviations of 37.4 and 14.2 respectively. The time series of the swap spread vs. the floating spread for all the countries are illustrated in Appendix A, B, and C.

4. Data and methodology

4.1. Data

We collect most of the data from Bloomberg, but other sources, such as Thomson Reuters Eikon, are also used. Regarding the Bloomberg system, we use the internet appendix from the paper by Du, Im, and Schreger (2018) to find appropriate tickers for international bonds and swaps in the Bloomberg system. We use an extensive dataset from the swap and bond markets covering a period from June 1996 to December 2018 for the US market, and from July 1998 to December 2018 for both the UK and Japanese space. The reason for using data starting from July 1998 has to do with the general collateral repurchase agreements (repo rates) explained below.

For the US market, we collect month-end observation of three- and six-month, one-, two-, three-, five-, seven-, and ten-year constant maturity Treasury (CMT) from the Bloomberg system. Duarte et al. (2007) obtained the constant maturity Treasury data from the Federal Reserve (FRED) in the H-15 release, and we, therefore, validate the obtained data from Bloomberg by cross-checking the dataset used by Duarte et al. (2007) with our data. Figure 1 below illustrates the difference in the dataset for the ten-year CMT rate. The correlation is nearly 100% for each maturity, which is further specified and shown in Appendix D. For the UK and Japanese market, we obtain three- and six-month, one-, two-, three-, five-, seven-, and ten-year GBP UK Gilts and three- and six- month, one-, two-, three-, five-, seven-, and ten-year JPY Japan Sovereign. We cannot do a similar cross-check of the bonds from the UK and Japanese space since constant maturity bonds are not reported online, meaning that the only source of the bond data from the UK and Japan available for us are the ones from the Bloomberg system.

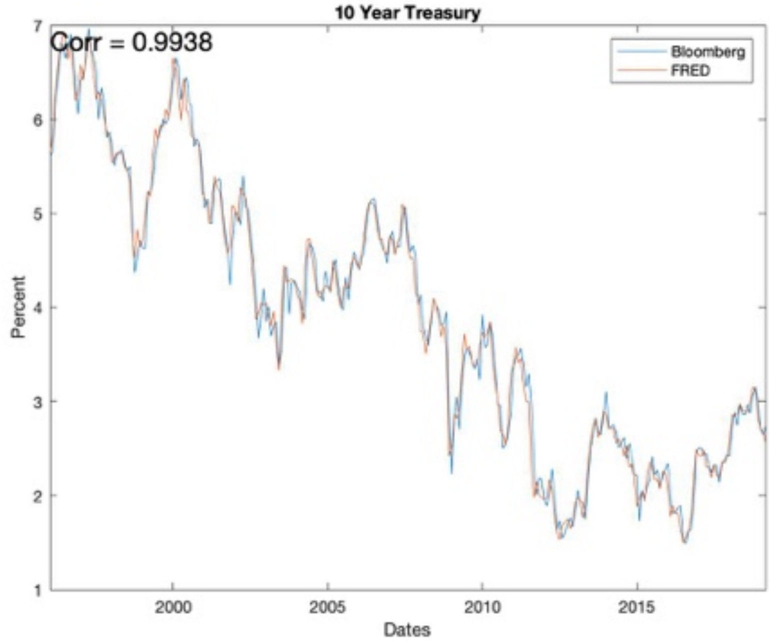

Figure 1. Time series of 10-year constant maturity Treasury. This figure illustrates the difference between the dataset from June 1996 to December 2018 collected from the Bloomberg system and the Federal Reserve H-15 release. The rates are month-end midmarket quotes.

The mid-market one-, two-, three-, five-, seven-, and ten-year constant maturity fixed for floating swap rates (CMS), we obtain from the Bloomberg system. The US swap with one-year maturity was first reported in the Bloomberg system in June 1996. Thus, we start our dataset for the US from this date. The floating leg of the swap is indexed against the three-month USD LIBOR for the US market, while for the UK and Japanese space, the floating leg is indexed against the six-month GBP LIBOR and six-month JPY LIBOR.

The LIBOR rates are reported by Intercontinental Exchange (ICE), and we obtain them from the Bloomberg system. Specifically, we collect both three- and six-month LIBOR rates for the US, the UK, and Japan.

We collect repo rates from both the Thomson Reuters and the Bloomberg system. For the US, we collect the three-month repo rate while for the UK and Japan, we collect the six-month repo rate. The repo rates for the US market from the Bloomberg system seem strange, so we conduct an independent check of the data. First, we check the correlation of the repo rate from the two sources and find it to be 96.66%. Secondly, we look at the maximum value of the difference between the LIBOR rate and repo rate and find that the spread is largest with the repo data from the Bloomberg system. Thirdly, the repo rate is a discount interest rate at which a central bank repurchases government securities. This means that the correlation between the repo rate and the three-month Treasury rate should be close to one. We find that the repo rate from the Bloomberg system correlates 97.02% while the repo rate from Thomson Reuters correlates 98.96%. We also notice that the repo rate obtained from the Bloomberg system is constant at 0.525% from December 2015 to December 2018 and that the repo rate in the same period from Thomson Reuters varied more similarly to previous periods. However, Thomson Reuters Eikon first started quoting repo rates at the end of October 1999, so we cannot use Thomson Reuters as our only source without cutting the dataset and losing key data (the Russian debt default and hedge fund crisis of 1998).

We also notice that the repo rates collected from Thomson Reuters are constant and strange in some periods prior to 2007. So, we decide to use the repo rates collected from Bloomberg until July 2007 and use the repo rates collected from Thomson Reuters from July 2007 to December 2018 for the US market. The correlation between the time series of our repo rates and the time series of the three-month Treasury is now at a satisfactory level of 99.46%.

For the UK and Japanese market, we use the six-month repo rate collected from the Bloomberg system since the repo rate is not obtainable from Thomson Reuters. The repo rates were first quoted from July 1998 for the UK and Japan. Luckily, these repo rates do not contain odd sequences where the rates are constant. The correlation between the UK repo rate and six-month maturity gilts are calculated to be 99.62%, while the correlation between the Japanese repo rate and six-month maturity sovereign bonds are calculated to be 93.21%.

The Fama-French three research factors: market return minus risk-free, small-minus-big (SMB), and high-minus-low (HML), for the US and Japan, are obtained from the Fama-French data section on Kenneth R. French's website.[4] The same factors for the UK are obtained from the data-page of University of Exeter Business school.[5] We also collect the momentum factor, up-minus-down (UMD), for all countries considered. Additionally, we collect robust-minus-weak (RMW), and conservative-minus-aggressive (CMA) for the US and Japanese market since the factors are only available for these countries.

The bank stock index for all countries investigated is obtained from the Bloomberg system. We create the return index by taking the percentage change from one month to the next and then subtract the risk-free rate, which we obtain

[4] https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html
[5] http://business-school.exeter.ac.uk/research/centres/xfi/famafrench/files/

from Kenneth French's website.[6] We also collect a betting-against-beta equity factor (BAB) for all countries from AQR Capital Management website.[7] Furthermore, we obtain a time series of excess returns on US Treasuries with 7-10 years maturity (Term tradable) and excess returns on US BBB bonds over US Treasuries with 7-10 years maturity (Credit tradable).

For the US strategies, we collect a BBB corporate bond index, from Thomson Reuters, that we transform into monthly returns and then subtract the risk-free rate, to get excess returns. We conduct the same procedure on a corporate bond index for both the UK and Japan, which we collect from Bloomberg. Furthermore, we collect a broker-dealer factor constructed by He, Kelly, Manela (2017) from Manela's website.[8] A noise measure constructed by Hu, Pan, and Wang (2013), which, unfortunately, is only updated until the end of 2016, is obtained from Jun Pan's website.[9]

Finally, we collect historical prices of matured Treasuries with maturities up to seven years from the Bloomberg system to test the precision of our valuation methodology. We collect exchange rates from the Bloomberg system as well. Tickers for data acquired from Bloomberg are shown in table 1 below.

TABLE 1 - Tickers used in the Bloomberg system

US tickers	C0823M, C0826M, C0821Y, C0822Y, C0823Y, C0825Y, C0827Y, C08210Y, USSW1, USSW2, USSW3, USSW5, USSW7, USSW10, US0001M, US0003M, US0006M, USRGCGC, SPTR5BNK, JPY Curncy
UK tickers	C1103M, C1106M, C1101Y, C1102Y, C1103Y, C1105Y, C1107Y, C11010Y, BPSW1, BPSW2, BPSW3, BPSW5, BPSW7, BPSW10, BP0001M, BP0003M, BP0006M, BPRPF, F3BANK, SPUKICGT, GBP Curncy
Japan tickers	C1053M, C1056M, C1051Y, C1052Y, C1053Y, C1055Y, C1057Y, C10510Y, JYSW1, JYSW2, JYSW3, JYSW5, JYSW7, JYSW10, JY0001M, JY0003M, JY0006M, JYRPF, N5BANK, SPBJPCPT, GBPJPY Curncy

Note: This table shows tickers of different securities that are obtainable in the Bloomberg system. The securities are government bonds, fixed for floating interest rate swaps, one-, two-, and three-month LIBOR, general collateral repurchase agreement (repo), bank stock indices, corporate bond indices, and exchange rates.

[6] https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html
[7] https://www.aqr.com/Insights/Datasets/Betting-Against-Beta-Equity-Factors-Monthly
[8] http://apps.olin.wustl.edu/faculty/manela/data.html
[9] http://www.mit.edu/~junpan/

4.2. Trading strategy methodology

4.2.1. The carry

Each month we check if the spread between the swap spread and floating spread exceeds +/- 10 basis points, considering transaction costs. If the trade is triggered, we next find the month that the trade ceases to exist, which is either at maturity or when the spread between the swap spread and the floating spread have converged. We then compute the cash flows for each position in each given trade to be received or paid in the period between initiation and exit of the trade. The cash flows are assumed to be received and paid at the last trading day of the corresponding months.

If we exit the trade at a date which is not a payment date before maturity, we need to consider the accrued interest to be received or paid. The accrued interest of the fixed annuity SS is considered through mark-to-market, which is explained below, while for the floating spread we need to calculate the accrued interest. When calculating this accrued interest, we also consider the day count convention for the LIBOR and repo rate for the countries considered.

4.2.2. Valuation

To value our position in the sovereign bonds and the fixed leg of the swaps, we need to construct both a discount function for the sovereign bonds and the swaps, for each month.

To value the bonds on a monthly basis, we construct a discount function with monthly intervals. As we only have constant maturity rates of six-month, one-, two-, three-, five-, seven-, and ten-year maturities, we estimate the mid-yields in-between these rates at semi-annual intervals. We estimate these mid-yields using a cubic spline interpolation, where all points of our initial data are perfectly fitted. This leaves us with 20 mid-yields with six-month maturity separation. We use these rates to construct a cash flow matrix of par bonds with maturity from 6-months up to 10-years with 6-month maturity separation of each bond. The 6-month and 1-year bonds are of course zero-coupon bonds and are treated as such in the cash flow matrix (we have for simplicity scaled it such that the price of the zero-coupon bonds are 100). All these bonds have the same price of 100 (par value). We now have a linear system of 20 equations which we solve by multiplying the inverse of the cash flow matrix with the vector of the par values. The solution to the linear system of equations give us 20 discount factors (the six-month and 1-year discount factors are of course known, but the corresponding zero-coupon bonds are included to bootstrap coupon payments in these months) which are consistent with the constant maturity rates in the sense that there are no arbitrage opportunities left on the table in-between these yields. Next, we use these 20 discount factors together with the three-month discount factor to interpolate a discount function with monthly intervals. Once again, we use a cubic spline where each discount factor is perfectly fitted to the spline.

We construct the discount function for the swap similarly to the discount function for the bonds, only using CMS rates rather than CMT rates. As we do not have swap rates with shorter maturities than one year, we use the three- and six-month LIBOR in our estimation of the swap discount function since the floating leg of the swaps are indexed against LIBOR. Specifically, we include the six-month LIBOR in our first interpolation to get all estimates of the mid-yields needed to construct a cash flow matrix, and the three-month LIBOR is used to derive the three-month discount factor which we further use in the second interpolation. Similarly to the construction of the sovereign bond discount function, a cubic spline is also used in both cases for the swap discount function, and the one-, two-, three-, five-, seven-, and ten-year constant maturity swap rates are perfectly fitted to the spline, in addition to the six-month LIBOR. In the second interpolation, the cubic spline is fitted to all swap discount factors acquired from the first interpolation as well as the three-month LIBOR discount factor.

To test the accuracy of our value-estimation, we collect historical monthly prices of matured bonds through the Bloomberg system. As our discount functions are created at a monthly basis and at the end of each month, we pick bonds that were issued close to these dates such that we could easily create cash flow arrays that correspond closely to the dates we use up until this point. We cherry-pick 102 US Treasury bonds of varying maturity and coupon rates and collect their monthly prices from issuance until maturity. These monthly prices are the quoted prices, or “clean prices,” meaning that we have to calculate the accrued interest on these bonds at each date and add this accrued interest, to get the invoice price. Once we have the invoice price or the “dirty price,” we subtract the coupon payments from the invoice price at the coupon dates to get ex-coupon invoice prices, which are comparable to our estimates of the prices (which are the present value of future cash flows, ex-coupon). Next, we create cash flows for each bond that correspond to their coupon rate and use our discount function at each date to get our estimates of the monthly ex-coupon prices of each bond.

Moving on, we calculate the monthly changes in prices on each bond, both the actual price changes and the price changes on our estimates. The average correlation of the changes on the actual bonds and our estimates is at a satisfactory level of 98.54%, and the minimum value is 92.13%. A histogram of the correlations is displayed in Appendix E.

4.2.3. Return index construction

To construct the return indices, we first sum the monthly cash flows of all trades for the long and short positions in the strategy each month. Next, we calculate the changes in value on the bond positions as well as the positions on the fixed leg of the swap each month and for each trade. These changes are then added together at each month for each trade (as we are long on either the bond or the swap and short the other contract, the changes should offset each other and be quite small).

The carry, or the cash flows, are then added to the changes in value on the relative positions, or the mark-to-market, which are then at each month divided by the number of active long and short positions that month to get an equally-weighted return index. We further normalize the annualized volatility on our return indices at ten percent by adjusting the initial amount of capital invested in order to study the risk and return properties without the distortion of leverage effects. We peg the annualized volatility to specifically ten percent to better compare our results with Duarte et al. (2007).

4.3. Regression analysis methodology

As the swap spread strategy is supposed to be somewhat market-neutral, we regress our return indices upon a variety of market factors to control for market risks. Firstly, we use the widely used Fama and French (1993) three-factor model which include factors such as the excess market return, size or small-minus-big (SMB), and book to market equity or high-minus-low (HML). We also include a fourth factor, which is the momentum factor, known as up-minus-down (UMD), which is suggested by Carhart (1997). Moreover, we include monthly excess returns on bank stock indices from the US, the UK, and Japan. Additionally, Frazzini and Pedersen (2014) suggest using a betting-against-beta equity (BAB) factor. The factor is constructed of portfolios that are long low-beta securities and short high-beta securities. We also include the factors robust-minus-weak (RMW) and conservative-minus-aggressive (CMA) in the US and Japanese regression. These factors help us control for equity-market risk.

Additionally, since the swap spread arbitrage strategy deals with sophisticated asset classes, we include a broker-dealer risk factor constructed by He, Kelly, and Manela (2017). The risk factor is the intermediary capital ratio (ICR). The ICR is the end of the period ratio of the total market capitalization of New York Federal Reserve Bank primary dealers' publicly traded holding companies. The empirical result of the paper is that assets' exposure to intermediary capital ratio shocks possesses a strong and consistent ability to explain cross-sectional differences in average returns for assets in different markets.

Secondly, we control for credit risk by using the monthly excess returns on corporate bond indices. For the US, we include monthly excess returns on a BBB rated corporate bond index, while for the UK and Japan, we include monthly excess returns on a corporate bond total return index.

We also follow Sadka (2010) and include two additional tradable factors to control for credit risk. Specifically, we use the excess return of Treasuries with 7- to 10-years to maturity (Term tradable), and excess return of BBB-rated bonds over Treasuries with 7- to 10-years to maturity (Credit tradable).

A noise measure constructed by Hu et al. (2013) by exploiting the connection between observed price deviations in US Treasury bonds and the amount of arbitrage capital in the market, is further included. The noise measure captures periods of illiquidity as there is more "noise" in Treasury prices when there is a shortage of arbitrage capital in the market. Unfortunately, the noise measure is only updated until the end of 2016, but as we regard this factor as super relevant, we, therefore, run two separate regressions for all countries. We run the first regression on all countries with the whole dataset and then a regression only up until the end of 2016 that includes the noise measure. The three regressions with the noise measure are illustrated below.

$$
\begin{aligned}
R_t^{US} = \alpha + \beta^{Mkt} R_t^{Mkt} &+ \beta^{SMB} SMB_t + \beta^{HML} HML_t + \beta^{UMD} UMD_t \\
&+ \beta^{RMW} RMW_t + \beta^{CMA} CMA_t + \beta^{BAB} BAB_t + \beta^{S} R_t^{S} \\
&+ \beta^{Bond\_ret} R_t^{Bond\_ret} + \beta^{ICR} R_t^{ICR} \\
&+ \beta^{Term\_Tradable} R_t^{Term\_Tradable} \\
&+ \beta^{Credit\_Tradable} R_t^{Credit\_Tradable} + \beta^{Noise} R_t^{Noise} + \varepsilon_t
\end{aligned}
$$

$$
\begin{aligned}
R_t^{UK} = \alpha + \beta^{Mkt} R_t^{Mkt} &+ \beta^{SMB} SMB_t + \beta^{HML} HML_t + \beta^{UMD} UMD_t + \beta^{BAB} BAB_t \\
&+ \beta^{S} R_t^{S} + \beta^{Bond\_ret} R_t^{Bond\_ret} + \beta^{ICR} R_t^{ICR} \\
&+ \beta^{Term\_Tradable} R_t^{Term\_Tradable} \\
&+ \beta^{Credit\_Tradable} R_t^{Credit\_Tradable} + \beta^{Noise} R_t^{Noise} + \varepsilon_t
\end{aligned}
$$

$$
\begin{aligned}
R_t^{JPY} = \alpha + \beta^{Mkt} R_t^{Mkt} &+ \beta^{SMB} SMB_t + \beta^{HML} HML_t + \beta^{UMD} UMD_t \\
&+ \beta^{RMW} RMW_t + \beta^{CMA} CMA_t + \beta^{BAB} BAB_t + \beta^{S} R_t^{S} \\
&+ \beta^{Bond\_ret} R_t^{Bond\_ret} + \beta^{ICR} R_t^{ICR} \\
&+ \beta^{Term\_Tradable} R_t^{Term\_Tradable} \\
&+ \beta^{Credit\_Tradable} R_t^{Credit\_Tradable} + \beta^{Noise} R_t^{Noise} + \varepsilon_t
\end{aligned}
$$

We further investigate the correlation between the independent variables for the US, the UK, and Japan space to check if multicollinearity problems can occur. The correlation matrix of the variables used in the US regression are displayed in table 2, for the UK in table 3, and for Japan in table 4, Appendix F. The highest correlation is between the intermediary capital ratio and the excess returns on US BBB corporate bond index factor at a level of -78%. However, multicollinearity is generally not regarded as a problem until correlation exceeds 80%. Furthermore, we correct the t-statistics for heteroscedasticity and serial correlation by implementing Newey-West autocorrelation consistent standard errors. The optimal truncation lag or bandwidth is automated, as suggested by Andrews (1991).

5. Results

5.1. Risk and return characteristics

Duarte et al. (2007) investigated the swap spread strategy from 1988 to 2004, and found that only the strategy using 5-year maturities had a negative skewness, they also found that all strategies had a kurtosis above 2 and that the strategies offered average monthly returns ranging from 0.305% to 0.546%.

As we do not have access to all data needed to implement the strategy before 1996, we cannot perfectly replicate the strategy. We can, however, implement the strategy from 1996 to 2004 to try to compare our results and see if they are as expected. As our dataset to compare is a lot shorter, and since the hedge fund crisis and the IT-bubble is included in this short dataset, we could expect a higher kurtosis, as well as somewhat similar proportions of negative excess returns. The average return would normally, also, be quite similar, but as Duarte et al. (2007) calculated the average return of the strategies by including the months when there are no active positions, a comparison would be of no value.

We find that the kurtosis of all our strategies is higher than Duarte et al. (2007). Additionally, we find that the proportion of negative excess returns are similar. For the two-year strategy, we have a ratio of 34.0%, for the three-year we have 32.0%, the five-year we have 38.8%, and for the ten-year we have 43.7%, compared to the findings of Duarte et al. (2007) of 32.6%, 32.6%, 33.2%, and 42.5%. Further risk and return characteristics of the strategies implemented in this sample period are displayed in table 5, Appendix G.

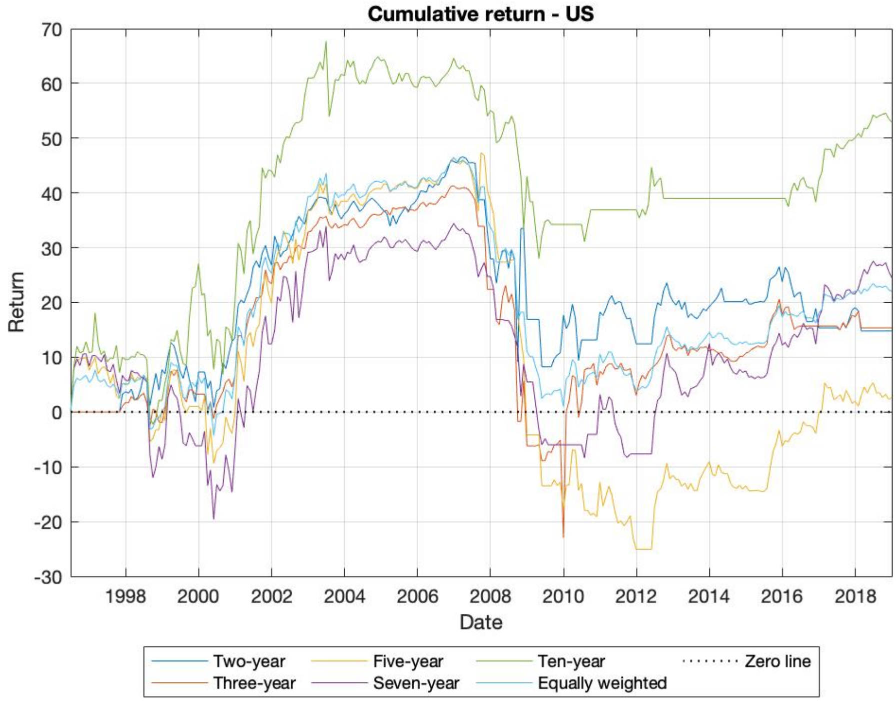

Figure 2: Cumulative return of the return indices in the US.

Implementing the strategy from end of June 1996 to the end of December 2018, we have a dataset that spans over 20 years and covers the financial crisis of 2008, the IT-bubble in 2001, and the hedge fund crisis of 1998. We find that the only strategy that provides a positive skewness is the two-year strategy. The kurtosis of all strategies has also substantially increased, now ranging from 6.737 to 32.396. The excessive kurtosis indicates that extreme outliers are not out of the norm for this strategy, neither positive or negative, which is obvious by looking at the minimum and maximum monthly returns that these strategies provide in table 6, Appendix G. The average excess returns, while still positive, have dropped substantially, now ranging from 0.010% to 0.195%. Even the averages that are calculated by excluding the months with no active positions are substantially lower. Further details on the risk and return characteristics of the strategies implemented in the US from the end of June 1996 to the end of December 2018 are specified in Appendix G table 6.

Looking at the cumulative return of the strategies in figure 2 above, we can see that the cumulative return on all strategies turned positive again by 2017. Interestingly, it took almost ten years before the cumulative return on the five-year strategy became positive again after the crisis of 2008.

The cumulative return of each trade for each strategy is displayed in Appendix H, in addition to a histogram of the cumulative returns of each trade in each strategy, in Appendix I, such that one can get a better picture of the risks involved of engaging in a single trade. Looking at the histograms, we can see that several trades accumulated a loss of up to 30%. Interestingly, the largest monthly return was achieved on the trade triggered on 31. September 2008 on the two-year strategy where the trade closed the month after. Looking at the cumulative return in Appendix H, we observe that although there were large losses in the outbreak of the hedge fund crisis in 1998, the following months offered large returns, such that the cumulative return on the strategies turned positive again relatively fast. The same happened once more in 2000, but not in 2008. Specifically, the floating spread turned negative in 1998 (i.e., the repo was larger than the LIBOR) for four months, resulting in huge gains for long positions, while in 2008 the floating leg increased so much, due to the spike in LIBOR (increased credit risk of banks), that all long positions were closed, resulting in major losses. The losses of 1998, on the other hand, were due to large losses on the relative value between bond- and swap-positions, evident by the mark-to-market time series in Appendix J, which are especially dramatic for longer-term contracts as they are more sensitive to interest rate changes. These losses would of course only be temporary as mark-to-market losses would reverse if positions are held to maturity, but as hedge funds are typically heavily levered, substantial margin calls forced arbitrageurs to liquidate their positions at unfavorable times.

However, as the swap spreads increased, while the floating spread remained low until the end of 1999, more profitable trades were triggered while previous trades triggered offered positive carry, resulting in increased returns following the crisis. In the outbreak of the financial crisis of 2008, however, both the floating spread (increasing payments on long strategies) and the swap spreads (decreasing the value of the swap position relative to the bond position) spiked upwards, resulting in dramatic losses on long positions. Interestingly, looking at the mark-to-market time-series in Appendix J, the relative value losses were more dramatic for short term contracts in the crisis of 2008 compared to longer-term contracts, meaning that it was primarily short term interest rates that changed, while longer-term swap spreads remained more stable. This is also evident by looking at the plotted swap spreads in Appendix A.

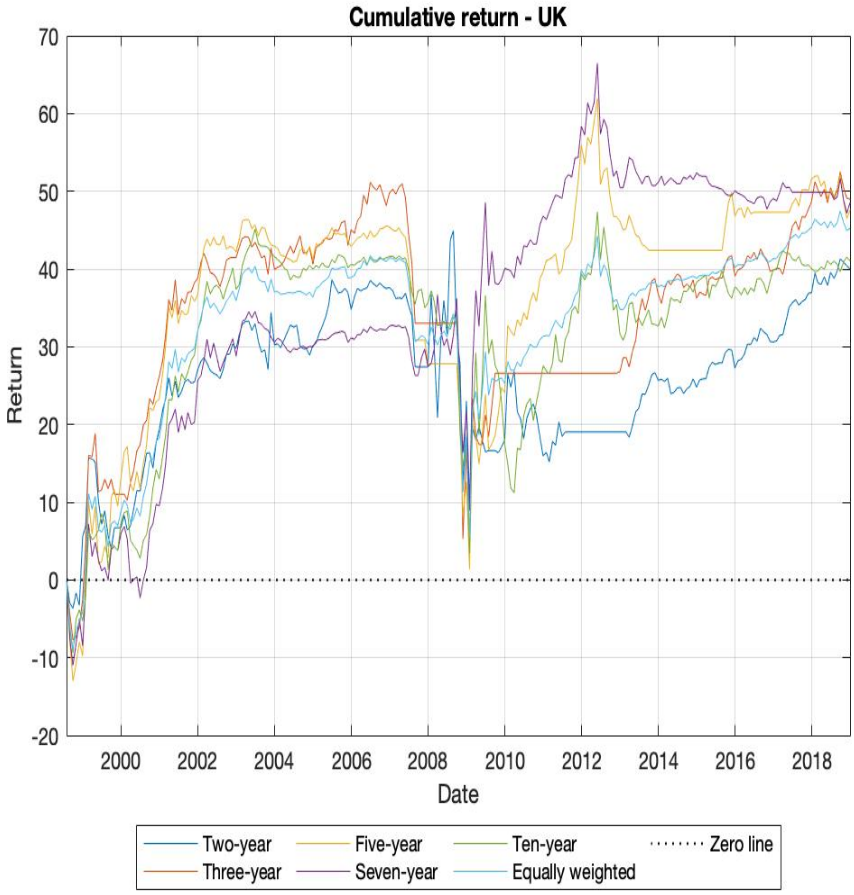

Figure 3: Cumulative return of the return indices in the UK.

The strategies in the UK, implemented from July 1998 to December 2018, however, offers substantially better risk and return characteristics than the strategies implemented in the US. The average excess returns are substantially larger, ranging from 0.163% to 0.199%, although none are statistically significant. Three of the strategies has a positively skewed distribution as well, that is, the five-year, seven-year, and the equally-weighted strategy. The kurtosis of the strategies ranges from 12.696 to 25.047. Further risk and return characteristics are presented in table 6, Appendix G. Cumulative returns of the return indices are displayed above in figure 3, the cumulative return of each trade on each strategy are displayed in Appendix K, and the histogram of the cumulative return on each trade of each strategy are displayed in appendix L.

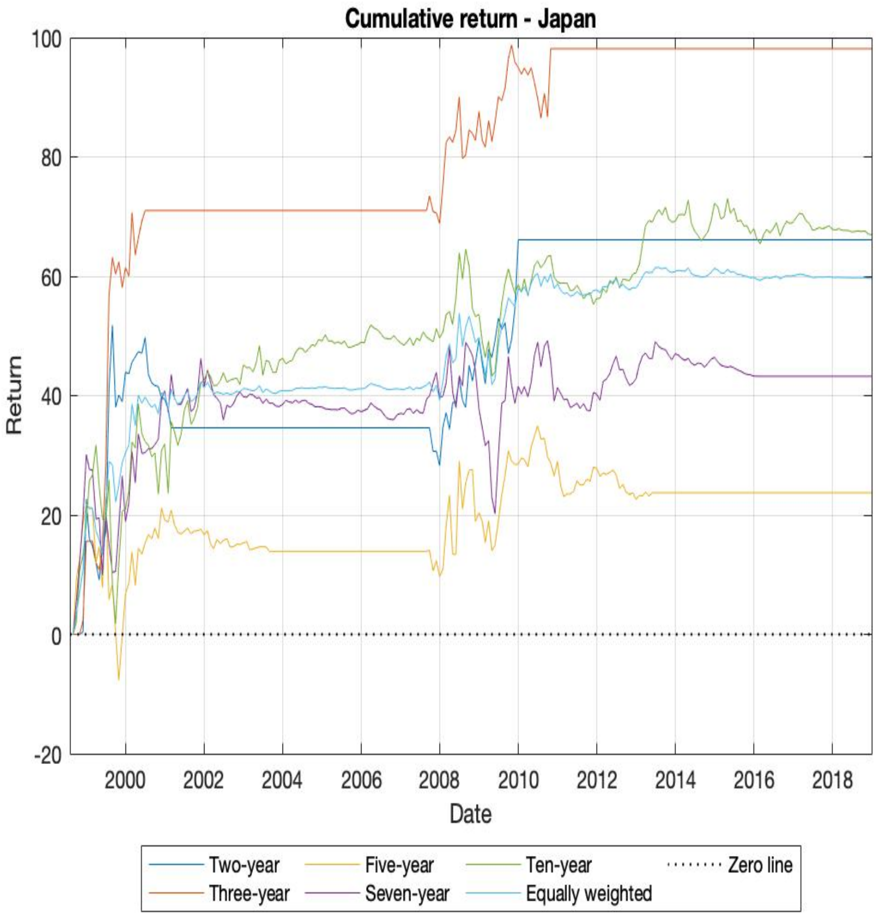

Figure 4: Cumulative return of the return indices in Japan.

Looking at the strategies implemented in Japan, the risk and return characteristics are superior compared to both the US and the UK. The average excess returns range from 0.096% to 0.399%, and two are statistically significant at the 10 percent significance level, and one at the five percent level. All these strategies have a positively skewed distribution. Cumulative returns of the return indices are displayed above in figure 4, the cumulative return of each trade on each strategy are displayed in Appendix M, and the histogram of the cumulative return on each trade of each strategy are displayed in Appendix N.

While long positions on the strategies are predominantly the strategies triggered for the US and the UK space, for Japan, it is primarily short positions on the strategies that are triggered. Interestingly, there are very few trades triggered before the financial crisis of 2008 in Japan.

The strategies implemented in the UK and Japan are evidently a lot less affected by the crisis of 2008 compared to the US. Sharpe ratios for the US range from 0.012 to 0.234, for the UK from 0.195 to 0.274 and for Japan from 0.116 to 0.479, displayed in table 6, Appendix G.

The risk and return characteristics of the strategies implemented in the UK and especially Japan, are surely superior to the strategies implemented in the US. These findings are consistent with our hypothesis that the strategy offers better risk and return properties when implemented in less liquid markets. However, as we assume the same transaction costs across all markets, in terms of basis points, the results of Japan and the UK strategies will be skewed somewhat towards better results, relative to the US, than what can, in reality, be achieved, as frictions are generally higher in more illiquid markets. Nonetheless, the results are of such a difference in magnitude that the general conclusion should not be largely affected by this assumption.

To extend our research a bit further, we check if there are diversification benefits for a US investor, a UK investor, and a Japanese investor. There should be diversification benefits for a domestic investor if our constructed return indices have low correlation with each other. Thus, we create correlation matrices for all the strategies between the countries. We can see from the correlation matrices in appendix O that the correlation is low for all maturities, which indicates that there are diversification benefits for the domestic investor in the US, the UK, and Japan. As the correlation is of such a small nature, diversifying across countries would increase the performance of the strategies, at least if we ignore the costs of currency hedging. To get an idea of the diversifications benefits, we construct a naïve approach where we disregard currency risk and simply invest a notional amount of 100USD in the US, UK and the Japanese return indices each, where we each month convert the monthly return to the domestic investor's home currency. Hedging the currency risk could of curse be achieved by, for example, using cross-currency swap agreements. However, this is beyond the scope of this thesis. For the US investor, we create an equally weighted portfolio of the strategies across countries for which we get better Sharpe ratios ranging from 0.159 to 0.345. For the UK investor, we get Sharpe ratios ranging from 0.201 to 0.391, and for the Japanese investor, we get Sharpe ratios ranging from 0.173 to 0.375. The two-year strategy, as well as the three-year strategy, for the domestic Japanese investor, are the only portfolios that did not increase its Sharpe ratios. Thus, the Sharpe ratios generally increase when diversifying across countries. The Sharpe ratios are displayed in table 12, Appendix P.

5.2. Risk-adjusted returns

As the US strategies considered all offer positive average excess returns and with most of them also having a negatively skewed distribution, most of these strategies are in fact offering nickels in front of a steamroller. Are these strategies even worthwhile for the nickels or are one better off investing elsewhere? Are the strategies that do both offer positive average excess returns and positively skewed distributions, mainly the strategies implemented in Japan, really market-neutral, or are the returns merely compensations for market risks?

Table 13 in appendix Q reports the alphas, t-statistic of the alphas, t-statistics of the risk factors, and the R-squared of the regressions for the US, UK, and Japan. Interestingly, we find that all alphas are negative for the US and that two are statistically significant. This is a clear indication that the swap spread strategies implemented in the US are carrying a lot of market risks, and that there are no abnormal returns, in fact, the finding of negative alphas are an indication that the returns are not even compensation enough to offset the risk that these strategies carry.

The results are similar for the strategies implemented in the UK. All alphas on the strategies implemented in the UK are also negative, but none of them are statistically significant.

Turning to Japan, the strategies still perform better when controlling for market risks. Specifically, we find that four of the strategies have a positive alpha. However, none are statistically significant. The R-squared of the regressions for the US range from 7.0% to 12.6%, for the UK it ranges from 2.0% to 5.7%, and for Japan, it ranges from 5.5% to 16.4%.

The only factor loading that is statistically significant for the strategies implemented in the UK is the corporate bond return index, which is statistically significant at the ten percent level for the two-year strategy. Surprisingly, there are no other statistically significant factors, indicating that either our choice of factors was subpar or that the strategies implemented in the UK are quite market-neutral, which would be consistent with the small R-squared values observed.

Japan, on the other hand, has quite different results. The two- and three-year strategies have positive equity loadings, such as the market return and HML, which are statistically significant at the five percent level. Also, the monthly return on the bank stock index factor has a negative loading, significant at the 5% level on the three-year, five-year, and the equally-weighted strategy. The CMA is negative and significant for all strategies, except for the two-year strategy, where the significance level ranges from one to ten percent.

The alphas, t-statistic of the alphas, t-statistics of the factors, and the R-squared of the regressions with the noise factor for the US, the UK, and Japan are displayed in table 14, Appendix Q. The noise measure is statistically significant at the 5% level for the seven-year strategy implemented in Japan, the two-year strategy implemented in the UK, and the five-year strategy implemented in the US. The statistically significant noise-factor coefficients are all negative, indicating that higher noise in the US market affects the excess returns on these strategies negatively. The results are quite similar to the regression without the noise measure (with the larger sample), although when the noise measure is included, none of the alphas are significant anymore. Additionally, the alpha of the seven-year strategy implemented in the UK are now positive, the two-year- and three-year strategy implemented in Japan have turned negative, while the alpha of seven-year strategy turned positive.

6. Conclusion

Duarte et al. (2007) found evidence to the contrary to the claim that the swap spread arbitrage strategy in the US was picking up nickels in front of a steamroller. However, they found that the strategies did contain substantial market risks, with some of the strategies offering negative alphas.

Can the strategy be considered an arbitrage strategy when the event of the financial crisis of 2008 is included in the sample? A resounding no is our resulting conclusion. The finding of positive skewness of the strategies in the US is a blast from the past, the hidden risk exposed in 2008 blew the seemingly attractive risk and return characteristics out of the water. The finding of negative alphas, although insignificant, suggests that capital is better placed elsewhere.

Looking elsewhere, the risk and return properties for the UK strategies are slightly better, with positive skewness for the five- and seven-year strategy, as well as the equally-weighted strategy, and generally offering larger average excess returns. However, after controlling for market risk, all alphas are negative and insignificant, also suggesting capital is better placed elsewhere.

The risk and return properties for Japan are even better, with positive skewness for all strategies and generally offering larger average excess returns. All strategies, except the seven-year and ten-year strategy, offered positive alphas, although none were statistically significant. The strategies implemented in Japan generally had the highest R-squared values as well as significant risk factors, indicating that the strategies are far from market-neutral. While the strategies in Japan, offering positive skewnesses and positive alphas, may have been worthwhile so far, there are systematic risks involved. Although it seems like the crisis of 2008 was not the true steamroller for these strategies, there may be a future steamroller awaiting, but for now, we cannot disregard the attractive risk and return characteristic of these strategies, but to consider them as arbitrage strategies would be a stretch as there are substantial market risks involved.

Thus, our study suggests that the strategies implemented in the US, the UK, and Japan cannot be considered as arbitrage strategies. Secondly, our findings suggest, as hypothesized, that the strategies implemented in less liquid markets outperform the strategies implemented in more liquid markets.

Lastly, our study suggests that there are diversification benefits between the countries investigated, as the correlations between the return indices generated by the strategies are small in magnitudes.

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Appendix A: Swap spread vs floating spread – US

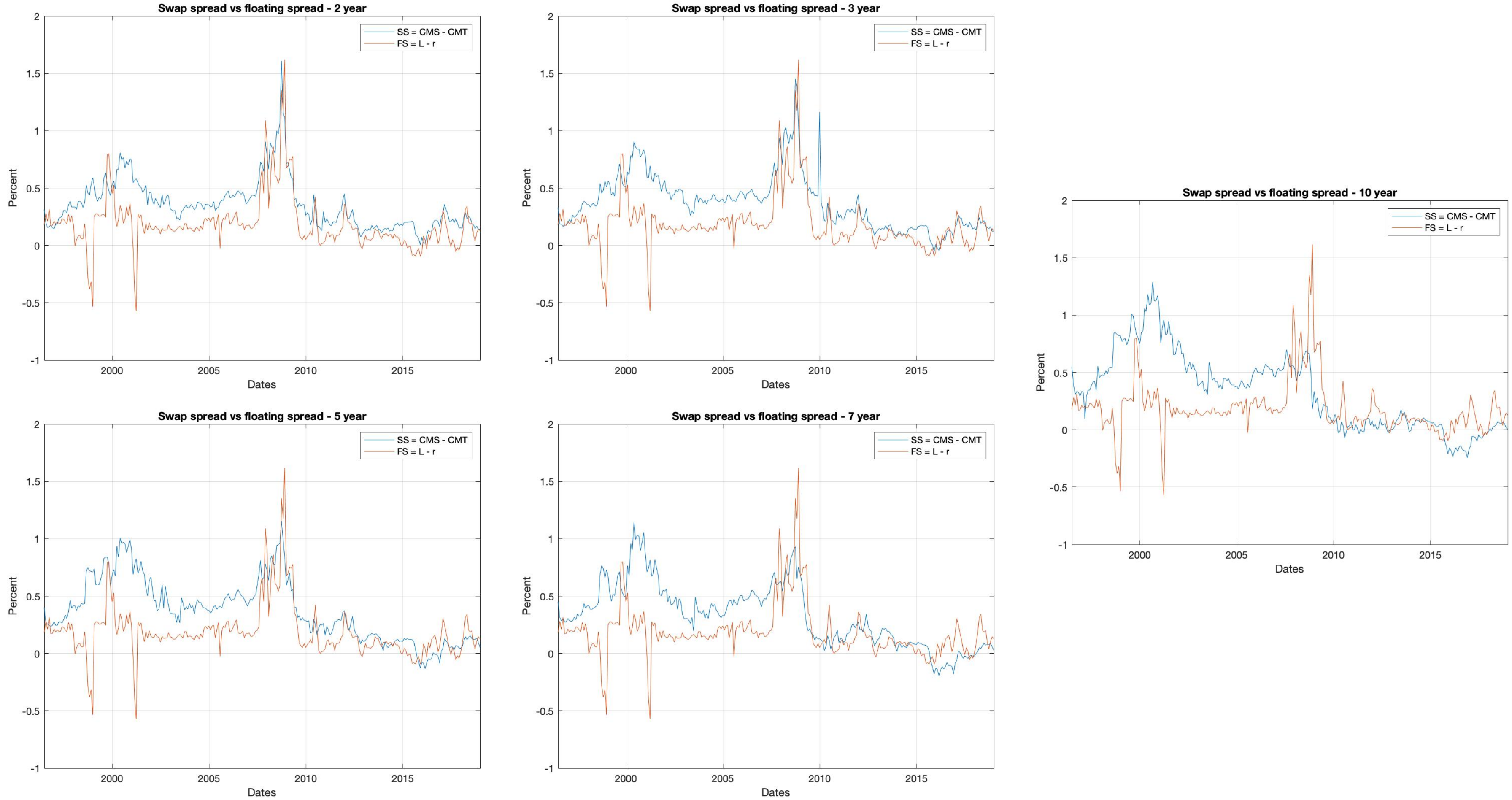


Figure 5. These graphs show the swap spread and the floating spread over time for the US market. All spreads are in percent.

Appendix B: Swap spread vs floating spread – UK

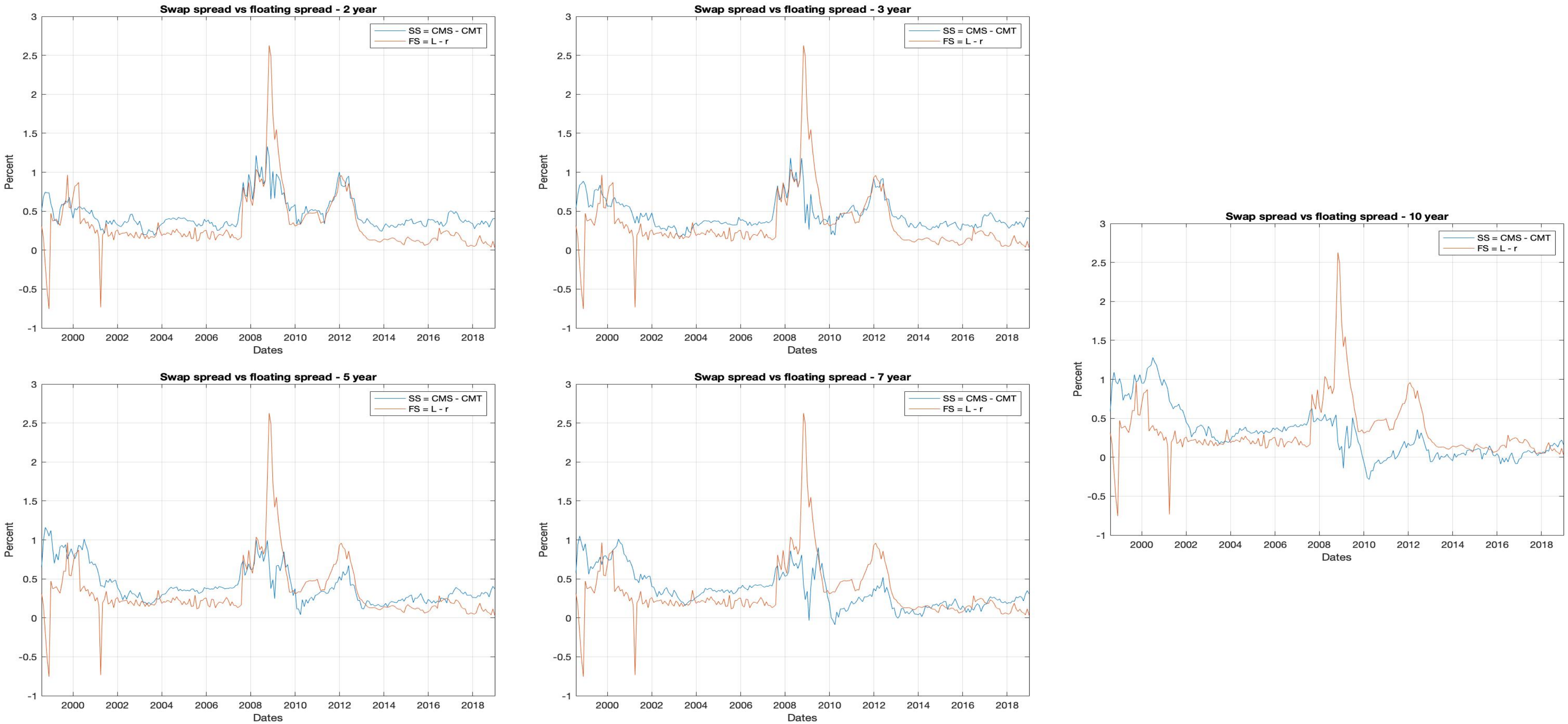


Figure 6. These graphs show the swap spread and the floating spread over time for the UK market. All spreads are in percent.

Appendix C: Swap spread vs floating spread – Japan

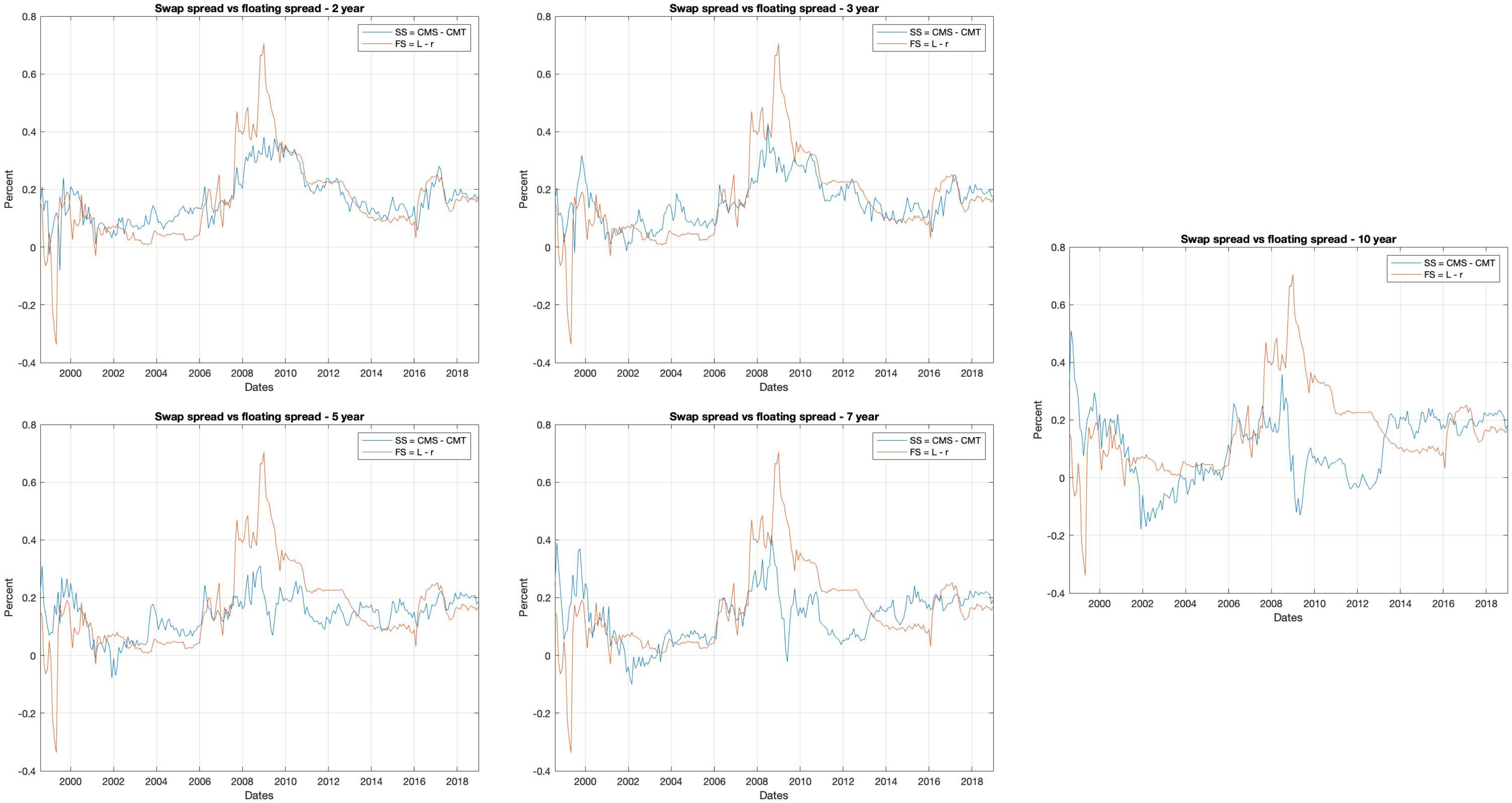


Figure 7. These graphs show the swap spread and the floating spread over time for the Japanese market. All spreads are in percent.

Appendix D: Constant maturity Treasury time series

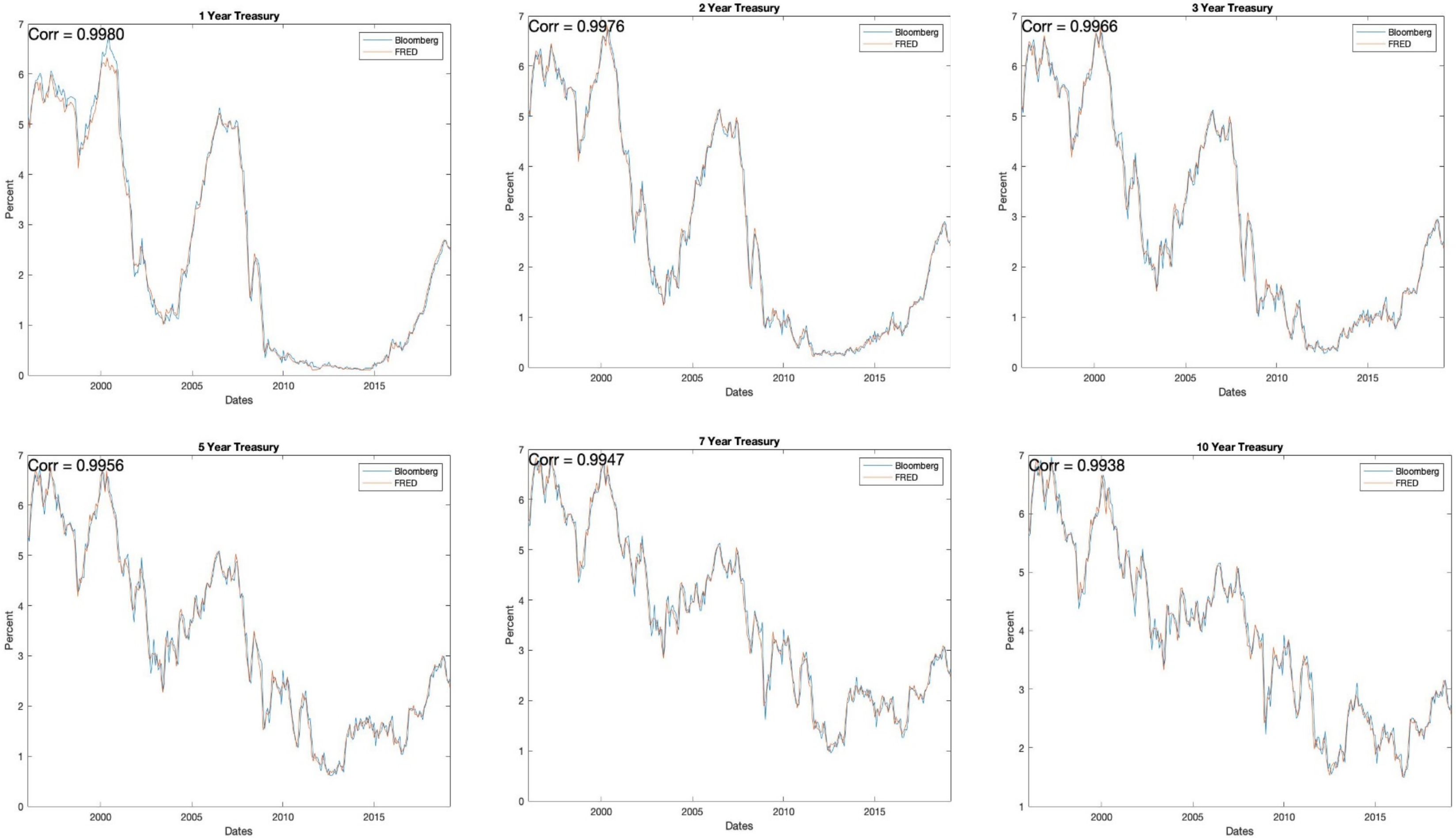


Figure 8. These graphs show the constant maturity Treasury (CMT) from the Bloomberg system and from the Federal Reserve H-15 release over time. Correlation is nearly one on each of the graphs. The yields are in percent.

Appendix E: Histogram of correlation between estimated and actual prices on US Treasuries

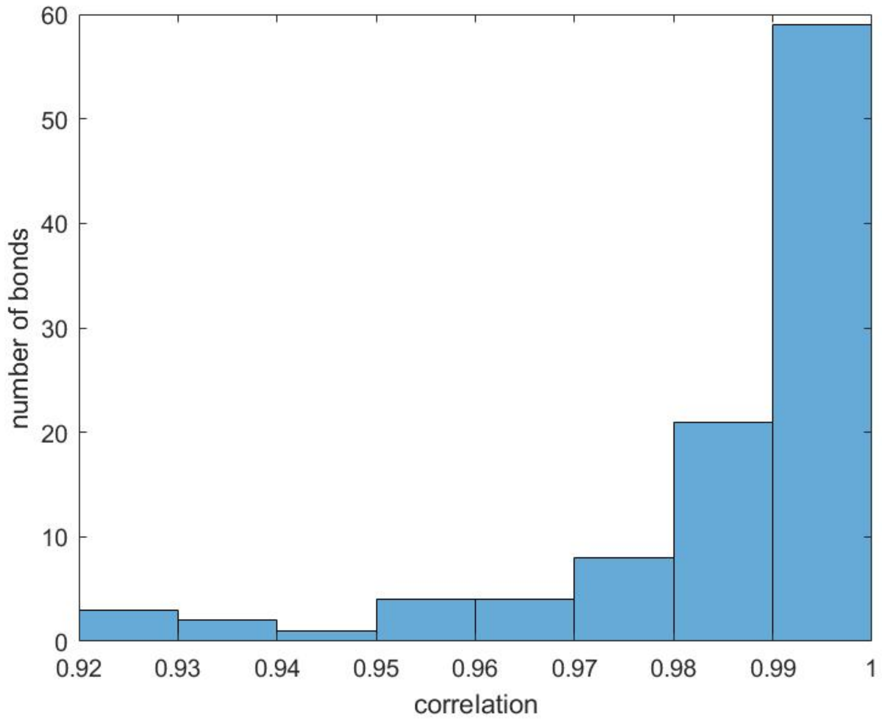


Figure 9. This histogram shows the distribution of the correlation between our estimated prices of the bonds and the actual prices of the bonds.

Appendix F: Correlation matrices between the independent variables used in the regressions

TABLE 2 - Correlation between the independent variables - US

Factors	Market return	SMB	HML	RMW	CMA	UMD	BAB	Bank stock return index	Corporate bond return index	ICR	Term tradable	Credit tradable	Noise
Market return	1,000												
SMB	0,215	1,000											
HML	-0,148	-0,113	1,000										
RMW	-0,495	-0,497	0,450	1,000									
CMA	-0,350	-0,025	0,642	0,318	1,000								
UMD	-0,287	0,039	-0,205	0,087	0,030	1,000							
BAB	-0,357	-0,182	0,425	0,573	0,365	0,272	1,000						
Bank stock return index	0,640	-0,018	0,399	-0,109	0,013	-0,403	-0,050	1,000					
Corporate bond return index	0,082	0,074	-0,088	-0,078	-0,074	-0,109	0,032	0,035	1,000				
ICR	0,051	-0,016	0,111	0,001	0,077	0,114	0,060	0,109	-0,781	1,000			
Term tradable	-0,254	-0,200	-0,037	0,252	0,016	0,172	0,077	-0,191	0,065	-0,098	1,000		
Credit tradable	0,560	0,215	0,010	-0,297	-0,109	-0,325	0,038	0,315	0,141	0,003	-0,441	1,000	
Noise	-0,260	0,007	-0,199	0,076	0,013	0,008	-0,193	-0,293	0,013	-0,134	0,065	-0,215	1,000

Note: Correlation matrix of the independent variables used in the US regression.

TABLE 3 - Correlation between the independent variables - UK

Factors	Market return	SMB	HML	UMD	BAB	Bank stock return index	Corporate bond return index	ICR	TERM Tradable	CREDIT Tradable	Noise
Market return	1,000										
SMB	0,113	1,000									
HML	0,138	-0,166	1,000								
UMD	-0,243	-0,075	-0,541	1,000							
BAB	-0,203	0,311	0,059	0,116	1,000						
Bank stock return index	0,776	0,259	0,312	-0,393	-0,138	1,000					
Corporate bond return	0,218	0,047	0,005	-0,015	0,001	0,171	1,000				
ICR	0,009	0,088	0,124	0,040	0,204	0,151	-0,114	1,000			
TERM Tradable	-0,282	-0,222	-0,025	0,100	-0,029	-0,258	0,464	-0,123	1,000		
CREDIT Tradable	0,555	0,382	0,140	-0,209	0,296	0,483	0,219	0,006	-0,450	1,000	
Noise	-0,210	-0,098	-0,121	0,006	-0,305	-0,251	-0,078	-0,106	0,071	-0,217	1,000

Note: Correlation matrix of the independent variables used in the UK regression.

TABLE 4 - Correlation between the independent variables - Japan

Factors	Market return	SMB	HML	RMW	CMA	UMD	BAB	Bank stock return index	Corporate bond return index	ICR	Term tradable	Credit tradable	Noise
Market return	1,000												
SMB	-0,079	1,000											
HML	-0,246	0,051	1,000										
RMW	-0,052	0,001	-0,578	1,000									
CMA	-0,210	0,118	0,634	-0,631	1,000								
UMD	-0,008	0,150	-0,323	0,251	-0,148	1,000							
BAB	0,103	0,098	0,135	-0,030	-0,112	-0,122	1,000						
Bank stock return index	0,643	-0,041	0,146	-0,340	0,054	-0,214	0,191	1,000					
Corporate bond return index	0,087	0,138	-0,112	0,032	0,025	-0,078	-0,037	0,103	1,000				
ICR	0,076	-0,043	0,052	0,038	-0,146	0,081	0,204	0,017	-0,757	1,000			
Term tradable	-0,119	0,190	0,007	-0,029	0,112	0,146	-0,029	-0,145	0,035	-0,123	1,000		
Credit tradable	0,400	-0,161	-0,129	0,118	-0,299	-0,227	0,296	0,283	0,104	0,006	-0,450	1,000	
Noise	-0,140	0,057	-0,001	-0,020	0,052	0,050	-0,305	-0,184	-0,024	-0,106	0,071	-0,217	1,000

Note: Correlation matrix of the independent variables used in the Japan regression.

Appendix G: Summary statistics for the swap spread arbitrage strategy

TABLE 5 - Summary statistics for the swap spread arbitrage strategy - US

Strategy	N	Capital	Mean	Mean w/o zeros	t-statistics	Std. Dev	Min	Max	Skewness	Kurtosis	Ratio negative	Serial corr.	Gain/Loss	Sharpe ratio
SS2 - US	103	35,532	0,533	0,645	2,110	2,887	-7,262	8,900	0,291	3,807	0,340	-0,121	1,429	0,639
SS3 - US	103	28,259	0,620	0,770	2,230	2,887	-7,689	13,338	0,848	6,582	0,320	0,002	1,515	0,744
SS5 - US	103	12,021	0,351	0,362	1,416	2,887	-10,303	10,281	-0,186	6,206	0,388	-0,158	1,500	0,422
SS7 - US	103	7,285	0,218	0,225	0,892	2,887	-9,628	7,111	-0,392	4,457	0,476	-0,142	1,041	0,262
SS10 - US	103	4,826	0,456	0,456	1,859	2,887	-10,121	7,975	-0,308	5,009	0,437	-0,151	1,289	0,547
EW - US	103	17,584	0,436	0,436	1,947	2,385	-8,482	9,521	-0,238	6,579	0,369	-0,065	1,711	0,633

Notes: This table reports the summary statistics for the monthly excess returns on the swap spread strategies performed in the US. N is the number of observations. The sample period is from the end of June 1996 to the end of December 2004. SS2 are the strategy using 2-year maturities, SS3 are the strategy using 3-year maturities, and similarly for SS5, SS7, and SS10. The EW strategy consists of taking an equally-weighted (on notional amount) position each month in each individual-maturity strategy. Capital is the amount of capital per 100 notional domestic currency required to fix the annualized volatility at ten percent. Mean w/o zeros are average excess returns when not considering months where there are no positions. The t-statistics are corrected serial correlation by using Newey-West standard errors with L = 4 suggested by (Greene, 2003, p. 200). Serial corr. is the serial correlation coefficient of the first lag. Ratio negative is the proportion of negative excess returns. Gain/Loss is the Bernardo and Ledoit (2000) gain/loss ratio.

TABLE 6 - Summary statistics for the swap spread arbitrage strategy

Strategy	N	Capital	Mean	Mean w/o zeros	t-statistics	Std. Dev	Min	Max	Skewness	Kurtosis	Ratio negative	Serial corr.	Gain/Loss	Sharpe ratio
SS2 - US	271	23,839	0,055	0,070	0,404	2,887	-18,408	24,351	0,406	30,381	0,343	-0,210	1,280	0,066
SS3 - US	271	15,785	0,057	0,069	0,386	2,887	-20,182	23,094	-0,676	32,396	0,354	-0,178	1,323	0,068
SS5 - US	271	13,430	0,010	0,010	0,053	2,887	-13,894	11,486	-0,445	8,192	0,432	-0,031	1,188	0,012
SS7 - US	271	9,972	0,091	0,101	0,539	2,887	-13,180	9,734	-0,256	6,737	0,458	-0,088	0,960	0,109
SS10 - US	271	6,572	0,195	0,256	1,244	2,887	-13,784	10,860	-0,099	7,790	0,362	-0,125	1,112	0,234
EW - US	271	13,919	0,081	0,081	0,617	2,063	-11,142	9,100	-0,907	9,676	0,446	-0,023	1,240	0,137
SS2 - UK	246	22,007	0,163	0,180	1,048	2,887	-15,932	12,067	-0,503	12,696	0,378	-0,236	1,387	0,195
SS3 - UK	246	20,263	0,199	0,253	1,200	2,887	-20,220	20,130	-0,279	25,047	0,321	-0,259	1,456	0,239
SS5 - UK	246	11,624	0,193	0,236	1,115	2,887	-12,212	18,797	0,460	13,413	0,370	-0,126	1,220	0,232
SS7 - UK	246	7,347	0,197	0,208	1,249	2,887	-12,814	18,242	0,347	13,151	0,455	-0,174	1,080	0,237
SS10 - UK	246	4,954	0,167	0,168	0,974	2,887	-14,606	16,183	-0,242	12,948	0,480	-0,117	1,076	0,200
EW - UK	246	13,239	0,184	0,184	1,341	2,328	-12,996	16,463	0,047	20,643	0,366	-0,183	1,733	0,274
SS2 - Japan	246	58,281	0,269	1,181	1,683	2,887	-13,758	23,891	4,030	36,858	0,110	-0,016	1,074	0,322
SS3 - Japan	246	47,911	0,399	1,722	1,945	2,887	-10,317	28,106	4,646	41,411	0,106	0,170	1,192	0,479
SS5 - Japan	246	26,676	0,096	0,183	0,653	2,887	-17,176	15,638	0,029	15,455	0,232	-0,299	1,281	0,116
SS7 - Japan	246	17,833	0,176	0,206	1,019	2,887	-9,607	10,507	0,566	6,652	0,455	-0,073	0,875	0,211
SS10 - Japan	246	10,163	0,272	0,273	1,544	2,887	-17,567	12,006	0,361	10,837	0,455	-0,051	1,188	0,327
EW - Japan	246	32,173	0,242	0,243	2,165	1,851	-6,231	10,938	1,619	11,560	0,472	-0,037	1,112	0,454

Notes: This table reports the summary statistics for the monthly excess returns on the swap spread strategies performed in the US, the UK, and Japan. N is the number of observations. The sample period for the US is from the end of June 1996 to the end of December 2018. The sample period for the UK and Japan are from the end of July 1998 to the end of December 2018. SS2 are the strategy using 2-year maturities, SS3 are the strategy using 3-year maturities, and similarly for SS5, SS7, and SS10. The EW strategy consists of taking an equally-weighted (on notional amount) position each month in each individual-maturity strategy. Capital is the amount of capital per 100 notional domestic currency required to fix the annualized volatility at ten percent. Mean w/o zeros are average excess returns when not considering months where there are no positions. The t-statistics are corrected serial correlation by using Newey-West standard errors with L = 4 suggested by (Greene, 2003, p. 200). Serial corr. is the serial correlation coefficient of the first lag. Ratio negative is the proportion of negative excess returns. Gain/Loss is the Bernardo and Ledoit (2000) gain/loss ratio.

Appendix H: Cumulative return per trade - US

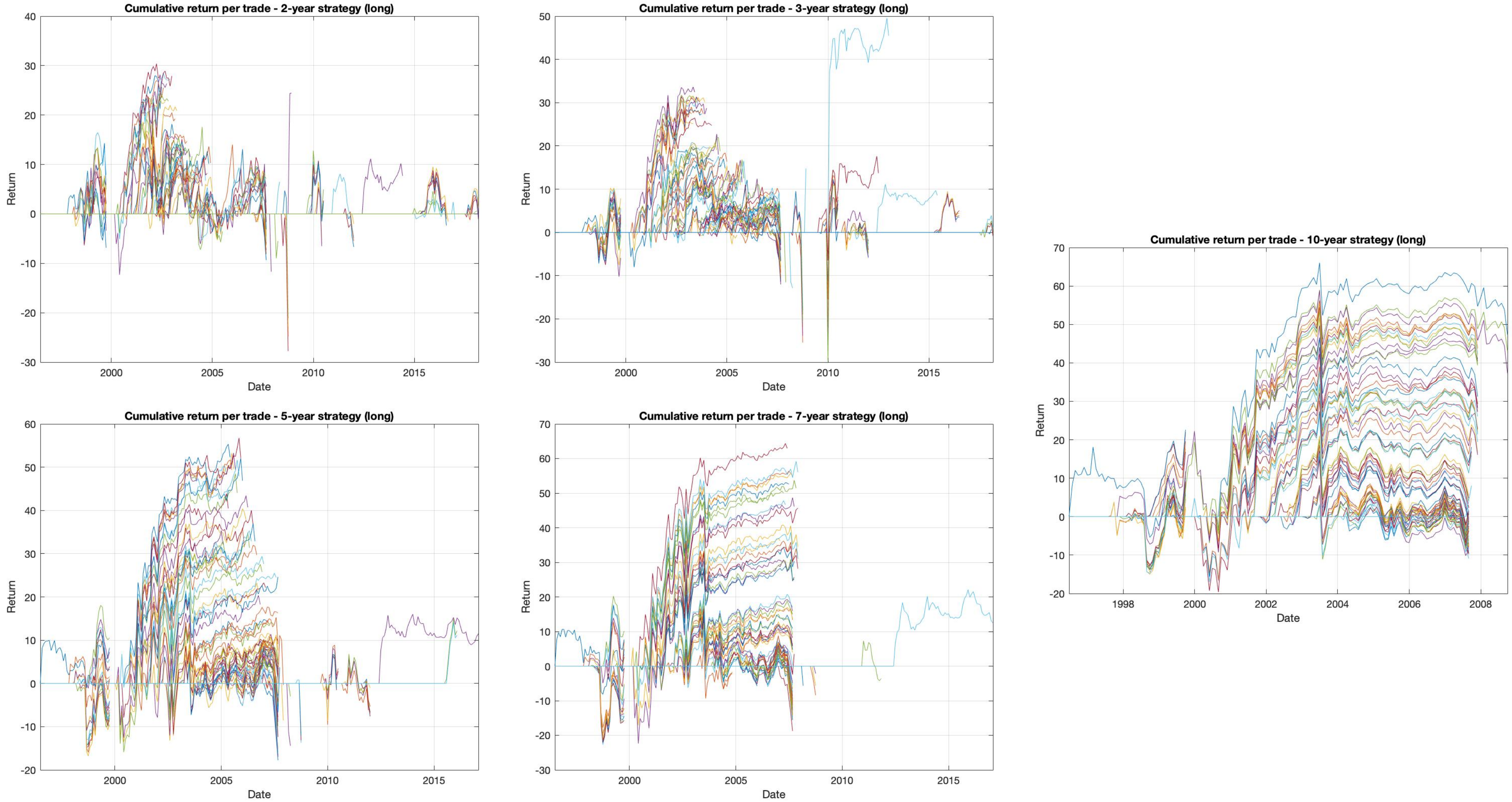


Figure 9. These graphs show the cumulative return per trade for the long positions of different maturities.

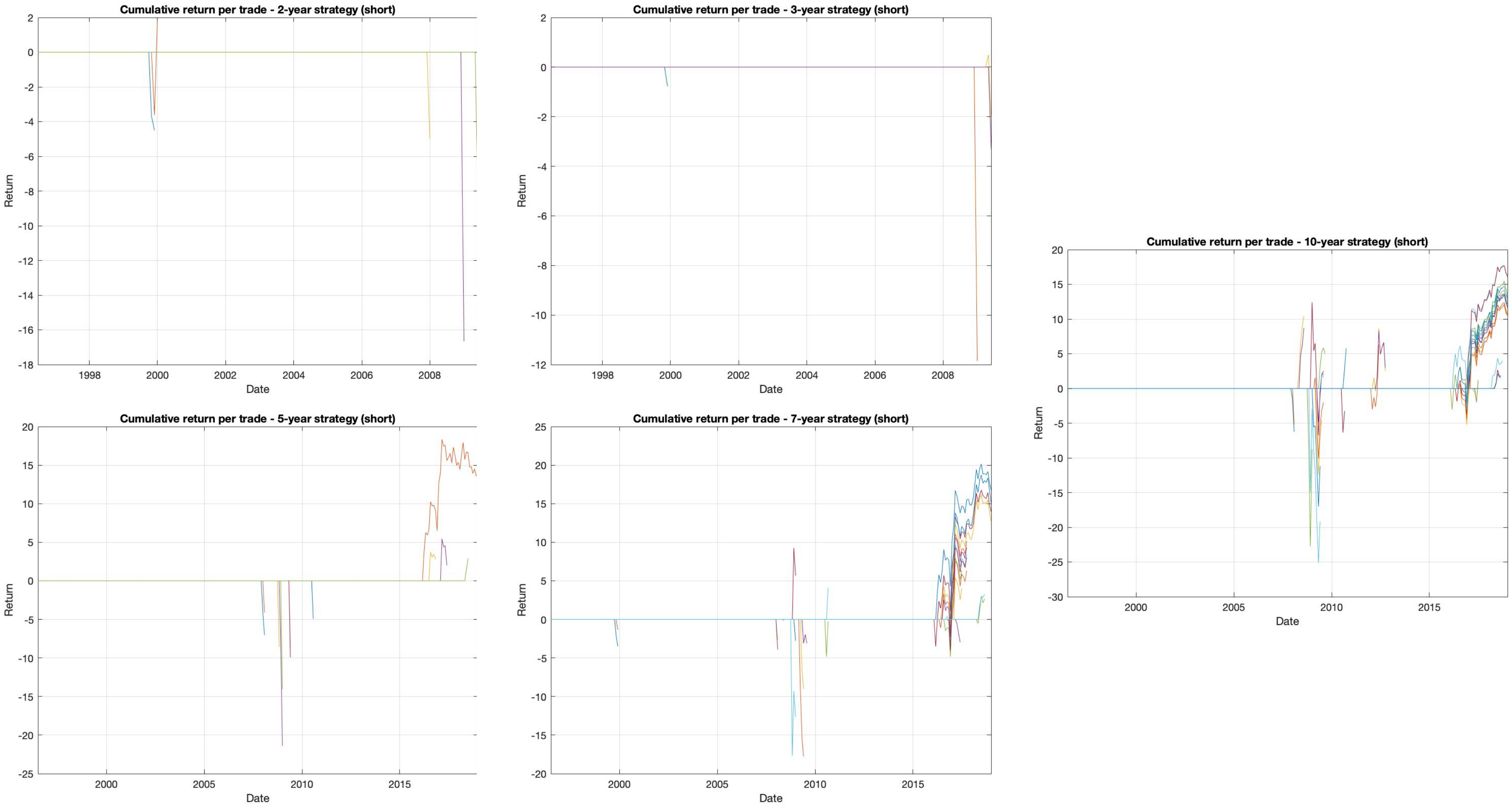


Figure 10. These graphs show the cumulative return per trade for the short positions of different maturities.

Appendix I: Histogram of cumulative return per trade - US

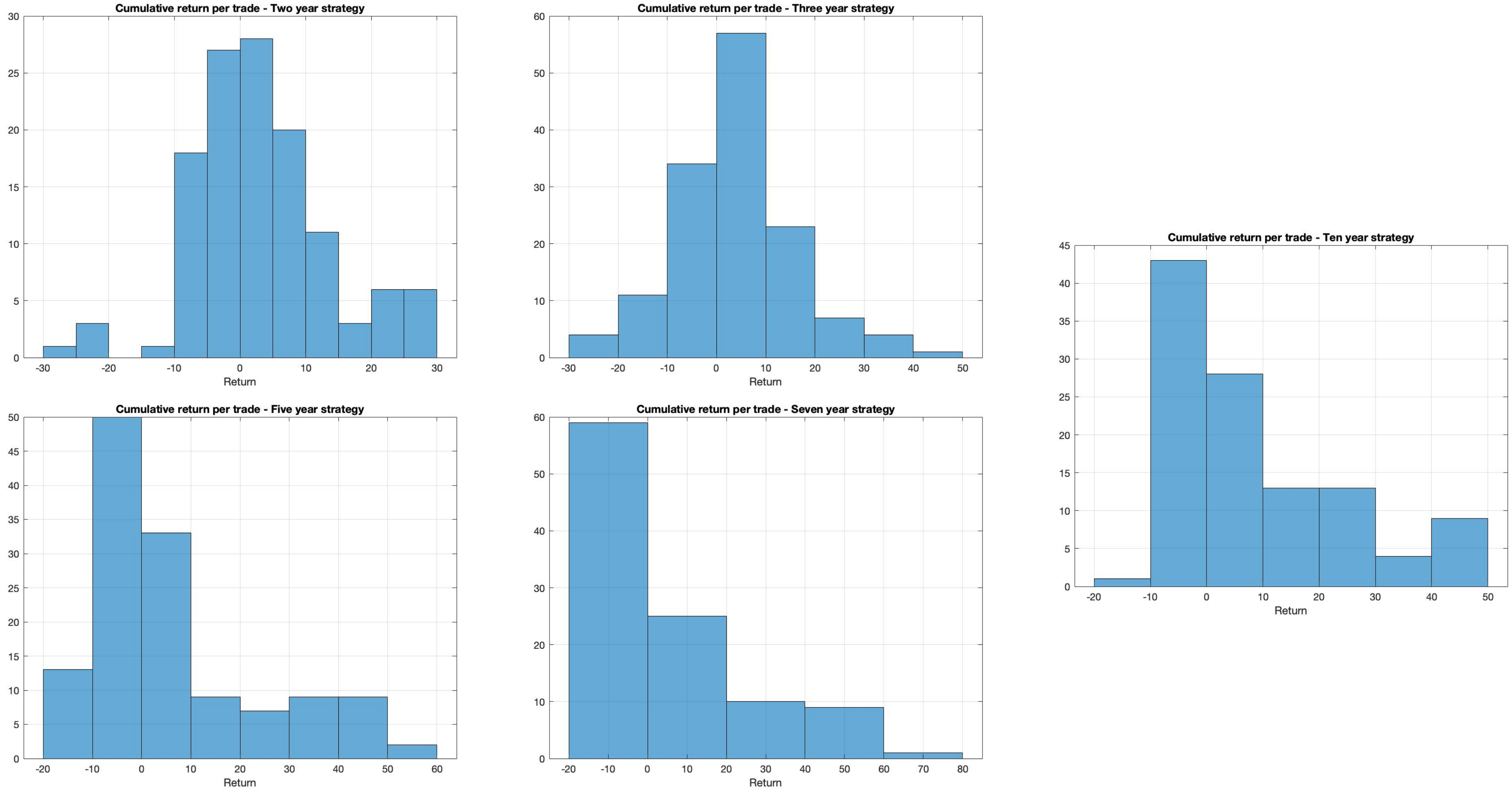
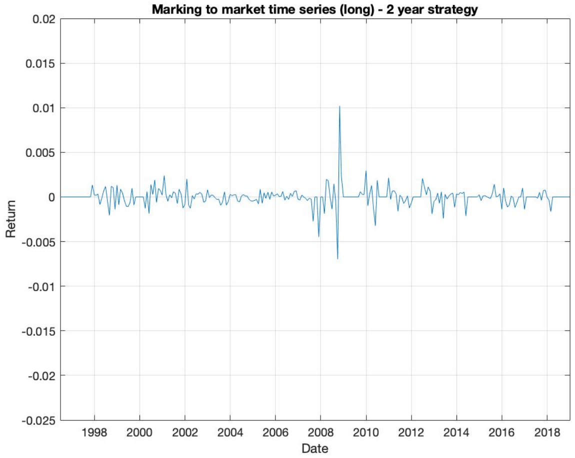
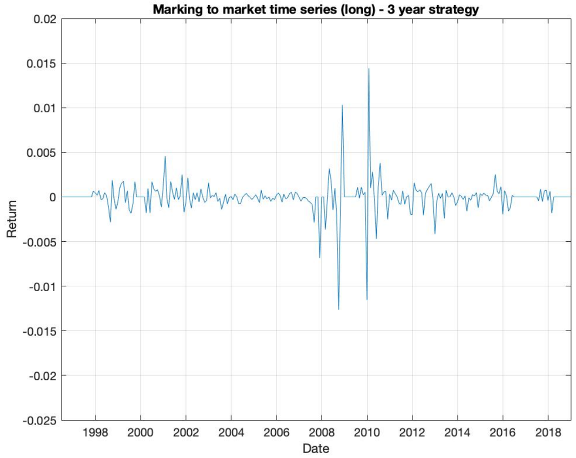
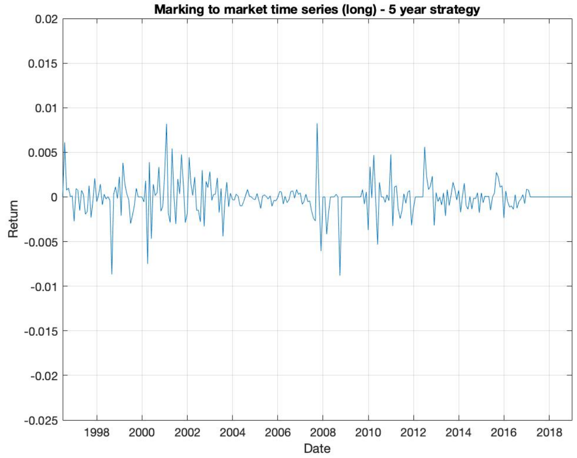


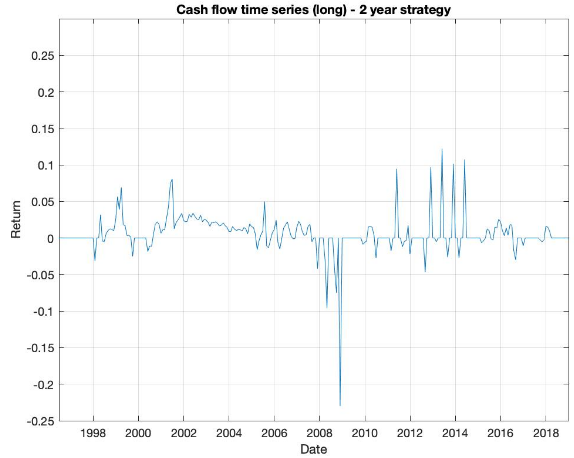
Figure 11. These histograms show the distribution of the cumulative return per trade for the long positions of different maturities.

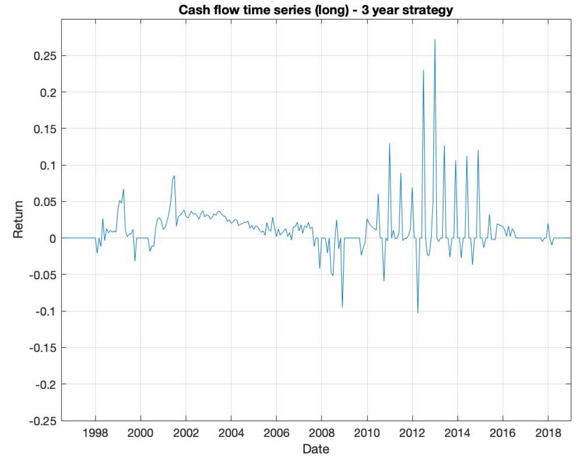
Appendix J: Mark-to-market and carry time-series – US

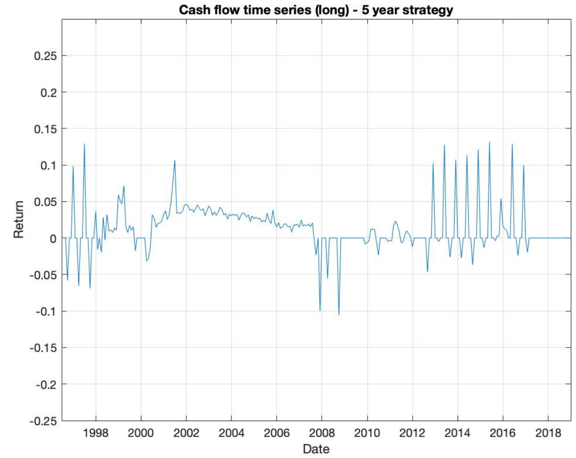












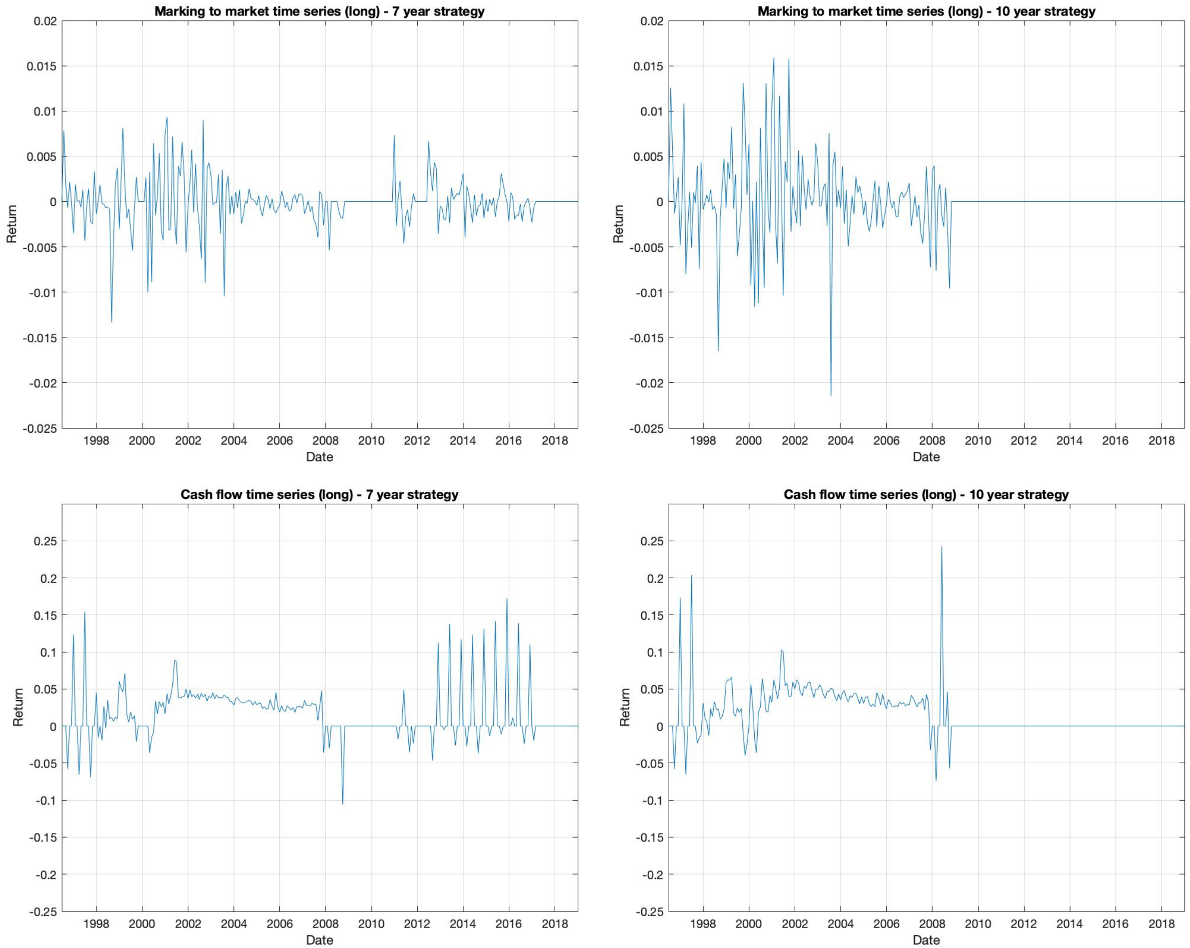


Figure 12. These graphs plot the changes in value on the relative positions as well as the carry for the strategies that we are “long”. The changes are equally-weighted.

Appendix K: Cumulative return per trade - UK

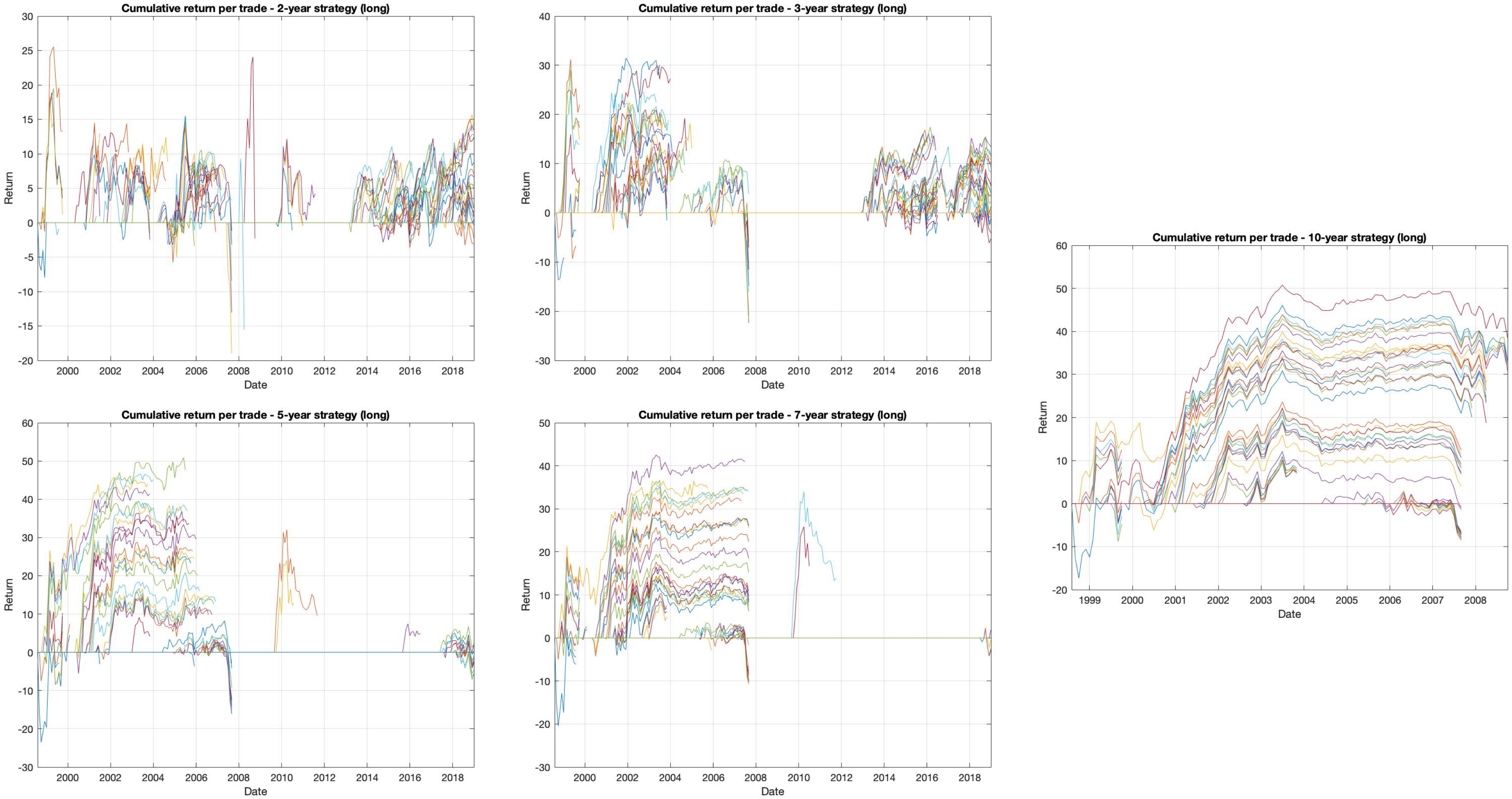


Figure 13. These graphs show the cumulative return per trade for the long positions of different maturities.

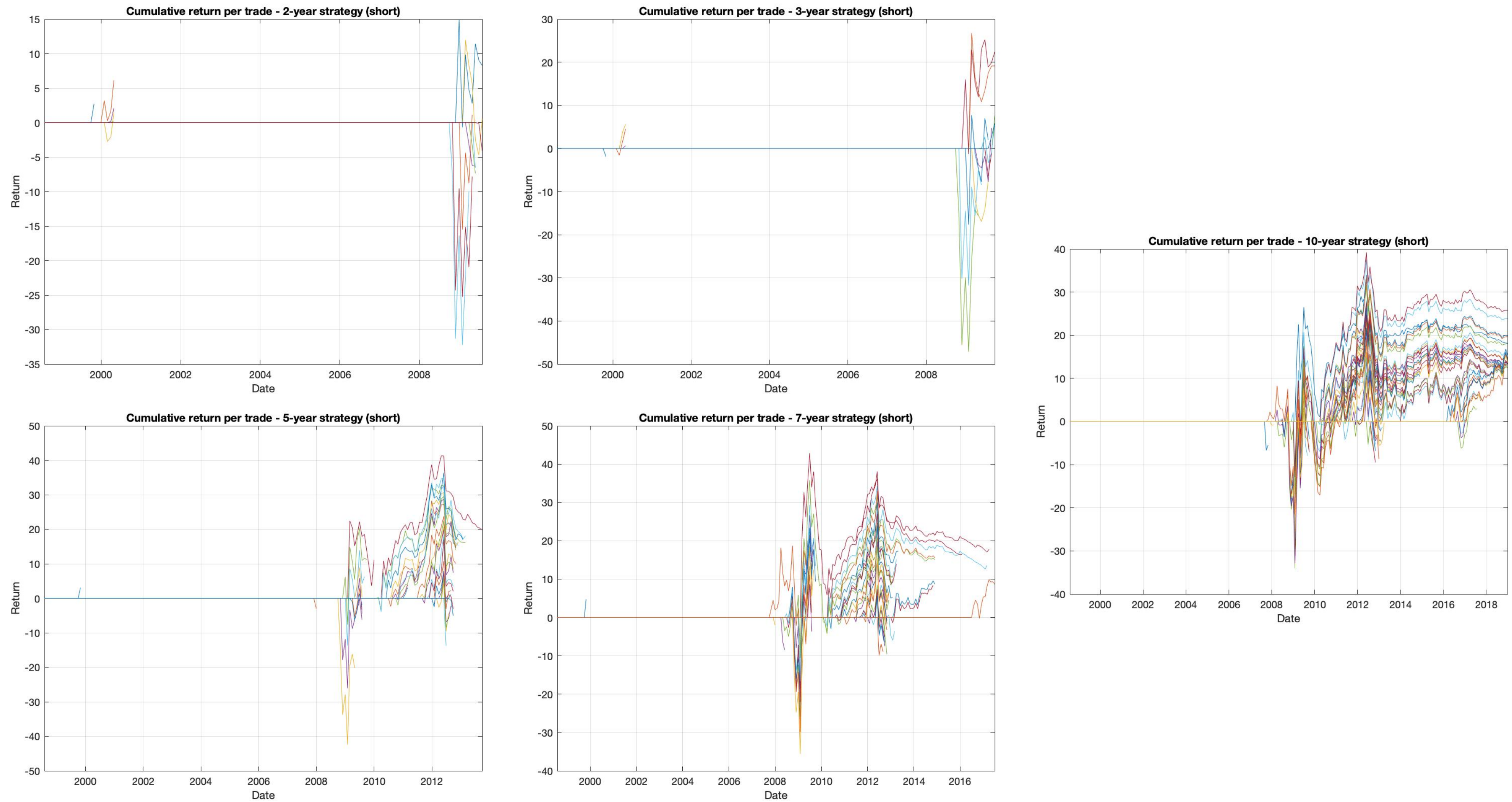


Figure 14. These graphs show the cumulative return per trade for the short positions of different maturities.

Appendix L: Histogram of cumulative return per trade - UK

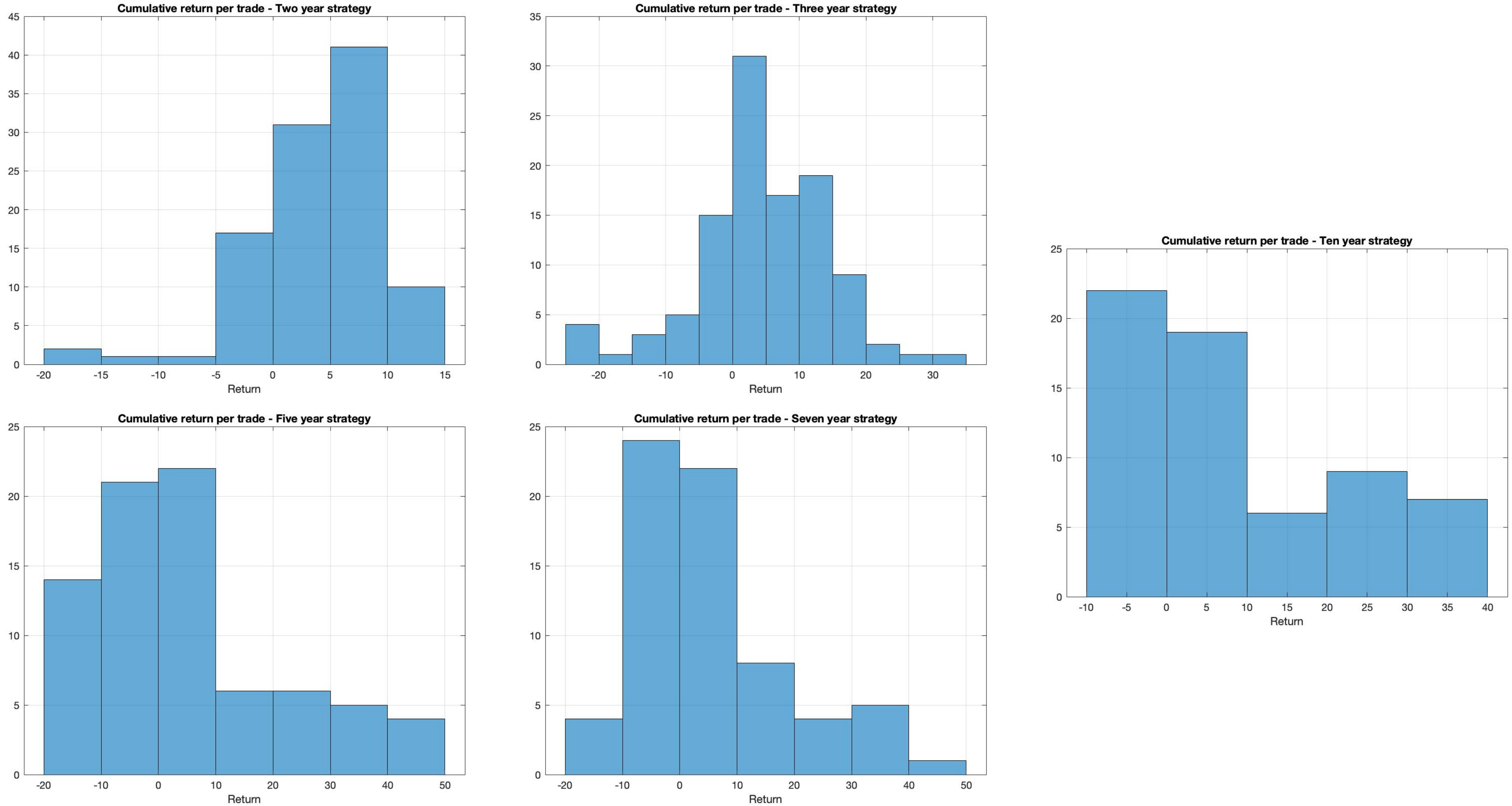


Figure 15. These histograms show the distribution of the cumulative return per trade for the long positions of different maturities.

Appendix M: Cumulative return per trade - Japan

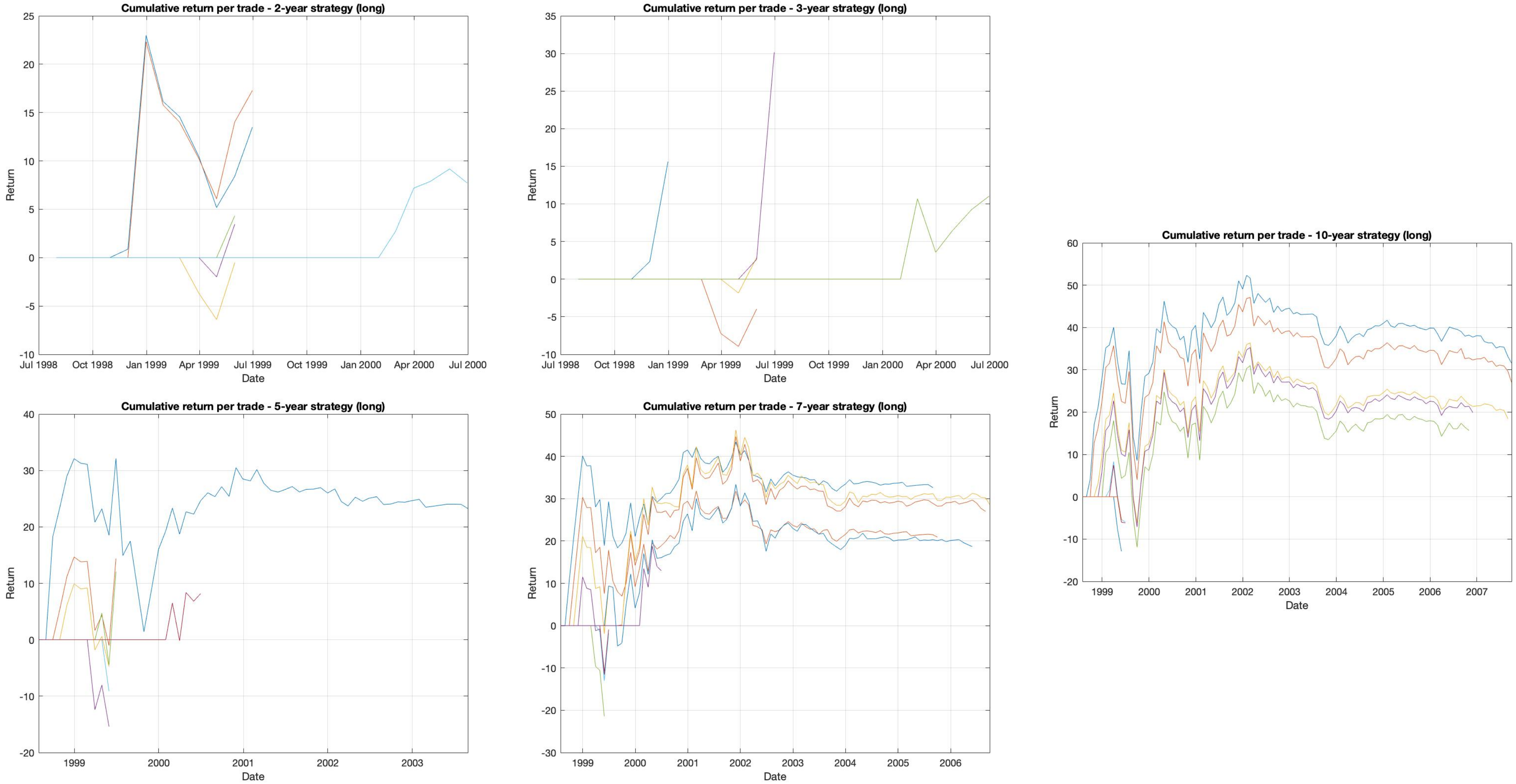


Figure 16. These graphs show the cumulative return per trade for the long positions of different maturities.

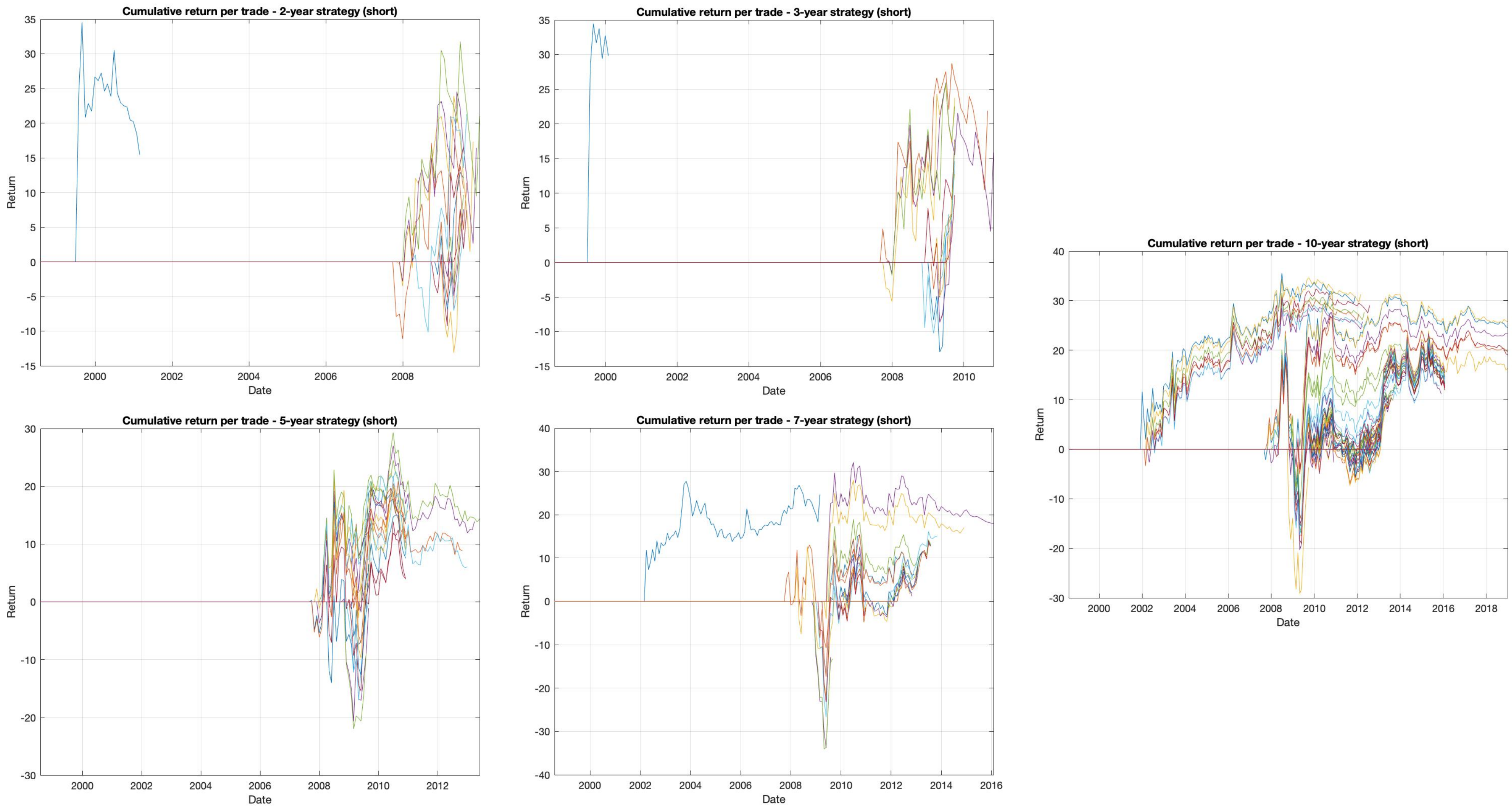


Figure 17. These graphs show the cumulative return per trade for the short positions of different maturities.

Appendix N: Histogram of cumulative return per trade - Japan

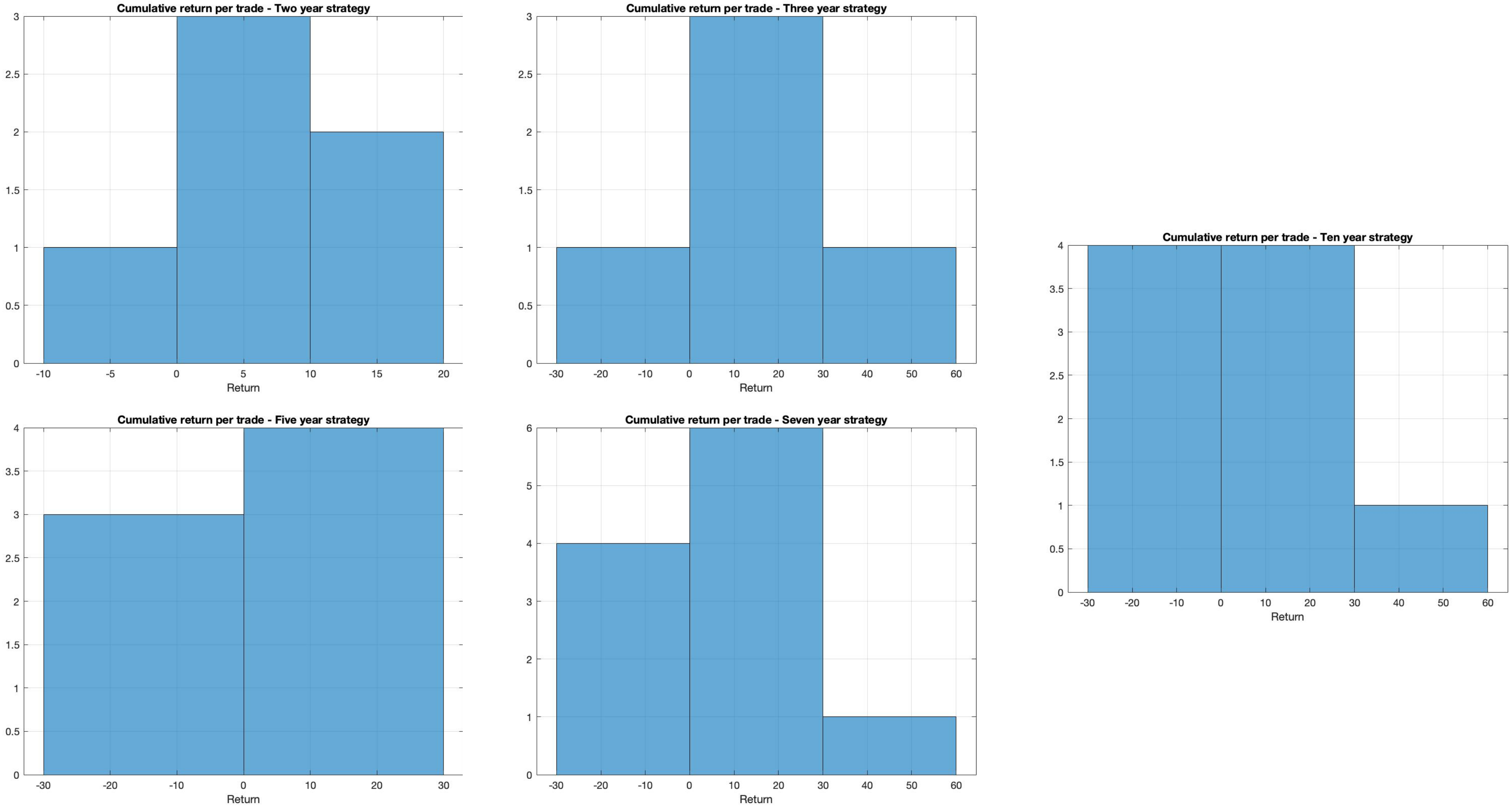


Figure 18. These histograms show the distribution of the cumulative return per trade for the long positions of different maturities.

Appendix O: Correlation matrices between return indices

TABLE 7 - Correlation matrix - Two year strategy

Two-year strategy	US	UK	Japan
US	1,0000		
UK	0,0807	1,0000	
Japan	-0,0658	0,0521	1,0000

Notes: Correlations between the return indicies between the three countries.

TABLE 8 - Correlation matrix - Three year strategy

Three-year strategy	US	UK	Japan
US	1,0000		
UK	-0,0765	1,0000	
Japan	-0,1701	0,0841	1,0000

Notes: Correlations between the return indicies between the three countries.

TABLE 9 - Correlation matrix - Five year strategy

Five-year strategy	US	UK	Japan
US	1,0000		
UK	0,1200	1,0000	
Japan	0,0013	0,0470	1,0000

Notes: Correlations between the return indicies between the three countries.

TABLE 10 - Correlation matrix - Seven year strategy

Seven-year strategy	US	UK	Japan
US	1,0000		
UK	0,1371	1,0000	
Japan	0,0073	0,0516	1,0000

Notes: Correlations between the return indicies between the three countries.

TABLE 11 - Correlation matrix - Ten year strategy

Ten-year strategy	US	UK	Japan
US	1,0000		
UK	0,2920	1,0000	
Japan	-0,0090	0,1699	1,0000

Notes: Correlations between the return indicies between the three countries.

Appendix P: Sharpe ratios of cross-country diversified return indices

TABLE 12 - Sharpe ratios of cross-country diversified return indices

Strategy	N	Sharpe ratio	N	Sharpe ratio
SS2 - US	271	0,066	246	0,260
SS3 - US	271	0,068	246	0,341
SS5 - US	271	0,012	246	0,159
SS7 - US	271	0,109	246	0,288
SS10 - US	271	0,137	246	0,345
SS2 - UK	246	0,195	246	0,285
SS3 - UK	246	0,239	246	0,391
SS5 - UK	246	0,232	246	0,201
SS7 - UK	246	0,237	246	0,320
SS10 - UK	246	0,200	246	0,372
SS2 - Japan	246	0,322	246	0,274
SS3 - Japan	246	0,479	246	0,359
SS5 - Japan	246	0,116	246	0,173
SS7 - Japan	246	0,211	246	0,294
SS10 - Japan	246	0,327	246	0,375

Note: This table reports the number of observations and Sharpe ratios of the diversified and undiversified portfolios of the domestic Japanese-, UK-, and US-investor. N is the number of observations in the sample period. The number of observations and the Sharpe ratios of the undiversified return indices of the strategies is displayed in the grey area, while the Sharpe ratios and the number of observations for the diversified return indices are displayed in the white area. The sample period for the undiversified return indices for the US is from the end of June 1996 to the end of December 2018. The sample period for the undiversified return indices for the UK and Japan are from the end of July 1998 to the end of December 2018. The diversified sample period is from the end of July 1998 to the end of December 2018.

Appendix Q: Regression results

TABLE 13 - Regression results without noise measure

			t-Statistics												
Strategy	α	t-Statistic	Market return	SMB	HML	RMW	CMA	UMD	BAB	Bank stock return index	Corporate bond return index	ICR	Term tradable	Credit tradable	R^2
SS2 - US	-0,701	-1,001	0,103	0,063	-0,856	0,043	0,866	0,412	0,537	0,706	0,346	1,017	-1,035	-0,940	0,070
SS3 - US	-1,033	-1,432	-0,945	-0,500	-1,573	-1,188	0,792	-0,744	1,361	1,337	0,543	1,490	1,912*	1,950*	0,126
SS5 - US	-1,250	-1,622	-0,064	0,072	-0,367	-1,496	0,297	0,067	0,896	0,347	0,529	1,537	0,302	1,458	0,094
SS7 - US	-0,833	-1,282	-0,122	-0,100	-0,501	-0,814	1,062	1,238	-0,762	0,060	1,293	1,478	1,095	3,188***	0,117
SS10 - US	-1,238	-2,071**	-0,509	0,248	0,102	-0,416	-0,512	0,997	-0,757	0,513	1,078	2,221**	1,823*	2,601***	0,087
EW - US	-1,011	-1,915*	-0,485	-0,023	-1,076	-1,234	0,739	0,554	0,443	0,863	0,988	1,983**	1,028	1,574	0,100
SS2 - UK	-0,591	-1,098	-0,126	-0,636	-0,133	N/A	N/A	-0,600	0,384	0,850	1,649	1,447	-0,841	0,173	0,053
SS3 - UK	-0,498	-0,948	0,086	0,062	0,954	N/A	N/A	-0,367	1,549	0,275	1,207	1,163	-1,126	-0,278	0,057
SS5 - UK	-0,558	-0,769	-0,608	0,545	-0,073	N/A	N/A	0,399	0,569	-0,121	1,134	0,982	-0,623	0,372	0,043
SS7 - UK	-0,075	-0,111	-0,711	0,963	0,478	N/A	N/A	-0,285	-0,335	-0,024	0,592	0,424	0,081	0,425	0,020
SS10 - UK	-0,745	-1,076	0,088	0,825	0,558	N/A	N/A	-0,131	0,599	-0,565	1,740*	1,291	0,168	0,144	0,049
EW - UK	-0,493	-0,933	-0,280	0,470	0,423	N/A	N/A	-0,188	0,581	0,026	1,559	1,191	-0,628	0,191	0,048
SS2 - Japan	0,425	0,671	2,107**	-1,195	2,133**	0,622	-1,327	1,084	0,453	-1,746*	-0,183	-0,451	-0,750	-1,278	0,079
SS3 - Japan	0,164	0,226	1,665*	0,560	2,394**	-0,402	-2,812***	1,702*	0,544	-2,336**	-1,329	-0,195	-0,939	-1,455	0,153
SS5 - Japan	0,597	0,723	0,757	1,647	2,295**	-0,419	-3,204***	0,987	-0,854	-2,016**	-1,229	-0,863	-0,275	-0,336	0,142
SS7 - Japan	-0,528	-0,587	-0,430	1,167	1,205	0,304	-1,853*	1,621	-2,082**	-0,313	-0,499	0,526	0,926	0,491	0,115
SS10 - Japan	-0,398	-0,449	0,343	-0,500	0,475	-0,435	-2,101**	1,060	-0,843	-0,270	0,461	0,691	1,744*	0,824	0,055
EW - Japan	0,052	0,093	1,600	0,938	2,642***	-0,032	-3,595***	2,048**	-0,949	-2,321**	-0,770	-0,024	0,260	-0,409	0,164

Note: This table reports the t-statistics for the regression of monthly excess returns and the corresponding alpha of each strategy. The sample period for the US is from the end of June 1996 to the end of September 2018. The sample period for the UK is from the end of July 1998 to the end of December 2017, and Japan is from the end of July 1998 to the end of October 2018. SS2 are the strategy using 2-year maturities, SS3 are the strategy using 3-year maturities, and similarly for SS5, SS7, and SS10. The EW strategy consists of taking an equally-weighted (on notional amount) position each month in each individual-maturity strategy. The t-statistics are corrected for heteroscedasticity and serial correlation by using the Newey-West standard errors and automated bandwidth (or truncation lag) selection suggested by Andrews (1991). The market return is the excess return collected from Fama-French. SMB, HML, RMW, CMA, and UMD are the Fama-French small-minus-big, high-minus-low, robust-minus-weak, conservative-minus-aggressive, and up-minus-down factors. BAB is the betting against beta equity factor. Bank stock return index is the excess return on the S&P bank stock index for the US, excess return on the FTSE bank stock index for the UK, and excess return on the Nikkei bank stock index for Japan. Corporate bond return index is the excess return on a BBB rated corporate bond index for the US and excess return on a corporate bond total return index for the UK and Japan. ICR is the intermediary capital ratio, which is a broker-dealer risk factor constructed by He et al. (2017). Term and Credit tradable are the excess return of Treasuries with 7- to 10-years to maturity, and excess return of BBB-rated bonds over Treasuries with 7- to 10-years to maturity.
*** p<0.01, ** p<0.05, * p<0.1

TABLE 14 - Regression results with noise measure

			t-Statistics													
Strategy	α	t-Statistic	Market return	SMB	HML	RMW	CMA	UMD	BAB	Bank stock return index	Corporate bond return index	ICR	Term tradable	Credit tradable	Noise	R^2
SS2 - US	-0,560	-0,751	-0,074	0,135	-0,895	0,166	0,850	0,392	0,414	0,763	0,554	1,165	-1,098	-0,929	-0,371	0,077
SS3 - US	-0,733	-1,067	-1,067	-0,286	-1,650*	-0,940	0,841	-0,799	1,112	1,368	0,609	1,522	1,838*	1,860*	-0,812	0,132
SS5 - US	-0,240	-0,334	-0,300	0,188	-0,853	-0,719	0,679	0,044	0,233	0,363	0,356	1,281	0,150	1,478	-2,002**	0,129
SS7 - US	-0,389	-0,578	-0,203	-0,073	-0,670	-0,476	1,243	1,272	-1,108	0,022	1,033	1,220	1,071	3,489***	-1,176	0,128
SS10 - US	-0,999	-1,585	-0,577	0,248	0,081	-0,196	-0,485	1,074	-1,051	0,471	0,907	2,060**	1,832*	2,688***	-0,583	0,092
EW - US	-0,584	-1,145	-0,667	0,076	-1,293	-0,701	0,932	0,577	0,029	0,880	0,882	1,822*	0,921	1,463	-1,297	0,112
SS2 - UK	-0,039	-0,091	-0,229	-0,483	-0,184	N/A	N/A	-0,697	-0,432	0,323	1,493	2,125**	-0,792	0,267	-2,009**	0,072
SS3 - UK	-0,173	-0,314	0,034	0,155	0,950	N/A	N/A	-0,397	0,749	0,002	1,165	1,280	-1,105	-0,268	-0,767	0,064
SS5 - UK	-0,336	-0,449	-0,599	0,590	-0,126	N/A	N/A	0,291	0,311	-0,306	1,119	1,011	-0,599	0,404	-0,503	0,047
SS7 - UK	0,027	0,042	-0,732	0,973	0,517	N/A	N/A	-0,243	-0,390	-0,026	0,489	0,399	0,111	0,442	-0,163	0,021
SS10 - UK	-0,333	-0,527	-0,026	0,905	0,509	N/A	N/A	-0,186	0,130	-0,805	1,622	1,288	0,215	0,208	-0,875	0,057
EW - UK	-0,171	-0,338	-0,363	0,558	0,406	N/A	N/A	-0,233	0,069	-0,214	1,437	1,256	-0,585	0,261	-0,792	0,058
SS2 - Japan	-0,078	-0,091	2,072**	-1,233	2,071**	0,659	-1,213	1,099	0,671	-1,630	0,226	-0,115	-0,760	-1,098	1,058	0,090
SS3 - Japan	-0,272	-0,283	1,682*	0,441	2,370**	-0,372	-2,786***	1,619*	0,727	-2,369**	-0,887	0,087	-1,014	-1,397	0,950	0,165
SS5 - Japan	1,285	1,403	0,930	1,730*	2,285**	-0,569	-3,263***	0,864	-1,015	-2,295**	-1,333	-1,023	-0,356	-0,753	-1,475	0,165
SS7 - Japan	0,302	0,332	-0,354	1,301	1,222	0,150	-2,093**	1,588	-2,577**	-0,617	-0,740	0,315	0,983	0,275	-2,093**	0,142
SS10 - Japan	-0,007	-0,007	0,358	-0,408	0,418	-0,496	-2,145**	1,001	-0,988	-0,361	0,459	0,633	1,712*	0,741	-1,079	0,062
EW - Japan	0,246	0,449	1,700*	1,042	2,591***	-0,117	-3,650***	1,965**	-0,983	-2,527**	-0,706	-0,011	0,158	-0,618	-0,713	0,173

Note: This table reports the t-statistics for the regression of monthly excess returns and the corresponding alpha of each strategy. The sample period for the US is from the end of June 1996 to the end of December 2016. The sample period for the UK and Japan are from the end of July 1998 to the end of December 2016. SS2 are the strategy using 2-year maturities, SS3 are the strategy using 3-year maturities, and similarly for SS5, SS7, and SS10. The EW strategy consists of taking an equally-weighted (on notional amount) position each month in each individual-maturity strategy. The t-statistics are corrected for heteroscedasticity and serial correlation by using the Newey-West standard errors and automated bandwidth (or truncation lag) selection suggested by Andrews (1991). The market return is the excess return collected from Fama-French. SMB, HML, RMW, CMA, and UMD are the Fama-French small-minus-big, high-minus-low, robust-minus-weak, conservative-minus-aggressive, and up-minus-down factors. BAB is the betting against beta equity factor. Bank stock return index is the excess return on the S&P bank stock index for the US, excess return on the FTSE bank stock index for the UK, and excess return on the Nikkei bank stock index for Japan. Corporate bond return index is the excess return on a BBB rated corporate bond index for the US and excess return on a corporate bond total return index for the UK and Japan. ICR is the intermediary capital ratio, which is a broker-dealer risk factor constructed by He et al. (2017). Term and Credit tradable are the excess return of Treasuries with 7- to 10-years to maturity, and excess return of BBB-rated bonds over Treasuries with 7- to 10-years to maturity. Noise is a liquidity measure constructed by Hu et al. (2013).

*** $p<0.01$, ** $p<0.05$, * $p<0.1$