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FIXED-INCOME ARBITRAGE STRATEGIES: SWAP SPREAD ARBITRAGE AND YIELD CURVE ARBITRAGE

Master's Thesis
Department of Finance
November 2012

UNIVERSITY OF OULU Oulu Business School	ABSTRACT OF THE MASTER'S THESIS

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Title Fixed-income arbitrage strategies: swap spread arbitrage and yield curve arbitrage			
Subject Finance	Type of the degree M.Sc. in Econ.&Bus.Adm.	Time of publication November 2012	Number of pages 65

Abstract

There is a mythical question, well described by Duarte, Longstaff and Yu (2006), whether fixed-income arbitrage strategies are truly arbitrage or merely strategies that earn small positive returns most of the time, but occasionally experience dramatic losses. The question can be summarized in the anecdote “picking up nickels in front of a steamroller”. This master’s thesis studies two of these specific fixed-income arbitrage strategies: Swap Spread Arbitrage and Yield Curve Arbitrage.

The methodology used in this master’s thesis is to apply these two arbitrage strategies through time from November 1988 to December 2011, using R language coding developed by the author of the master’s thesis, and to analyze their risk and return characteristics. The data used in this master’s thesis was gathered from different sources such as: Bloomberg™, Federal Reserve System (FED), Thompson Reuters Datastream™, Federal Reserve Bank of St. Louis, Kenneth French and Yahoo® Finance.

The main hypothesis of this thesis is that the global financial crisis of 2008 had a big impact on these strategies return indexes. This proved to be wrong. These two fixed-income arbitrage strategies seem profitable on the long run even under financial crisis cycles, as they generate positive excess returns, and Yield Curve Arbitrage strategy even with significant α.

Keywords
portfolio returns, global financial crisis, two-factor affine model, excess returns

Additional information

ACKNOWLEDGEMENTS

I would sincerely like to thank Ph.D. and Head of Finance Department Hannu Kahra for supervising, guiding and commenting on this work throughout the whole process, from choosing the topic to approving the master's thesis.

I would also like to thank Mr. Mikko Kauppila for supporting me in innumerous sessions at the Oulu Business School, gathering data from the Bloomberg™ and Thompson Reuters Datastream™ terminals.

Furthermore, I want to thank Nokia Siemens Networks, my employer, personified in Mr. Vesa Kohtamäki, my previous superior, for supporting me in this endeavor by leveraging the Nokia Siemens Networks flexible working hour's policy. Furthermore, my thanks to Mr. Joachim Ungruh and Mr. Max Laiho, my current superiors, who both allowed me to use Nokia Siemens Networks study leave absence time in order to complete my master's thesis. The flexibility and advantages of the global Nokia Siemens Networks long term education policy greatly helped me to achieve this life goal.

Sincere thanks to Ms. Jonna Käsmä, my life partner, for proofreading the text and for suggesting improvements on the language, as well as for her patience and support.

My heartfelt thanks to my father, Mr. Carlos Francisco de Figueiredo Filho, who always supported and inspired me to succeed in this M.Sc. degree and life achievement. I will never forget his advice saying that "when one has something important to achieve, she / he forgets about everything else and focuses on it", or, in Portuguese, "quando há algo muito importante a se fazer, concentra-se naquilo e abandona-se as outras coisas", or simply "abandona tudo".

Carlos Francisco de Figueiredo Neto

Oulu, Finland, November 2012

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1. INTRODUCTION

There is a mythical question, well described by Duarte, Longstaff and Yu (2006), whether fixed-income arbitrage strategies are truly arbitrage or merely strategies that earn small positive returns most of the time, but occasionally experience dramatic losses. The question can be summarized in the anecdote “picking up nickels in front of a steamroller”. This master’s thesis studies two of these specific fixed-income arbitrage strategies: Swap Spread Arbitrage and Yield Curve Arbitrage.

Duarte, Longstaff and Yu (2006), studied this question for five fixed-income arbitrage strategies in their article “Risk and Return in Fixed-Income Arbitrage: Nickels in Front of a Steamroller?”. However, they used data from November 1988 until December 2004, so they analyzed these strategies over a period which included one major global financial crisis, the global financial crisis of 1998. My hypothesis is that their conclusions on executing Swap Spread and Yield Curve arbitrage strategies from 1988 until 2004, saying that these strategies are profitable, for instance, will not hold when also the 2008 global financial crisis is taken into account.

The research method used in my master’s thesis is based on gathering data from trustworthy commercial and academic sources, developing and simulating mathematical models for the fixed-income arbitrage strategies and finally making the linear regression analysis of their returns controlled by an eighteen-factor-list. Mitchell and Pulvino (2001) and Duarte, Longstaff and Yu (2006) used similar approaches; however, the approach of regressing returns to the eighteen-factor-list was inspired on the work of Hannu Kahra (2011).

The main hypothesis is that the global financial crisis of 2008 had a big impact on these strategies return indexes. This proved to be wrong. These two fixed-income arbitrage strategies seem profitable on the long run even under financial crisis cycles.

In order for a reader to understand the subject of this master’s thesis, some basic concepts and definitions will be introduced at appendix 1.

After this introductory chapter, I will move on to the main hypothesis of this work and the methodology used to obtain the results. Specific data descriptions, their sources and some assumptions on the data are also described in chapter 2.

Next, both arbitrage strategies on the scope of this master's thesis, i.e. swap spread arbitrage strategy and yield curve arbitrage strategy, are described in detail in chapters 3 and 4 respectively. For each of these strategies, there is first a detailed description on how the strategy works, including some graphics which visually depict the strategy and the arbitrage opportunities. Also, some numeric examples are provided to enhance the understandability of the text explaining the strategies. For each of these strategies' descriptions, details on the transaction costs, the valuation procedure to present value of return indexes and their normalization by adjusting them to a fix annualized volatility of 10% are also described. Figures with the results for each of the strategies with data from both Bloomberg™ and Thompson Reuters Datastream™ are presented. In appendices 2 and 4, tables with results for each of these strategies with data from both Bloomberg™ and Thompson Reuters Datastream™ are presented.

The conclusions from the results of each strategy are presented both separately and in contrast with the main hypothesis in chapter 5. A linear regression analysis is done in order to find a possible α for the strategies, as well. Appendices 7, 8, 9 and 10 present the linear regression analysis results. A final conclusion using all results is also laid out in chapter 5.

In appendix 3, there is a thorough deduction of the two-factor affine model. It takes some degree of intellectual capital to obtain the model. In appendix 4, a high level description of the structure of the over thousand five hundred lines of R language based coding created during this master's thesis is provided. Finally, all references to academic and non-academic sources are listed.

2. HYPOTHESIS AND METHODOLOGY

2.1 Hypothesis

My hypothesis is that the conclusions for executing swap spread and yield curve arbitrage strategies from 1988 until 2004, which include only the global financial crisis of 1998, will not hold when also the 2008 global financial crisis is taken into account.

If confirmed, at least from the perspective of swap spread and yield curve arbitrage strategies, this hypothesis may give more arguments to the affirmation “fixed-income strategies just earn small positive returns most of the time, but occasionally experience dramatic losses”, however if not confirmed, more arguments towards the assertion “these two fixed-income arbitrage strategies seem profitable on the long run even under financial crisis cycles” can be laid out.

2.2 Methodology

At subchapters 2.2.1 and 2.2.2 the gathering data part of the research method is presented. For the part of the research method concerned on developing and simulating mathematical models for the fixed-income arbitrage strategies, appendix 4 describes in high level R language based coding logic and appendix 2 deducts the two-factor affine model required for the yield curve arbitrage strategy. Other details on the implementation of the strategies are described on the respective strategy chapter.

Concerning making the linear regression analysis of their returns controlled by an eighteen-factor-list part of the research method, there is a specific subchapter at chapter 5, called risk adjusted returns, where the details of the linear regression analysis are listed.

2.2.1 Arbitrage strategies data description

The data used in this master's thesis was gathered from difference sources such as Bloomberg™, Federal Reserve System (FED) and Thompson Reuters Datastream™.

The month-end-date data series obtained from the FED website (http://www.federalreserve.gov/) were the one-year, two-year, three-year, five-year, seven-year and ten-year Constant Maturity Treasury (CMT) rates.

The data series obtained from Bloomberg™ and Thompson Reuters Datastream™ terminals at the Oulu Business School at the University of Oulu were (note: all of these rates are based on end-of-trading-day):

- Three-month Libor month-end-date rates
- One-year, two-year, five-year, seven-year and ten-year midmarket Constant Maturity Swap (CMS) rates
- Three-month general collateral repo rates

First, I ran an R-language based coding, which I developed myself, on the data until December 2004, which includes the 1998 global financial crisis. After that, I ran it again but then using data until December 2011, which includes the 1998 and 2008 global financial crises.

When both results were available (i.e. until 2004 and until 2011), comparison could be made and the final conclusions were summarized in chapter 5.

Some bits of data were neither available from Bloomberg™ nor from Thompson Reuters Datastream™. I therefore had to make some assumptions and approximations in order to proceed with the master's thesis analysis.

Firstly, the one-year maturity CMS monthly rates were not available from 30.11.1988 until 31.5.1996. We know there is correlation between different maturity yield curves, so taking the difference between the monthly one-year maturity CMS and the two-year maturity CMS rates from 28.06.1996 until 30.12.2011 I got the following statistics: mean = 0.2791 and standard deviation = 0.3116.

With the premise that I didn't have access to other commercial data bases such as Citigroup™, which was used for instance by Duarte, Longstaff and Yu (2006) to obtain such data, for the sake of simplicity, I assumed the one-year maturity CMS monthly rates from 30.11.1988 until 31.5.1996 to be equal to the two-year maturity CMS rates (form the same time span) minus 0.2791. This approach is reasonable since the two-year maturity CMS yields on such period were between 4% and 10%.

Also other approaches could have been made. One example of such would be to find a least residuals ARMA model for monthly rate differences from 28.06.1996 to 30.12.2011 and simulate, based on this ARMA model, the one-year maturity CMS monthly rate from 30.11.1988 until 31.05.1996.

Secondly, similarly to the one-year maturity CMS monthly rates, the three-month general collateral repo monthly rate was available only from 29.10.1999 onwards. The market for generalized collateral (GC) repo agreements began in January 1996. GC repos became a more satisfactory indicator of expectations of future interest rates after March 1997. Prior to this date the only available short maturity assets we could use would be Treasury bills. Therefore I assumed that from 30.11.1988 until 29.10.1999, the three-month CMT monthly rates represent a very good estimation of the three-month general collateral repo monthly rates in the same period.

Obviously another valid approach would have been to start the whole arbitrage strategies analysis from 29.10.1999 onwards; however, I didn't take this approach because the idea was to generate a tool to analyze both arbitrage strategies through the global financial crisis of 1998 and of 2008. Once such data for the one-year maturity CMS monthly rates (up to 31.5.1996) and three-month general collateral repo monthly rate (up to 29.10.1999) are available from other commercial databases, these assumptions above can be revoked, the R-language coding generated during the master's thesis can be easily re-executed and the results re-analyzed.

2.2.2 Linear regression analysis data description

The data for the regression analysis was gathered from diverse sources.

I used the FRED (Federal Reserve Economic Data) database from the Federal Reserve Bank of St. Louis to assemble the monthly data for: TWEXMMTH, AAA, TB3MS, BAA, GS30, TP30A28 and CPF3M.

Data series obtained from Thompson Reuters Datastream™ were gathered for: MSUSUAM, MSWXUS, MSEMKF, USMGUSRI, USMGEXRI, ECUSD1M, GOLDBLN, BMUS30Y, JPUS3ML, MSVWLD$, MSGWLD$, MSSAWF$, MSLAWF$, BMUS10Y and SP500.

The data for the three-month Euro- Dollar deposit rate (EDM3) was gathered from the FED economic and research data H15 database, three-month Eurodollar deposits (London), at http://www.federalreserve.gov/releases/h15/data.htm , which cite the sources as Bloomberg and CTRB ICAP Fixed Income & Money Market Products.

MOM, the average of the returns on two (big and small) high prior return portfolios minus the average of the returns on two low prior return portfolios returns, or in other words the Fama and French momentum factor was obtained from Kenneth French at http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html.

For more details and the descriptions of the indexes listed above, please see appendix 3.

3. SWAP SPREAD ARBITRAGE STRATEGY

As Duarte, Longstaff and Yu (2006) described, the swap spread arbitrage strategy is composed of two legs. Firstly an arbitrageur enters into a par swap and receives a fixed coupon rate CMS and pays the floating Three-month Libor. Secondly the arbitrageur shorts a par Treasury bond (CMT) with the same maturity as the CMS and invests the proceeds on a margin account earning the three-month general collateral repo rate, i.e. the arbitrageur pays the fixed coupon rate of the Treasury bond CMT and receives three-month general collateral repo rate from the margin account.

For the cash flow from the combination of the two legs, we have the arbitrageur receiving fixed annuity SS = CMS - CMT and paying floating spread S = Libor – Repo. Likewise, we will later on realize that also the opposite strategy will need to be implemented. For such, the cash flow is the arbitrageur paying fixed annuity SSo = CMS - CMT and receiving floating spread So = Libor – Repo.

In short, the swap spread arbitrage strategy is the bet on whether the fixed annuity (SS) or the floating spread (So) received will be larger than the floating spread (S) or the fixed annuity (SSo) paid respectively, on a monthly basis.

Figure 1 below depicts the three-month floating spread versus swap spread for two, three, five, seven and ten years maturity. They show arbitrage opportunities.

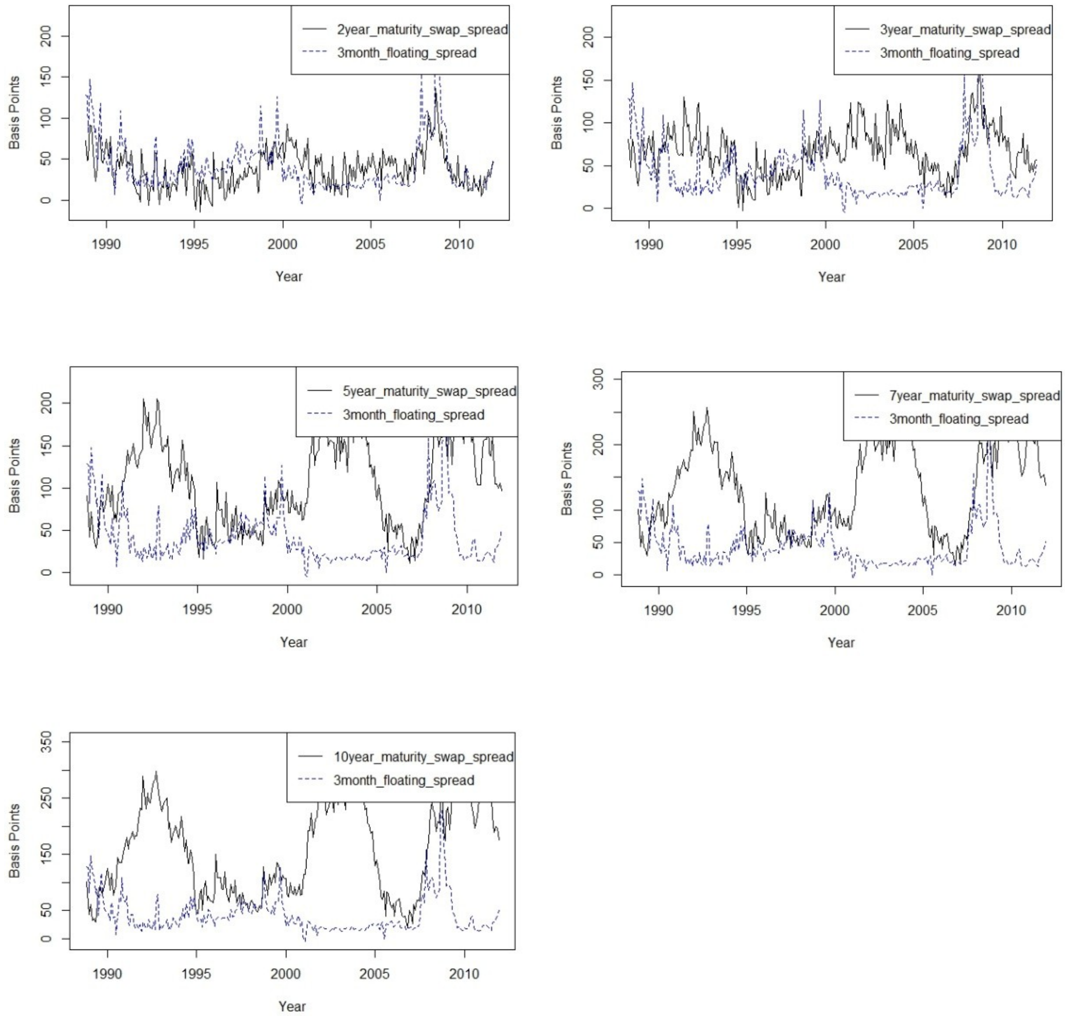

Figure 1: Three-month floating spread versus swap spread for 2, 3, 5, 7 and 10 years maturity.

To construct the return index, we determine for each month from November 1988 to December 2011, whether the current swap spread differs from the current value of the short term spread. If the difference exceeds a trigger value of 10 basis points, we implement the trade for a \$100 notional position (receive fixed on a \$100 notional swap, short a \$100 notional Treasury bond, or vice versa if the difference is less than -10 basis points). If the difference does not exceed the trigger, then the strategy invests in cash and earns an excess return of zero. We keep the trade on, until it converges (i.e. the swap spread converges to the short term spread) or until the maturity of the swap and Treasury bond.

Let me illustrate this strategy with one small example. For instance, let's take the 3 years maturity swap. Assuming we are on the closing of November 1988, the swap spread is the CMS minus CMT, in this case 9.48% - 8.72% = 0.76 %, or in other words 76 basis points. The respective short term spread is three-month Libor minus three-month repo rate, i.e. 9.31% - 8.03% = 1.28% or 128 basis points. The difference is then 76 – 128 = -52 basis points, which is less than -10 basis points, so we will implement the trade for a $100 notional position. This means we will receive on a $100 notional on the floating, i.e. $1.28 and pay fixed on a $100 notional swap, i.e. $0.76 plus the transactions costs of this transaction ($ 0.1103125, see more details on the assumptions for the transactions costs on the next paragraph), therefore profiting $0.4096875, in this case. In terms of excess return this means 0.4097% - 7.76% /12 = -0.23697%. We will keep this trade on, until it converges, i.e. the swap spread converges to the short term spread or until the maturity of the swap and bond. On the next month, December 1988, we would start a new trade if the difference exceeds the 10 basis points trigger (or is less than -10 basis points) and the return index is the equally weighted average of the returns of the two trades so far. Every month we repeat this process, ending up with multiple trades each month. Note that when the respective swap matures, the trade cease to exists, therefore there will be a range from zero to 36 trades in any given month for the 3-year maturity Swap strategy, from which the equally weighted average of the returns of these trades make the return index for that month for the swap spread arbitrage strategy.

The return index calculation from the swap spread arbitrage strategy takes into account transaction costs in initializing or termination positions, such costs are assumed to be relatively large in comparison to those paid by large institutional investors such as major fixed income arbitrage hedge funds, so that those estimated transaction costs can be assumed as conservative and realistic. I assumed 1 basis point for the swap bid-ask spread, 10 basis point for the Repo bid-ask spread and 1/32 of basis points for the Treasury bond bid-ask spread similarly as Duarte, Longstaff and Yu (2006). For the valuation of the return index to present value, the cash flows for the return index for each month were discounted by the respective monthly TB3MS rates from that respective month until December 2011.

To have the possibility of the data comparison with Duarte, Longstaff and Yu (2006)'s results, I also adjusted the return index to a fix annualized volatility of 10%.

The figure 2 below, depicts the return indexes for the swap spread arbitrage strategies with two, three, five, seven and ten years maturity, as well as the equally weighted portfolio on all these returns.

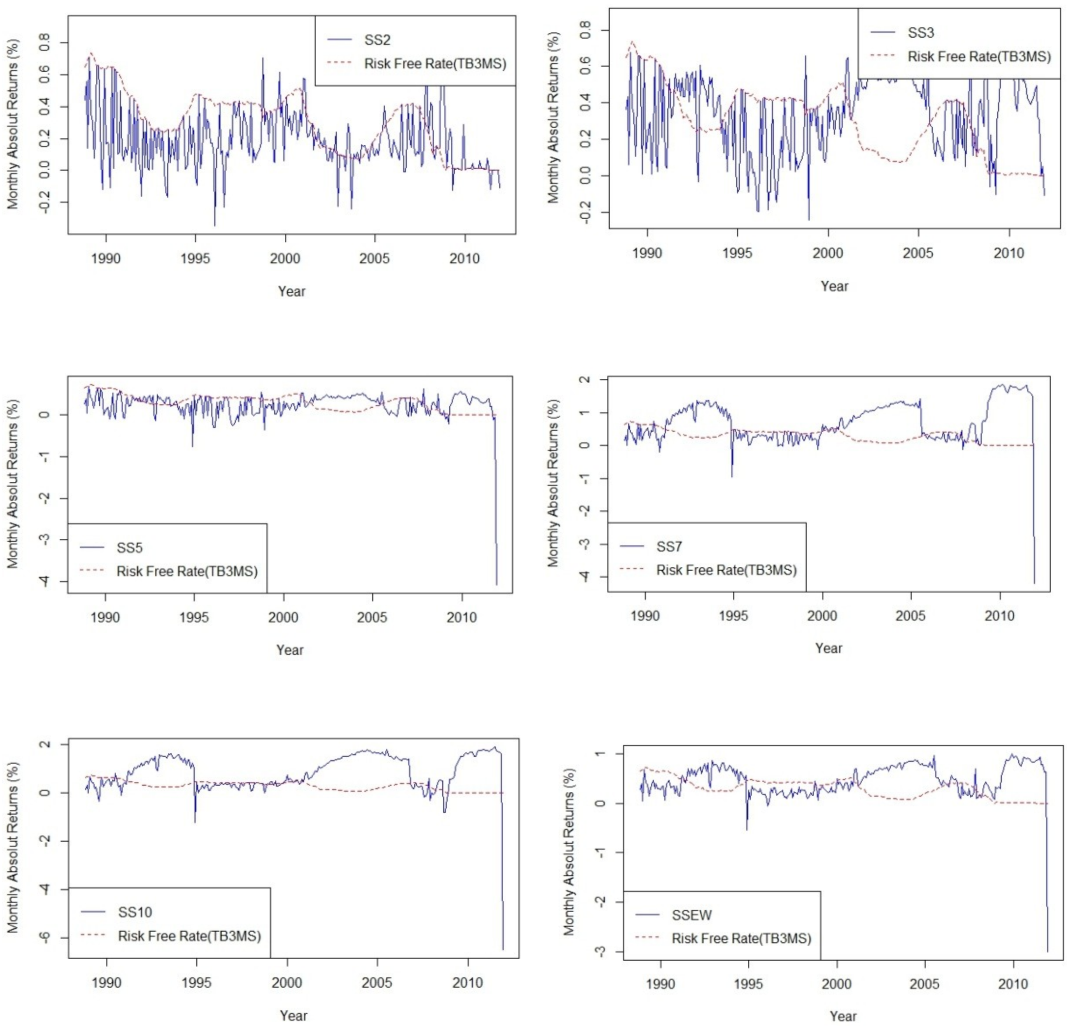

Figure 2: Return indexes for the swap spread arbitrage strategies with 2, 3, 5, 7 and 10 years maturity as well as the equally weighted portfolio on all these returns.

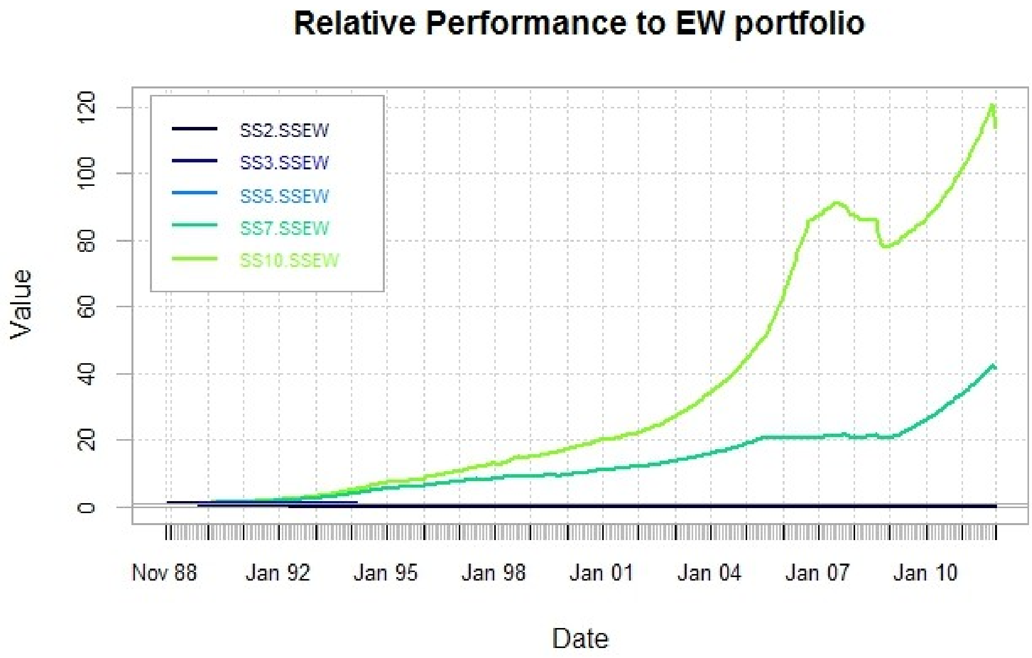

Figure 3: Relative performance of each swap spread arbitrage strategy in relation to the equally weighted portfolio.

In appendix 5, tables 1, 2, 3 and 4 show the summary statistics for the monthly percentage excess returns of swap spread arbitrage strategies with CMS data from Bloomberg™ and from Thompson Reuters Datastream™, until 2004 and until 2011 respectively. Those summary statistics were obtained with R-package PerformanceAnalytics.

4. YIELD CURVE ARBITRAGE STRATEGY

Duarte, Longstaff and Yu (2006) describe yield curve arbitrage strategy as a strategy based on taking long and short positions at different points along the yield curve. It often takes the form of a ‘‘butterfly’’ trade, for instance an arbitrageur may go long on the five-year CMS and short one-year and ten-year CMS.

Firstly, an analysis is applied to identify points along the yield curve, which are either ‘‘rich’’ or ‘‘cheap”, i.e. “rich” means higher price than the analysis valuation model indicates and “cheap” means lower price than the analysis model indicates.

Secondly, the arbitrageur enters into a portfolio that exploits these perceived different valuations by going long and short CMS in a way that minimizes the risk of the portfolio.

Finally, the portfolio is held until the trade converges (or twelve months matures) and the relative values of the CMS come back in line with the analysis valuation model.

Here I assume that the term structure of the analysis valuation model is determined by a two-factor affine model. We then fit the model to match exactly the one-year and 10-year points along the CMS curve each month.

The model is defined in the following way:

We assume that the riskless rate is given by $\mathrm{r_t} = \mathrm{X_t} + \mathrm{Y_t}$, where $\mathrm{X_t}$ and $\mathrm{Y_t}$ follow the dynamics

$$dX = (\alpha - \beta X)\, dt + \sigma dZ_1 \tag{4.1}$$

$$dY = (\mu - \gamma Y)\, dt + \eta dZ_2 \tag{4.2}$$

under the risk-neutral measure, where Z_1 and Z_2 are standard uncorrelated ($\rho = 0$) Brownian motions.

I demonstrate in appendix 2 that the riskless rate can be described as:

$$r_t = X_t + Y_t = \frac{B_{10,y}\left(A_1 - CMS_1(t)\right) - B_{1,y}\left(A_{10} - CMS_{10}(t)\right)}{B_{1,y}B_{10,x} - B_{10,y}B_{1,x}} +$$

$$\frac{B_{10,x}(CMS_1(t) - A_1) - B_{1,x}(CMS_{10}(t) + A_{10})}{B_{1,y}B_{10,x} - B_{1,x}B_{10,y}} \tag{4.3}$$

and the rate for a maturity T swap is, according to the affine model:

$$CMS_T(t) = A_T + B_{T,x}X_t + B_{T,y}Y_t$$

Where:

$$B_{1,x} = \frac{1-e^{-K_x T1}}{K_x T1}, \quad B_{1,y} = \frac{1-e^{-K_y T1}}{K_y T1}, \quad B_{10,x} = \frac{1-e^{-K_x T10}}{K_x T10}, \quad B_{10,y} = \frac{1-e^{-K_y T10}}{K_y T10}$$

$$CMS_1(t) = A_1 + B_{1,x}X(t) + B_{1,y}Y(t)$$

$$CMS_{10}(t) = A_{10} + B_{10,x}X(t) + B_{10,y}Y(t)$$

$$A1 = \theta_x(1 - B_{1,x}) + \theta_y(1 - B_{1,y}) - \frac{{\sigma_x}^2}{2{K_x}^2}\left(1 + \frac{1 - e^{-2K_x T1}}{2K_x T1} - 2B_{1,x}\right) - \frac{{\sigma_y}^2}{2{K_y}^2}\left(1 + \frac{1 - e^{-2K_y T1}}{2K_y T1} - 2B_{1,y}\right) - \frac{\rho\sigma_x\sigma_y}{K_x K_y}\left(1 - \frac{B_{1,x}}{2} - \frac{1 - e^{-2K_y T1}}{2K_y T1} + \frac{1 - e^{-(K_x + K_y)T1}}{(K_x + K_y)T1}\right)$$

$$A10 = \theta_x(1 - B_{10,x}) + \theta_y(1 - B_{10,y}) - \frac{{\sigma_x}^2}{2{K_x}^2}\left(1 + \frac{1 - e^{-2K_xT10}}{2K_xT10} - 2\,B_{10,x}\right)$$
$$- \frac{{\sigma_y}^2}{2{K_y}^2}\left(1 + \frac{1 - e^{-2K_yT10}}{2K_yT10} - 2\,B_{10,y}\right)$$
$$- \frac{\rho\sigma_x\sigma_y}{K_xK_y}\left(1 - \frac{B_{10,x}}{2} - \frac{1 - e^{-2K_yT10}}{2K_yT10} + \frac{1 - e^{-(K_x + K_y)T10}}{(K_x + K_y)T10}\right)$$

With the model (4.3) defined, we compute deviations between market valuation and the model valuation for the two- , three-, five- and seven-year CMS rates.

For the sake of validating the used data and affine fitted model, let's visualize the difference between the market swap rates for the indicated horizons and the corresponding values implied by the two-factor affine model fitted to match exactly the one-year and 10-year swap rates.

In figure 4 below, we have such differences in basis points:

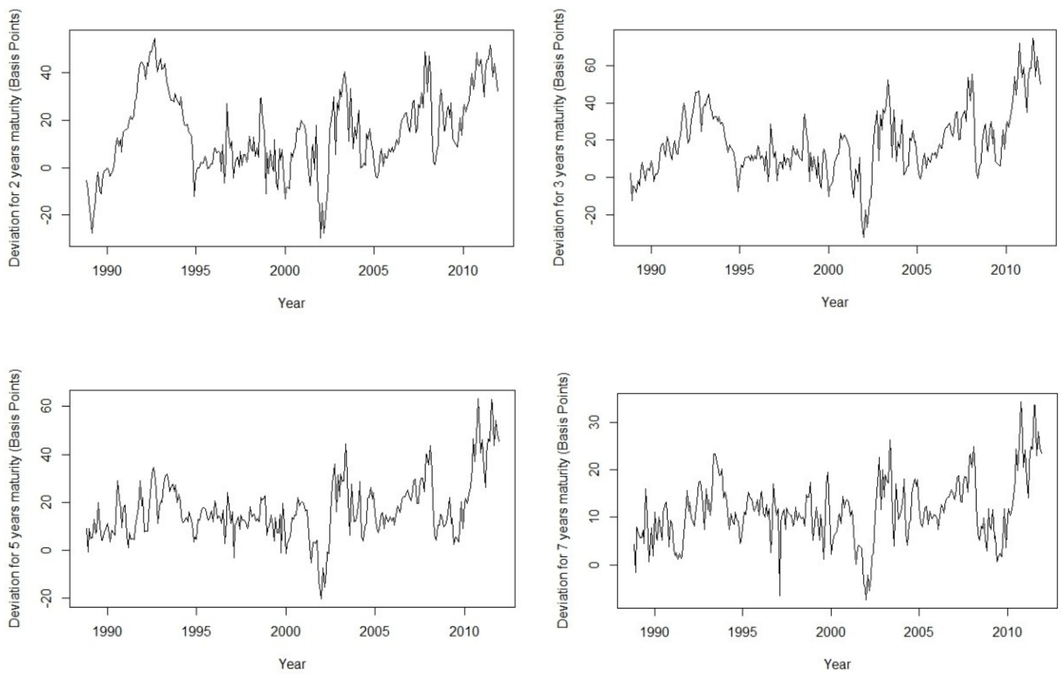

Figure 4: Difference between the market swap rates for the indicated horizons and the corresponding values implied by the two-factor affine model fitted.

Now we just need to determine which of those valuation differences are either ‘‘rich’’ or ‘‘cheap”, and then implement the ‘‘butterfly’’ trade.

Let’s have one illustrative example as well; taking seven-year CMS rate on 31st November 1988, we get 9.68%, whereas the affine model valuation gives:

$$CMS_7(t) = A_7 + B_{7,x}\, X(t) + B_{7,y}\, Y(t)$$

$\mathrm{A_7} = 0.0157476$

$\mathrm{B_{7,x}} = 0.9612305$

$\mathrm{X(t)} = 10.5700621$

$\mathrm{B_{7,y}} = 0.2965492$

$\mathrm{Y(t)} = -1.3996613$

$\mathrm{CMS_7(t)} = 0.0157476 + 0.9612305*10.5700621 + 0.2965492*(-1.3996613)$

$\mathrm{CMS_7(t)} = 9.76\%$

So, based on the affine model valuation we can conclude that the market seven-year CMS rate on 31st November 1988 is “cheap”, because it is 8 basis points below the fitted model valuation, so we will implement the following “butterfly” strategy: going short (paying fixed) $100 notional of seven-year CMS and going long a portfolio of one-year and 10-year CMS with the same sensitivity to the two affine factors as the seven-year CMS. Once this “butterfly” trade is put on, it is held for 12 months or until the market seven-year CMS rate converges to the model valuation.

The same process would continue for each month, with either a trade similar to the above, the reverse trade of the above, or no trade at all (in which case the strategy invests in cash and earns zero excess return).

Unlike the swap spread strategy, yield curve strategy involves a high degree of ‘‘intellectual capital’’ to implement both the process of identifying arbitrage opportunities and the associated hedging strategies require the application of a multi-factor term structure model.

Similarly to the swap spread arbitrage strategy, the return index calculation for this arbitrage strategy takes into account transaction costs in initializing or termination positions, such costs are assumed to be relatively large in comparison to those paid by large institutional investors such as major fixed income arbitrage hedge funds, so that those estimated transaction costs can be assumed as conservative and realistic. I assumed 1 basis point for the swap bid-ask spread, 10 basis points for the Repo bid-ask spread and 1/32 of basis point for the Treasury bond bid-ask spread.

For the valuation of the return index to present value, the cash flows for the return index for each month were discounted by the respective monthly TB3MS rates from that respective month until December 2011.

To have the possibility of the data validation with Duarte, Longstaff and Yu (2006)’s results, I also adjusted the return index to a fix annualized volatility of 10%.

The five figures below depict the return indexes for the yield curve arbitrage strategies with two, three, five and seven years maturity, as well as the equally weighted portfolio on all these returns.

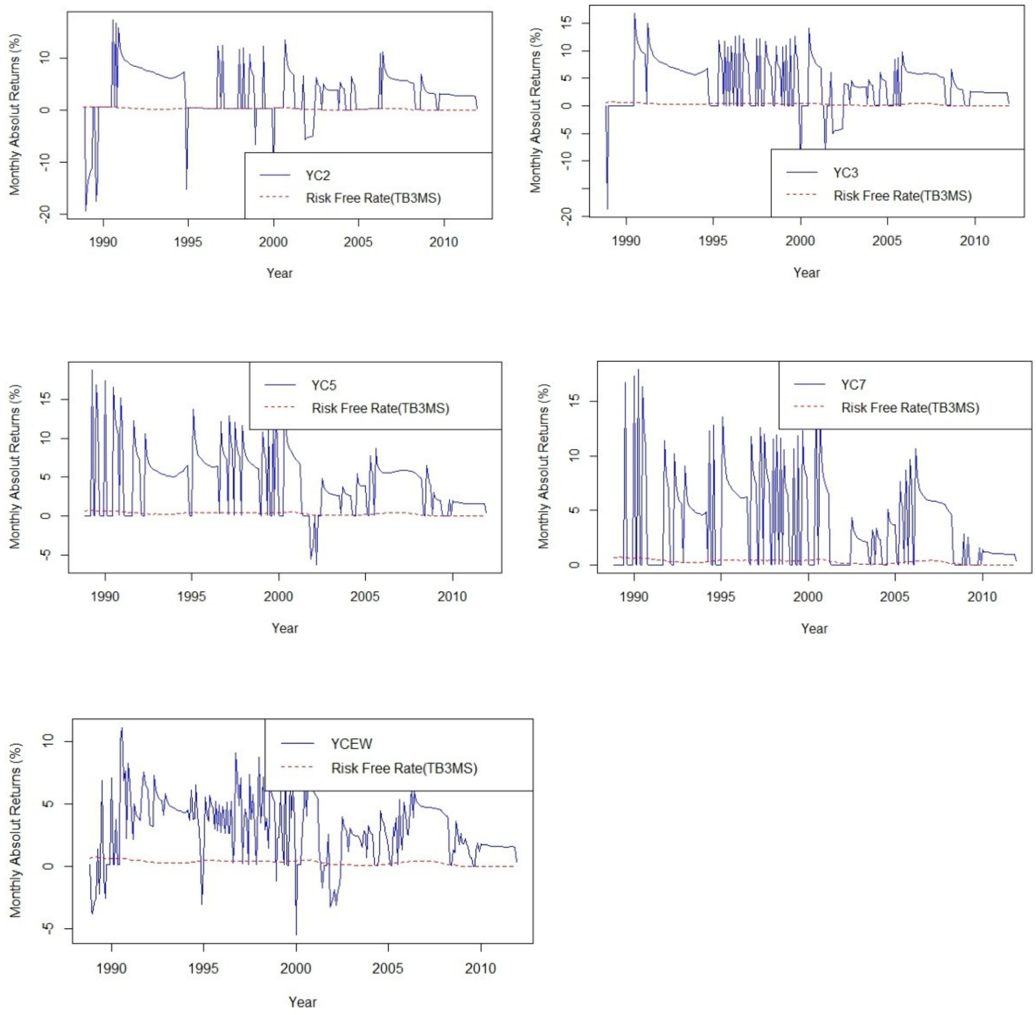

Figure 5: Yield curve arbitrage strategies with 2, 3, 5 and 7 years maturity, as well as the equally weighted portfolio on all these returns.

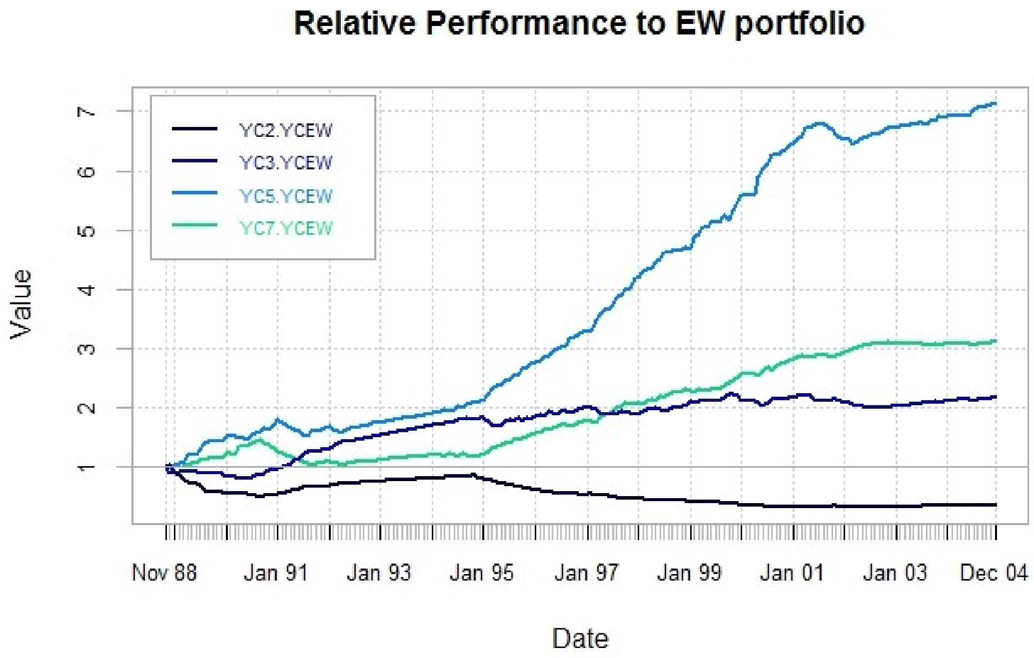

Figure 6: Relative performance of each yield curve arbitrage strategy in relation to the equally weighted portfolio.

At appendix 6, tables 5, 6, 7 and 8 show the summary statistics for the monthly percentage excess returns of yield curve arbitrage strategies with CMS data from Bloomberg™ and from Thompson Reuters Datastream™, until 2004 and until 2011 respectively. Those summary statistics were obtained with R-package PerformanceAnalytics.

5. CONCLUSIONS

5.1 Risk adjusted returns

In order to analyze whether the returns obtained are just a reward to market risks or have any significant α, I regressed the excess returns for the two strategies to an eighteen-factor-list. The list came from the twenty-factor list suggested by Hannu Kahra (2011). The eighteen-factor used on the regression analysis are described in appendix 3.

The linear regression analysis was based on the following equation:

$$Return - Rf = \alpha + \beta_1 MSUSAM + \beta_2 MSWXUS + \beta_3 MSEMKF + \beta_4 USMGUSRI + \beta_5 USMGEXRI + \beta_6 ECUSD1M + \beta_7 GOLDBLN + \beta_8 TWEXMMTH + \beta_9 CREDITaaa + \beta_{10} CREDITbaa + \beta_{11} TED + \beta_{12} TERM + \beta_{13} VALGRTH + \beta_{14} SMLG + \beta_{15} MOM + \beta_{16} VIX + \beta_{17} INF + \beta_{18} FINANCE$$

The linear regression analysis, for each return series, was done by starting with all 18 factors and removing one by one, the one with t-statistics < 1.98 and t-statistics > -1.98 and the smallest absolute t-statistics value. Each time one factor was removed, the analysis was re-executed using R function “lm” for fitting linear models.

The quantitative results are laid out in appendices 7, 8, 9 and 10. The qualitative results from the analysis of those appendices, however, brought me to the conclusion that, assuming a 95% confidence level and data from 1988 to 2011 from Bloomberg™, there are no significant *α*s for the swap spread arbitrage strategy excess returns and based on the coefficient of determination R^2, from 40% to 72% of these excess returns can be explained with the regression factors. Intuitively, the swap spread arbitrage strategy has a significant amount of market risk, and the excess returns are simply compensation for bearing that risk.

Different qualitative results, however, can be concluded for the yield curve arbitrage strategy excess returns. These have, assuming a 95% confidence level and data from

1988 to 2011 from Bloomberg^{TM}, significant αs, ranging from -3.22% up to 4.74%. Apparently these can be a consequence of a higher degree of "intellectual capital" required to implement the process of identifying the arbitrage opportunities with the use of an affine two-factor term structure model. Therefore yield curve arbitrage strategy appears to produce significant risk-adjusted excess returns. A drawback on those results nevertheless is the fact that only 9% to 19% of these excess returns can be explained with the regression factors, leading to a likely conclusion that better regression factors need to be found.

In summary, I have qualitatively obtained the same results as Duarte, Longstaff and Yu (2006) for these two fixed-income arbitrage strategies. Quantitatively, for the yield curve arbitrage strategy excess returns, based on the equally weighted portfolio, my results are roughly 2 times more than the results from Duarte, Longstaff and Yu (2006), and for the swap spread arbitrage strategy excess returns, my results are roughly half. This quantitative discrepancy is likely due to three main reasons: data assumptions for the repo until 29.10.1999, data assumptions for the one-year maturity CMS until 31.5.1996 and for the fact that Duarte, Longstaff and Yu (2006)'s study was until 2004 comparing to those above until 2011.

5.2 Swap spread arbitrage strategy

With CMS data from Bloomberg$^{\mathbf{TM}}$ and strategy horizon until December 2004, table 1 shows that the mean monthly excess returns range from -2.29 % to +1.4 %. It is worth noting that most of the means of the strategies, forSS2, SS3, SS5, SS7 and SS10 are significant at the 5% level, since t-statistics for these are greater than 1.98 or smaller than -1.98. However, for SSEW the mean is significant only at the 10% level, since t-statistics is less than -1,658.

All the skewness coefficients for the returns distributions have negative values; in other words, the tail on the left side of the probability density function is longer than the tail on the right side and the bulk of the values lie to the right of the mean.

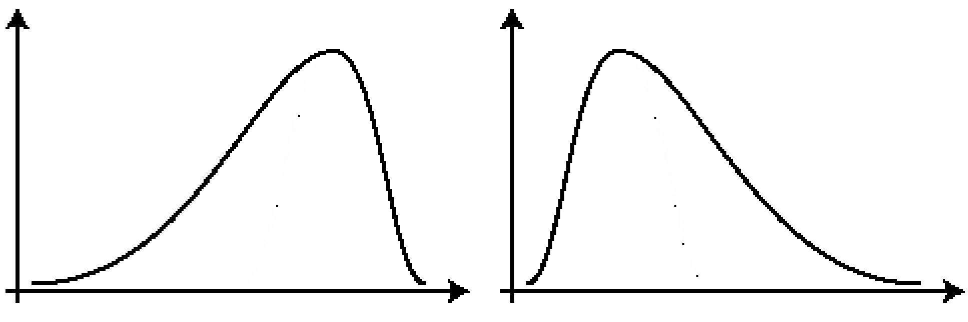

Figure 7: Diagrams illustrating negative and positive skew.

Source: Adapted from Rodolfo Hermans (2008)

Five of the distribution of returns for SS strategies (SS3, SS5, SS7, SS10 and SSEW) have excess kurtosis, i.e. more than the normal distribution kurtosis which equals to 3. This leads to the conclusion that those distributions have heavy tails.

The Sharpe Ratio calculates how well the return of an investment compensates the investor for the risk taken, or, in other words, measures the excess return per unit of risk (here standard deviation). The higher the Sharpe Ratio, the better return for the same risk is provided by the strategy. As shown in table 1, all distribution of returns for all SS strategies have negative Sharpe Ratios, ranging from -0.0079 to -0.1692.

The equally weighted (SSEW) portfolio strategy has smaller volatility since the returns of the individual strategies (SS2, SS3, SS5, SS7 and SS10) are not perfectly correlated, which therefore provides considerable diversification.

Now analyzing with CMS data from Bloomberg™ and strategies horizon until December 2011, table 2 shows that the mean monthly excess returns range from -1.74 % to +1.93 %, i.e. essentially the same range as obtained for the 2004 horizon. It is worth noting, however, that the means of the SS2, SS5, SS7, and SS10 strategies are significant at the 5% level, since t-statistics is greater than 1.98 (or smaller than -1.98). For SS3 and SSEW, the mean is not significant even at the 10% level, since those t-statistics are -0.289 and +1.363, which are more than -1.658 and less than 1.658 respectively.

Similarly, the skewness coefficients for the returns distributions have negative values. Only the kurtosis of SS5 (5.583) is greater than three.

Sharpe Ratios for the strategies horizon until December 2011 were different than the ones for the horizon until December 2004. SS2 and SS3 had positive Sharp Ratios of 0.0067 and 0.0112 respectively. In absolute terms, the Sharpe Ratio of SS5, SS7 and SS10 are approximately half of the Sharpe Ratios for the horizon until December 2004; or in other words less excess return per unit of risk.

As above, the equally weighted (EWSS) portfolio strategy provides considerable diversification.

For the sake of making also the SS strategy analysis with data from Thompson Reuters Datastream™, tables 2 and 3 depict the results of the SS strategies with time span until December 2004 and until December 2011 respectively. Very similar conclusions as above can be made from those results as well. One result is worth mentioning, the t-statistics for the equally weighted portfolio SSEW for the horizon until December 2011; with mean of 0.31% and t-statistics of 2.1875, makes the mean statistically significant at the 5% level.

Finally, we can conclude that, for SS strategies SS5, SS7 and SS10 with CMS data from both Bloomberg™ and from Thompson Reuters Datastream™ databases, the 2008 global financial crisis did not have a significant impact on the results of the returns. Some impact was visible for the SS2 and SS3, as the means of their excess returns with data until 2004, -2.4% and -0.49% were in absolute terms much greater than the equivalent with data until 2011, -1.74% and -0.05%.

5.3 Yield curve arbitrage strategy

With CMS data from Bloomberg™ and strategy horizon until December 2004, table 5 shows that the mean monthly excess returns range from +1.08 % to +2.66 %. It is worth noting that all of the means of the strategies (YC2, YC3, YC5, YC7 and EWYC) are significant at the 5% level, since t-statistics for these are greater than 1,98.

Some of the skewness coefficients for the returns distributions of YC strategies have negative values (YC2 and YC3), which means that the tail on the left side of the probability density function is longer than the tail on the right side and the bulk of the values lie to the right of the mean which suggests there are more positive returns than negative returns. YC5, YC7 and YCEW have positive skewness coefficients, which suggest that for these strategies there are more returns to the left of the means, i.e. smaller than the mean or negative returns.

Only YC2 has more kurtosis than a normal distribution, so its excess return distribution has heavy tails. All the other YC strategies have less kurtosis than the normal distribution, so they have only modestly sized deviations on the tails.

The Sharpe Ratios for all YC strategies distribution of returns are negative and ranging from -0.0012 to -0.0053.

Equally weighted (YCEW) portfolio strategy provides considerable diversification as its standard deviation is only 59.2% of that of the individual strategies which are 2.89%.

Now with CMS data from Bloomberg™ and strategy horizon until December 2011, table 6 shows that the mean monthly excess returns range from +1.25 % to +2.61 %, i.e. essentially the same range as obtained for the 2004 horizon. It is worth noting, however, that all of the means of the strategies are significant at the 5% level, since t-statistics for these are greater than 1.98.

Exactly as for the horizon until 2004, some of the skewness coefficients for the returns distributions of YC strategies have negative values (YC2 and YC3), which means that the tail on the left side of the probability density function is longer than the tail on the right side and the bulk of the values lie to the right side of the mean which suggests there are more positive returns than negative returns. As well as for the horizon until 2004 YC5, YC7 and YCEW have positive skewness coefficients, what suggests that for these strategies there are more returns to the left side of the means, i.e. smaller than the mean or negative returns.

YC2 and YC3 strategies distribution of excess returns have more kurtosis than the normal distribution, which leads to the conclusion that YC2 and YC3 have heavy tails comparing to the normal distribution but the other YC strategies (including the equally weighted) distribution of excess returns don't have heavy tails.

The Sharpe Ratios for YC strategies distributions of excess returns are ranging from -0.0008 and -0.0036.

Equally weighted (EWYC) portfolio strategy provides considerable diversification as its standard deviation is only 60.2% of that of the individual strategies.

For the sake of making also the YC strategy analysis with data from Thompson Reuters Datastream™ , tables 7 and 8 depict the results of the YC strategies with time span until December 2004 and until December 2011 respectively. There are some minor differences in the results. The ones worth noting are the YC3 (2004) skewness of 0.2860 and equivalent YC3(2011) skewness of 0.4456, YCEW (2004) skewness of -0.0644 and equivalent YCEW(2011) skewness of 0.1434, YC3 (2004) kurtosis of -0.2226 and equivalent YC3(2011) kurtosis of 0.5047. The Sharpe Ratios from 2004 and 2011 series, on the other hand, are roughly the same.

Finally, we can conclude that for YC strategies with CMS data from both Bloomberg™ and from Thompson Reuters Datastream™ databases, the 2008 global financial crisis did not have a significant impact on the results of the excess returns. This means that my hypothesis is wrong, because the results with or without the time period including the 2008 global financial crisis are very similar.

5.4 Possible continuation

Here I list possible new topics which could be considered if one would like to continue this study.

Two new factors could be added to the linear regression analysis, as proposed by Hannu Kahra (2011), QUALITY and SAFETY. QUALITY is the dynamic correlation between US benchmark 10 year ds govt. index return (BMUS10Y) and composite S&P 500 index return. SAFETY is the dynamic correlation between spot gold London morning fixing (GOLDBLN(UF)) unofficial price changes and composite S&P 500 index returns.

Portfolio optimization theory could be used, instead of using equally weighted portfolios. Test for unit root in the residuals of the regression analysis could improve the results. The yield curve arbitrage strategy could be scrutinized further, for instance by finding out new regression factors. As a new cost, hedge fund management fees could be modeled and considered, for instance 2/20 , since these arbitrage strategies are mainly used by hedge funds.

5.5 Final considerations

Based on both swap spread arbitrage strategy and yield curve arbitrage strategy results, I concluded that the hypothesis that the 2008 global financial crisis would have a significant impact on the results is not correct.

These arbitrage strategies seem profitable on the long run, even under financial crisis cycles, which shows some robustness since the data used on this master's thesis was collected over the span of 24 years.

Interestingly, the yield curve arbitrage strategy excess return index provided fatter profit and α, apparently as a consequence of its higher degree of "intellectual capital" required to implement the process of identifying the arbitrage opportunities with the use of an affine two-factor term structure model.

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APPENDICES

Appendix 1 – Basic concepts

It is necessary to understand some basic concepts and definitions in order to understand the text in this master's thesis. I've listed here, not exhaustively though, the most important concepts and definitions.

FED (The Federal Reserve System) is the central bank of the United States. It was founded by Congress in 1913 to provide the nation with a safer, more flexible, and more stable monetary and financial system. Over the years, its role in banking and in the economy has expanded. Today, the Federal Reserve's duties fall into four general areas:

• conducting the nation's monetary policy by influencing the monetary and credit conditions in the economy in pursuit of maximum employment, stable prices, and moderate long-term interest rates

• supervising and regulating banking institutions to ensure the safety and soundness of the nation's banking and financial system and to protect the credit rights of consumers

• maintaining the stability of the financial system and containing systemic risk that may arise in financial markets

• providing financial services to depository institutions, the U.S. government, and foreign official institutions, including playing a major role in operating the nation's payments system.

Source: http://www.federalreserve.gov/

According to the Federal Reserve System, *CMS* (Constant Maturity Swap) are the International Swaps and Derivatives Association (ISDA®) mid-market par swap rates. Rates are for a Fixed Rate Payer in return for receiving three month LIBOR, and are based on rates collected at 11:00 a.m. Eastern time by Garban Intercapital plc and published on Reuters Page ISDAFIX®1. ISDAFIX is a registered service mark of ISDA.

The yields on Treasury nominal securities at "constant maturity" are interpolated by the U.S. Treasury from the daily yield curve for non-inflation-indexed Treasury securities. According to the Federal Reserve System, this curve called *CMT* (Constant Maturity Treasury), which relates the yield on a security to its time to maturity, is based on the closing market bid yields on actively traded Treasury securities in the over-the-counter market. These market yields are calculated from composites of quotations obtained by the Federal Reserve Bank of New York. The constant maturity yield values are read from the yield curve at fixed maturities, currently 1, 3, and 6 months and 1, 2, 3, 5, 7, 10, 20, and 30 years. This method provides a yield for a 10-year maturity, for example, even if no outstanding security has exactly 10 years remaining to maturity.

As defined by the Federal Reserve System, *LIBOR* (London Interbank Offered Rate) is a reference interest rate published by the British Bankers' Association (BBA). The BBA surveys a panel of major banks daily and asks each bank to provide the interest rate at which it believes it could borrow funds unsecured in a particular currency and for a particular maturity in the wholesale money market in London. The published rate is a trimmed average of the rates obtained in the survey.

According to Duffie Darell and Kenneth J. Singleton (2003), *affine* process is a jump-diffusion process for which the drift vector, the instantaneous covariance matrix, and the jump-arrival intensities all have affine (constant-plus-linear) dependence on the current state of vector Xt. Prominent among affine processes in the term-structure literature are Gaussian and square-root diffusion models of Vasicek (1977) and Cox el al. (1985), respectively. Affine processes allow for a wide variety, such as stochastic volatility, jumps and correlations among the elements of the state vector Xt.

According to Duffie Darell and Kenneth J. Singleton (2003), an asset *SWAP* is a derivative security that can be viewed, in its simplest version, as a portfolio consisting of a fixed-rate note and an interest-rate swap of the same notional amount that pays fixed and receives floating, say *LIBOR*, to the stated maturity of the underlying fixed-rate note. At the origination of the asset *SWAP*, the fixed rate of the interest-swap component is chosen so that the market value of the asset *SWAP* is equal to the face value of the underlying note. We can also view the interest rate SWAP as one that pays fixed-rate coupons at a rate equal to the coupon rate C on the underlying fixed-rate *SWAP* and receives floating-rate coupons at a rate equal to *LIBOR* plus some fixed spread, say S.

According to Taylor Stephen (1986, pages 13–14), financial prices and hence returns are determined by many political, corporate and individual decisions. A *model* for prices or returns is a detailed description of how successive prices or returns are determined. They say that the description contains enough detail to be called a model if it can be used to simulate prices or returns. A good model will be capable of providing simulated prices or returns which look like just like real prices or returns. For such a model, if we gave someone a long series of real prices (from an un-named market) and an equally long series of simulated prices, then the person could only guess which of the two series was real. Thus, a good model must describe all the known properties of recorded prices or returns. Models can be constructed using concepts from statistics, economics and other sciences. Models can be conjectured from data or they can be suggested by economic theory. Any model will only be an approximation to the rules which convert relevant information and numerous beliefs and actions into market prices.

As stated by Mark Fisher (2002), a repurchase agreement, or *repo*, can be thought of as a collateralized loan. The collateral will be Treasury securities (that is, Treasury bills, notes, and bonds). At the inception of the agreement, the borrower turns over the collateral to the lender in exchange for funds. When the loan matures, the funds are returned to the lender along with interest at the previously agreed-upon repo rate, and the collateral is returned to the borrower. Repo agreements can have any maturity, but most are for one business day, referred to as overnight. From the perspective of the owner of the security and the borrower of funds, the transaction is referred to as a repo while from the lender’s perspective the same transaction is referred to as a reverse repo, or simply a reverse. For most publicly traded U.S.

Treasury securities, the financing rate in the repo market is the *general collateral rate* (which can be thought of as the risk-free interest rate). In contrast, for some Treasury securities — typically recently issued securities — the financing rate is lower than the general collateral rate. These securities are said to be on special, and their financing rates are referred to as specific collateral rates, also known as special repo rates. The difference between the general collateral rate and the specific collateral rate is the repo spread.

According to Bruce Tuckman and Angel Serrat (2012), a repurchase agreement or *repo* is a contract in which a security is traded at some initial price with the understanding that the trade will be reversed at some future date at some fixed price. In effect, a repurchase agreement is a collateralized loan with the seller handing over the security as collateral.

As stated by Adam Kobor, Lishan Shi and Ivan Zelenko (2005), the *swap spread* , or the price of swaps relative to Treasuries, cannot be captured in a pricing formula but results instead from joint equilibrium of bond and swap markets. Due to their wide use, swap spread and their fluctuations have a decisive impact on some of the most essential financial operations. For an issuer of bonds based on the LIBOR systematically swapping its debt into floating at issuance, the relative evolution of the swap spread versus its own spread against Treasuries will result in its final funding costs as measured against the *LIBOR* curve (or swap curve).

According to Robert Dubil (2004), governments, financial, and non-financial corporations raise debt funds by borrowing from financial institutions, like banks, or by issuing securities in the financial markets in order to finance their activities. Securities are distributed in the primary markets and they are sold directly from borrowers to investors, sometimes with the help of an investment bank. They are traded among investors in the secondary markets. Securities' markets can be, in general, divided into money and capital markets. Money market instruments are those whose maturities are less than one year. Capital markets' instruments are those whose maturities are more than one year. This division is largely artificial and due to different legal requirements. The spot markets for debit securities, also called *fixed income securities*, are markets where debt contracts typically have a stated maturity date and pay interest defined through a coupon rate or a coupon formula. Examples of fixed income securities are: corporate and government bonds, interest rate swaps, U.S. Treasury Bills (T-Bills), U.S. federal agency discount notes, Fed Funds, repurchase agreements (repo), Eurocurrency deposits, commercial papers and Certificates of Deposit (CD).

According to Robert Dubil (2004), *arbitrage* is defined in most text books as riskless, instantaneous profit. It occurs when the law of one price, which states that the same item cannot sell at two different prices at the same time, is violated. The same stock cannot trade for one price at one exchange and for a different price at another, unless there are fees, taxes, etc. If it does, traders will buy it on the exchange where it sells for less, and sell it on the one where it sells for more. More complicated pure arbitrage involves forward and contingent markets. It can take a static form, where the trade is put on at the outset and liquidated once at a future date (e.g. trading forward rate agreements against spot *LIBOR*s for two different terms), or a dynamic one, in which the trader commits to a series of steps that eliminate all directional market risk and ensures virtually riskless profit on completion of these steps.

According to Siddhartha Jha (1984), the *yield curve* is mathematically the set of yields as a function of time; the yield curve can be thought of as a "machine" that takes time to maturity as an input and outputs the yield for a bond of that maturity. The yield curve can also be thought of as the price of lending (borrowing) money over different points in time. As rates markets have matured, the presence of investors such as hedge funds that are more nimble in their investments and can take advantages of mispricing across the yield curve makes segmentation (certain investor classes preferring to invest in certain maturity ranges) unlikely as a major source of yield differences. In sum, the yield curve is likely a mix of market expectations as well as some risk aversion, while certain niche sectors may feel the effects of segmentation.

According to Tzong-shian Yu and Dianqing Xu (2001), the *financial crisis of 1998* first broke in Thailand on July 2nd, 1997, and swept the region like a tornado, engulfing Malaysia, Indonesia, Philippines and Singapore, and encroaching upon

Hong Kong, Taiwan, Korea, Japan and China. No country in East Asia managed to completely evade its impact. One year later (1998), the far-reaching effects of the economic storm had still not died down in East Asia, and they had spread even to Russia and Latin America. All the countries that succumbed to the crisis found themselves facing a sharp depreciation in their currencies and collapse of stock market; these effects had in turn resulted in a decline in exports, a slowdown in economic growth and a rise in unemployment.

According to Amitendu Palit (2010), the *financial crisis of 2008* was in several ways a crisis due to globalization. The globalized modern world had not experienced a crisis of this magnitude before. The Asia meltdown of 1997 was an event which was confined to Southeast and Northeast Asia. The latest crisis, however, took on a much greater geographical shape. Although it began as a 'trans-Atlantic' crisis, it soon spread rapidly to various parts of the world, including Asia. This happened on account of the substantial links that the world had developed through financial globalization channels of trade and banking. Thus, the crisis was largely interpreted as a catastrophe arising from the close interconnectedness of financial and commercial systems which successfully transmitted the damage from its core to the periphery.

According to the R Project for Statistical Computing (source: http://www.r-project.org/), **R** is a language and environment for statistical computing and graphics. It is a GNU project which is similar to the S language and environment which was developed at Bell Laboratories (formerly AT&T, now Lucent Technologies) by John Chambers and colleagues. R can be considered as a different implementation of S. There are some important differences, but much code written for S runs unaltered under R. R provides a wide variety of statistical (linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering...) and graphical techniques, and is highly extensible. The S language is often the vehicle of choice for research in statistical methodology, and R provides an Open Source route to participation in that activity. One of R's strengths is the ease with which well-designed publication-quality plots can be produced, including mathematical symbols and formulae where needed. Great care has been taken over the defaults for the minor design choices in graphics, but the user retains full control. R is available as

Free Software under the terms of the Free Software Foundation's GNU General Public License in source code form. It compiles and runs on a wide variety of UNIX platforms and similar systems (including FreeBSD and Linux), Windows and MacOS.

According to the Unicode Consortium, *basis point* = 1 per myriad = one one-hundredth percent = percent of a percent = 1‱ = 0.01%

Appendix 2 – Deduction of the two-factor affine model

The model is defined in the following way:

We assume that the riskless rate is given by $r_t = X_t + Y_t$, where X_t and Y_t follow the dynamics

$$dX = (\alpha - \beta X)\,dt + \sigma dZ_1 \text{ (ap3.1)}$$

$$dY = (\mu - \gamma Y)\,dt + \eta dZ_2 \text{ (ap3.2)}$$

under the risk-neutral measure, where Z_1 and Z_2 are standard uncorrelated ($\rho = 0$) Brownian motions.

Looking at the dynamics above, we realize this is a two-factor Vasicek model, which has the following dynamics

$$dX_t = K_x(\theta_x - X_t)\,dt + \sigma_x dW_t^x \qquad \text{(ap3.3)}$$

$$dY_t = K_y(\theta_y - Y_t)\,dt + \sigma_y dW_t^y \qquad \text{(ap3.4)}$$

Where:

K_x and K_y are the speed of mean reversion for factors X and Y, respectively.

θ_x and θ_y are long run average for factors X and Y, respectively.

σ_x and σ_y are volatility for factors X and Y, respectively.

dW_t^x and dW_t^y are random shocks to factors X and Y, respectively.

dW_t^x and dW_t^y are correlated with correlation coefficient ρ, but since we assume these are standard uncorrelated Brownian motions, ρ = 0.

The spot rate for the two factor Vasicek model, as described at Simon Babbs (1993), is

$$r(T) = \theta_x + \frac{1-e^{-K_x T}}{K_x T}(X_0 - \theta_x) + \theta_y + \frac{1-e^{-K_y T}}{K_y T}(Y_0 - \theta_y) - \frac{\sigma_x{}^2}{2K_x{}^2}(1+\frac{1-e^{-2K_x T}}{2K_x T} - 2\,\frac{1-e^{K_x T}}{K_x T}) - \frac{\sigma_y{}^2}{2K_y{}^2} * (1+\frac{1-e^{-2K_y T}}{2K_y T} - 2\,\frac{1-e^{K_y T}}{K_y T}) - \frac{\rho\sigma_x\sigma_y}{K_x K_y}(1 - \frac{1-e^{-K_x T}}{2K_x T} - \frac{1-e^{-2K_y T}}{2K_y T} + \frac{1-e^{-(K_x+K_y)T}}{(K_x+K_y)T}) \quad \text{(ap3.5)}$$

One of the primary problems with multi-factor models is that we typically do not observe the factors, X and Y.

On the other hand, if we take two zero coupon bonds with maturities T1 and T2, the yields, Y1(t) and Y2(t) of the two bonds are related to the unobserved factors as follows:

$$Y1(t) = A_1 + B_{1,x}X(t) + B_{1,y}Y(t) \quad \text{(ap3.6)}$$

$$Y2(t) = A_2 + B_{2,x}X(t) + B_{2,y}Y(t) \quad \text{(ap3.7)}$$

where A1, A2, $B_{1,x}$, $B_{1,y}$, $B_{2,x}$ and $B_{2,y}$ can be recovered from the expression above for the spot rate (ap3.5) as follows:

$$B_{1,x} = \frac{1 - e^{-K_x T1}}{K_x T1}$$

$$B_{1,y} = \frac{1 - e^{-K_y T1}}{K_y T1}$$

$$B_{2,x} = \frac{1 - e^{-K_x T2}}{K_x T2}$$

$$B_{2,y} = \frac{1 - e^{-K_y T2}}{K_y T2}$$

$$A1 = \theta_x(1 - B_{1,x}) + \theta_y(1 - B_{1,y}) - \frac{\sigma_x{}^2}{2K_x{}^2}\left(1 + \frac{1 - e^{-2K_xT1}}{2K_xT1} - 2\,B_{1,x}\right)$$
$$- \frac{\sigma_y{}^2}{2K_y{}^2}\left(1 + \frac{1 - e^{-2K_yT1}}{2K_yT1} - 2\,B_{1,y}\right)$$
$$- \frac{\rho\sigma_x\sigma_y}{K_xK_y}\left(1 - \frac{B_{1,x}}{2} - \frac{1 - e^{-2K_yT1}}{2K_yT1} + \frac{1 - e^{-(K_x + K_y)T1}}{(K_x + K_y)T1}\right)$$

$$A2 = \theta_x(1 - B_{2,x}) + \theta_y(1 - B_{2,y}) - \frac{\sigma_x{}^2}{2K_x{}^2}\left(1 + \frac{1 - e^{-2K_xT2}}{2K_xT2} - 2\,B_{2,x}\right)$$
$$- \frac{\sigma_y{}^2}{2K_y{}^2}\left(1 + \frac{1 - e^{-2K_yT2}}{2K_yT2} - 2\,B_{2,y}\right)$$
$$- \frac{\rho\sigma_x\sigma_y}{K_xK_y}\left(1 - \frac{B_{2,x}}{2} - \frac{1 - e^{-2K_yT2}}{2K_yT2} + \frac{1 - e^{-(K_x + K_y)T2}}{(K_x + K_y)T2}\right)$$

We can now solve (ap3.6) and (ap3.7) for X(t) and Y(t) using the standard technique for solving two linear equations with two unknowns; but before that, let's assume that the Y1(t) is the one-year CMS and Y2(t) is the 10-year CMS, respectively $CMS_1(t)$ and $CMS_{10}(t)$.

$$CMS_1(t) = A_1 + B_{1,x}\,X(t) + B_{1,y}\,Y(t) \qquad \text{(ap3.8)}$$

$$CMS_{10}(t) = A_{10} + B_{10,x}\,X(t) + B_{10,y}\,Y(t) \qquad \text{(ap3.9)}$$

Multiplying (ap3.8) by $B_{10,x}$ and (ap3.9) by $-B_{1,x}$, we have:

$$CMS_1(t)B_{10,x} = A_1B_{10,x} + B_{1,x}B_{10,x}\,X(t) + B_{1,y}B_{10,x}\,Y(t) \quad \text{(ap3.10)}$$

$$-B_{1,x}CMS_{10}(t) = -B_{1,x}A_{10} - B_{1,x}\,B_{10,x}\,X(t) - B_{1,x}B_{10,y}\,Y(t) \quad \text{(ap3.11)}$$

Adding (ap3.10) to (ap3.11) we have:

$$CMS_1(t)B_{10,x} - B_{1,x}CMS_{10}(t) = A_1B_{10,x} - B_{1,x}A_{10} + Y(t)\,[B_{1,y}B_{10,x} - B_{1,x}B_{10,y}] \Rightarrow$$

$$Y(t) = \frac{B_{10,x}(CMS_1(t)-A_1) - B_{1,x}(CMS_{10}(t)+A_{10})}{B_{1,y}B_{10,x} - B_{1,x}B_{10,y}} \qquad \text{(ap3.12)}$$

Now multiplying (ap3.8) by $-B_{10,y}$ and (ap3.9) by $B_{1,y}$, we have:

$$-B_{10,y}CMS_1(t) = -B_{10,y}A_1 - B_{10,y}B_{1,x}\,X(t) - B_{10,y}B_{1,y}Y(t) \qquad \text{(ap3.13)}$$

$$B_{1,y}CMS_{10}(t) = B_{1,y}A_{10} + B_{1,y}B_{10,x}\,X(t) + B_{1,y}B_{10,y}Y(t) \qquad \text{(ap3.14)}$$

Adding (ap3.13) to (ap3.14) we have:

$$B_{1,y}CMS_{10}(t) - B_{10,y}CMS_1(t) = B_{1,y}A_{10} - B_{10,y}A_1 + B_{1,y}B_{10,x}\,X(t) - B_{10,y}B_{1,x}\,X(t) \Rightarrow$$

$$X(t) = \frac{B_{10,y}\left(A_1 - CMS_1(t)\right) - B_{1,y}(A_{10} - CMS_{10}(t))}{B_{1,y}B_{10,x} - B_{10,y}B_{1,x}} \qquad \text{(ap3.15)}$$

Based on (ap3.15) and (ap3.12), finally we can build the affine model as

$$r_t = \frac{B_{10,y}\left(A_1 - CMS_1(t)\right) - B_{1,y}\left(A_{10} - CMS_{10}(t)\right)}{B_{1,y}B_{10,x} - B_{10,y}B_{1,x}} +$$

$$\frac{B_{10,x}(CMS_1(t)-A_1) - B_{1,x}(CMS_{10}(t)+A_{10})}{B_{1,y}B_{10,x} - B_{1,x}B_{10,y}} \qquad \text{(ap3.16)}$$

Returning to the definitions of A1, A2, $B_{1,x}$, $B_{1,y}$, $B_{2,x}$, $B_{2,y}$, comparing (ap3.1), (ap3.2), (ap3.3) and (ap3.4) and making the correct analogies, we have:

$\alpha = K_x\theta_x$;

$\beta = K_x$;

$\sigma = \sigma_x$;

$\mu = K_y \theta_y$;

$\gamma = K_y$;

$\eta = \sigma_y$;

According to Duarte, Longstaff and Yu (2006), using the global minimum squared difference method for the differences between the model and market values for the two-, three-, five- and seven-year CMS rates, the resulting parameters estimates are $\alpha = 0.0009503$, $\beta = 0.0113727$, $\sigma = 0.0548290$, $\mu = 0.0240306$, $\gamma = 0.4628664$ and $\eta = 0.0257381$. This lead me to the following estimates for $K_x = 0.0113727$, $\theta_x = 0.0835598$, $\sigma_x = 0.0548290$, $K_y = 0.4628664$, $\theta_y = 0.0519169$ and $\sigma_y = 0.0257381$.

With those parameters I could easily calculate A1 = 0.0102472, A10 = -0.0017207, $B_{1,x} = 0.9943345$, $B_{1,y} = 0.8004968$, $B_{10,x} = 0.9452316$ and $B_{10,y} = 0.2139348$.

Appendix 3 – Eighteen risk factors used for the regression analysis

1. MSUSAM: MSCI North American Equities [Datastream series MSUSAM$(RI)]. Source: THOMSON REUTERS DATASTREAM.

2. MSWXUS: MSCI non-US Equities [Datastream series MSWXUS$(RI)]. Source: THOMSON REUTERS DATASTREAM.

3. MSEMKF: MSCI Emerging Market index monthly total return [Datastream series: MSEMKF$(RI)]. Source: THOMSON REUTERS DATASTREAM.

4. USMGUSRI: JPMorgan US Government Bonds [Datastream series USMGUSRI]. Source: THOMSON REUTERS DATASTREAM.

5. USMGEXRI: JPMorgan non-US Government Bonds [Datastream series USMGEXRI]. Source: THOMSON REUTERS DATASTREAM.

6. ECUSD1M: One-month Eurodollar deposit rate of the previous month [Datastream series ECUSD1M]. Source: THOMSON REUTERS DATASTREAM.

7. GOLDBLN: Unofficial price for spot gold London morning fixing [Datastream series GOLDBLN(UF)]. Source: THOMSON REUTERS DATASTREAM.

8. TWEXMMTH: Trade Weighted U.S. Dollar Index: Major Currencies. Source: http://research.stlouisfed.org/fred2/series/TWEXMMTH

9. CREDITaaa: Difference between Moody's Seasoned Aaa Corporate Bond Yield (AAA) and 3-Month Treasury Bill: Secondary Market Rate (TB3MS). Source: FED: http://research.stlouisfed.org/fred2/series/AAA and http://research.stlouisfed.org/fred2/series/TB3MS/

10. CREDITbaa: Difference between Moody's Seasoned Baa Corporate Bond Yield (BAA) and 3-Month Treasury Bill: Secondary Market Rate (TB3MS). Source: FED:

http://research.stlouisfed.org/fred2/series/BAA and http://research.stlouisfed.org/fred2/series/TB3MS/

11. TED: Difference between 3-Month Euro- Dollar deposit rate (EDM3) and 3-Month Treasury Bill: Secondary Market Rate (TB3MS). Source: FED: http://www.federalreserve.gov/releases/h15/data.htm , Bloomberg, CTRB ICAP Fixed Income & Money Market Products and http://research.stlouisfed.org/fred2/series/TB3MS/.

12. TERM: Difference in returns on the total return US Treasury 30-Years index (BMUS30Y(RI)) and the total return US Treasury Bill 3-Month index (JPUS3ML). Source: Ang, Goetzmann and Schaefer (2009) and THOMSON REUTERS DATASTREAM.

13. VALGRTH: Difference in returns between global "value" stocks ((MSVWLD$) and global "growth" stocks (MSGWLD$) computed using MSCI world indices. Source: Ang, Goetzmann and Schaefer (2009) and THOMSON REUTERS DATASTREAM.

14. SMLG: Difference in returns between global small cap stocks (MSSAWF$) and global large cap stocks (MSLAWF$) computed using MSCI all country indices. Source: Ang, Goetzmann and Schaefer (2009) and THOMSON REUTERS DATASTREAM.

15. MOM: Fama and French momentum factor. Difference in returns between US stocks with past high returns and US stocks with past low returns. The momentum factor is constructed from six value-weight portfolios formed using independent sorts on size and prior return of NYSE, AMEX, and NASDAQ stocks. Mom is the average of the returns on two (big and small) high prior return portfolios minus the average of the returns on two low prior return portfolios. The portfolios are constructed monthly. Big means a firm is above the median market cap on the NYSE at the end of the previous month; small firms are below the median NYSE market cap. Prior return is measured from month -12 to - 2. Firms in the low prior return portfolio are below the 30th NYSE percentile. Those in the high portfolio are above the 70th

NYSE percentile. Source: Ang, Goetzmann and Schaefer (2009) and Kenneth French at http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html .

16. VIX: VOLATILITY S&P500 (^VIX) - Chicago Options. Source: http://finance.yahoo.com/q?s=^VIX

17. INF: Difference between 30-Year Treasury Constant Maturity Rate (GS30) and 30-Year 3-5/8% Treasury Inflation-Indexed Bond (TP30A28). Source: FED: http://research.stlouisfed.org/fred2/series/GS30 and http://research.stlouisfed.org/fred2/series/TP30A28

18. FINANCE: Difference between 3-Month AA Financial Commercial Paper Rate (CPF3M) and 3-Month Treasury Bill: Secondary Market Rate (TB3MS). Source: FED: https://research.stlouisfed.org/fred2/series/CPF3M and http://research.stlouisfed.org/fred2/series/TB3MS/

Appendix 4 – R language based coding

I developed R-language based coding for the purpose of implementing the Swap Spread and Yield Curve arbitrage strategies for this master's thesis. Approximately one thousand and five hundred lines of R code were developed.

I use R version 2.14.2 (2012-02-29), copyright (C) 2012 The R Foundation for Statistical Computing, Platform: x86_64-pc-mingw32/x64 (64-bit).

R language based coding logic was split in 4 main parts: loading R-packages and generic data, swap spread strategy specific, yield curve strategy specific and generic functions.

For the loading R-packages and generic data part, the following R-packages were needed: fBasics, timeSeries, FinTS, quantmod, fUnitRoots, sde, termstrc, chron, tseries, boot, graphics, graphicsQC, dse, PerformanceAnalytics and xts. There were txt format files from where the data described at chapter 2.2 methodology.

The swap spread strategy specific part implements the strategy for the set of swap maturities, but paying attention to bringing the results to present values, i.e. discounted with a monthly variable risk free rate from the TB3MS, and normalizing returns to an annualized 10% volatility.

Similarly, the yield curve strategy specific part implements the strategy for the set of swap maturities, but besides paying attention to bringing the results to present values and normalizing returns to an annualized 10% volatility, also the two-factor affine model is developed in this part of the code.

The main generic function of my R language based code is the regression analysis.

Appendix 5 – Summary statistics for swap spread arbitrage strategy

For all tables on appendix 5, the following applies:

'Observations' refer to the number of observations. 'NAs' refers to the number of missing observations. 'T-stat' is the t-statistics and 'SE Mean' is the standard error of the mean. 'LCL Mean' is the lower confidence level of the mean and 'UCL Mean' is the upper confidence level of the mean. 'VaR' is the Value-at-Risk. The 'SSEW' strategy consists of an equally weighted position each month in the individual-maturity swap spread strategies.

Table 1: Summary statistics for the monthly percentage excess returns from the swap spread arbitrage strategies for the sample period from November 1988 to December 2004 with CMS data from Bloomberg™.

	Risk_free	SS2	SS3	SS5	SS7	SS10	SSEW
Observations	194	194	194	194	194	194	194
NAs	0	0	0	0	0	0	0
Minimum	0.0088	-0.1195	-0.2060	-0.2884	-0.2224	-0.1740	-0.1862
Quartile 1	0.0300	-0.0388	-0.0248	-0.0217	-0.0069	-0.0032	-0.0172
Median	0.0489	-0.0141	0.0000	-0.0065	0.0015	0.0031	-0.0057
Arithmetic Mean	0.0440	-0.0229	-0.0058	-0.0097	0.0093	0.0140	-0.0030
t-stat for the Arithmetic Mean	30.246	-11.0599	-2.8123	-4.6873	4.4655	6.7368	-1.7482
Geometric Mean	0.0438	-0.0234	-0.0063	-0.0102	0.0088	0.0135	-0.0034
Quartile 3	0.0553	0.0000	0.0203	0.0098	0.0319	0.0395	0.0173
Maximum	0.0882	0.0413	0.0316	0.0198	0.0549	0.0615	0.0331
SE Mean	0.0015	0.0021	0.0021	0.0021	0.0021	0.0021	0.0017
LCL Mean (0.95)	0.0411	-0.0270	-0.0099	-0.0138	0.0052	0.0099	-0.0065
UCL Mean (0.95)	0.0469	-0.0188	-0.0017	-0.0056	0.0133	0.0181	0.0004
Variance	0.0004	0.0008	0.0008	0.0008	0.0008	0.0008	0.0006
Stdev	0.0203	0.0289	0.0289	0.0289	0.0289	0.0289	0.0243
Skewness	-0.0138	-0.9770	-1.8956	-4.8495	-2.5674	-1.3346	-2.2784
Kurtosis	-0.6379	0.5611	10.0630	42.6029	19.3850	7.7016	14.7989
Maximum Drawdown		0.9898	0.8623	0.8947	0.3797	0.3297	0.7335
Historical VaR (95%)		-0.0776	-0.0473	-0.0476	-0.0243	-0.0190	-0.0347
Historical CVaR (95%)		-0.0949	-0.0710	-0.0804	-0.0529	-0.0480	-0.0597
Modified VaR (95%)		-0.0775	-0.0609	-0.0591	-0.0443	-0.0389	-0.0490
Modified CVaR (95%)		-0.0905	-0.1379	-0.0591	-0.1572	-0.1051	-0.1324
Sharpe Ratio (Rf= 4,4%)		-0,0079	-0,1316	-0,1656	-0,1692	-0,1471	-0,1548

Table 2: Summary statistics for the monthly percentage excess returns from the swap spread arbitrage strategies for the sample period from November 1988 to December 2011 with CMS data from Bloomberg™.

	Risk_free	SS2	SS3	SS5	SS7	SS10	SSEW
Observations	278	278	278	278	278	278	278
NAs	0	0	0	0	0	0	0
Minimum	0.0001	-0.1196	-0.0731	-0.1917	-0.1084	-0.1435	-0.0913
Quartile 1	0.0166	-0.0349	-0.0192	-0.0217	-0.0064	-0.0028	-0.0155
Median	0.0411	-0.0075	0.0000	0.0000	0.0085	0.0179	0.0020
Arithmetic Mean	0.0367	-0.0174	-0.0005	-0.0072	0.0156	0.0193	0.0020
t-stat for the Arithmetic Mean	26.729	-10.0735	-0.289	-4,1526	9.0201	11.1459	1.3629
Geometric Mean	0.0365	-0.0179	-0.0009	-0.0076	0.0152	0.0189	0.0017
Quartile 3	0.0509	0.0000	0.0247	0.0149	0.0432	0.0435	0.0242
Maximum	0.0882	0.0720	0.0463	0.0311	0.0651	0.0685	0.0389
SE Mean	0.0014	0.0017	0.0017	0.0017	0.0017	0.0017	0.0014
LCL Mean (0.95)	0.0340	-0.0208	-0.0039	-0.0106	0.0122	0.0159	-0.0009
UCL Mean (0.95)	0.0394	-0.0140	0.0029	-0.0038	0.0190	0.0227	0.0048
Variance	0.0005	0.0008	0.0008	0.0008	0.0008	0.0008	0.0006
Stdev	0.0229	0.0289	0.0289	0.0289	0.0289	0.0289	0.0239
Skewness	-0.0043	-0.8260	-0.5161	-1.5661	-0.2771	-0.7324	-0.5139
Kurtosis	-0.8255	1.2622	-0.6240	5.5830	-0.0322	2.3692	-0.0735
Maximum Drawdown		0.9952	0.9171	0.9581	0.4516	0.3433	0.7995
Historical VaR (95%)		-0.0746	-0.0542	-0.0604	-0.0229	-0.0185	-0.0360
Historical CVaR (95%)		-0.0911	-0.0626	-0.0806	-0.0400	-0.0399	-0.0505
Modified VaR (95%)		-0.0705	-0.0524	-0.0629	-0.0340	-0.0324	-0.0408
Modified CVaR (95%)		-0.0920	-0.0607	-0.1107	-0.0475	-0.0630	-0.0514
Sharpe Ratio (Rf=3,67%)		0,0067	0,0112	-0,0793	-0,0725	-0,1009	-0,0597

Table 3: Summary statistics for the monthly percentage excess returns from the swap spread arbitrage strategies for the sample period from November 1988 to December 2004 with CMS data from Thompson Reuters Datastream™.

	Risk_free	SS2	SS3	SS5	SS7	SS10	SSEW
Observations	194	194	194	194	194	194	194
NAs	0	0	0	0	0	0	0
Minimum	0.0088	-0.1126	-0.2022	-0.2888	-0.1905	-0.1731	-0.1789
Quartile 1	0.0300	-0.0403	-0.0234	-0.0196	-0.0064	-0.0015	-0.0154
Median	0.0489	-0.0186	0.0000	-0.0054	0.0011	0.0037	-0.0058
Arithmetic Mean	0.0440	-0.0244	-0.0049	-0.0086	0.0111	0.0152	-0.0023
t-stat for the Arithmetic Mean	30.246	-11.7578	-2.3753	-4.162	5.3354	7.3418	-1.3589
Geometric Mean	0.0438	-0.0248	-0.0054	-0.0091	0.0106	0.0148	-0.0026
Quartile 3	0.0553	0.0000	0.0209	0.0101	0.0358	0.0406	0.0179
Maximum	0.0882	0.0391	0.0329	0.0201	0.0581	0.0635	0.0348
SE Mean	0.0015	0.0021	0.0021	0.0021	0.0021	0.0021	0.0017
LCL Mean (0.95)	0.0411	-0.0285	-0.0090	-0.0127	0.0070	0.0111	-0.0057
UCL Mean (0.95)	0.0469	-0.0203	-0.0008	-0.0045	0.0151	0.0193	0.0011
Variance	0.0004	0.0008	0.0008	0.0008	0.0008	0.0008	0.0006
Stdev	0.0203	0.0289	0.0289	0.0289	0.0289	0.0289	0.0239
Skewness	-0.0138	-0.8974	-1.8814	-4.9415	-1.6281	-1.2485	-2.1476
Kurtosis	-0.6379	0.2243	9.5747	43.5990	10.3484	7.5237	13.7281
Maximum Drawdown		0.9923	0.8429	0.8754	0.4057	0.3350	0.7093
Historical VaR (95%)		-0.0823	-0.0486	-0.0460	-0.0245	-0.0215	-0.0347
Historical CVaR (95%)		-0.0959	-0.0737	-0.0806	-0.0498	-0.0450	-0.0582
Modified VaR (95%)		-0.0785	-0.0602	-0.0577	-0.0422	-0.0372	-0.0474
Modified CVaR (95%)		-0.0897	-0.1340	-0.0577	-0.1234	-0.1021	-0.1264
Sharpe Ratio (Rf= 4,4%)		0,0029	-0,1239	-0,1671	-0,1615	-0,1567	-0,1466

Table 4: Summary statistics for the monthly percentage excess returns from the swap spread arbitrage strategies for the sample period from November 1988 to December 2011 with CMS data from Thompson Reuters Datastream™.

	Risk_free	SS2	SS3	SS5	SS7	SS10	SSEW
Observations	278	278	278	278	278	278	278
NAs	0	0	0	0	0	0	0
Minimum	0.0001	-0.1106	-0.0822	-0.1875	-0.1104	-0.1435	-0.0908
Quartile 1	0.0166	-0.0364	-0.0195	-0.0226	-0.0052	-0.0013	-0.0147
Median	0.0411	-0.0094	0.0000	0.0000	0.0215	0.0195	0.0032
Arithmetic Mean	0.0367	-0.0190	0.0009	-0.0052	0.0184	0.0204	0.0031
t-stat for the Arithmetic Mean	26.729	-10.9651	0.5214	-3.0161	10.65	11.7544	2.1875
Geometric Mean	0.0365	-0.0194	0.0005	-0.0057	0.0180	0.0199	0.0028
Quartile 3	0.0509	0.0000	0.0276	0.0194	0.0453	0.0432	0.0247
Maximum	0.0882	0.0754	0.0455	0.0387	0.0663	0.0711	0.0403
SE Mean	0.0014	0.0017	0.0017	0.0017	0.0017	0.0017	0.0014
LCL Mean (0.95)	0.0340	-0.0224	-0.0025	-0.0086	0.0150	0.0169	0.0003
UCL Mean (0.95)	0.0394	-0.0156	0.0043	-0.0018	0.0218	0.0238	0.0059
Variance	0.0005	0.0008	0.0008	0.0008	0.0008	0.0008	0.0006
Stdev	0.0229	0.0289	0.0289	0.0289	0.0289	0.0289	0.0236
Skewness	-0.0043	-0.7063	-0.4785	-1.4547	-0.4150	-0.6396	-0.4822
Kurtosis	-0.8255	1.0259	-0.5478	5.3438	-0.0215	2.1637	-0.0104
Maximum Drawdown		0.9966	0.8945	0.9423	0.4329	0.3499	0.7680
Historical VaR (95%)		-0.0762	-0.0494	-0.0539	-0.0233	-0.0193	-0.0357
Historical CVaR (95%)		-0.0923	-0.0619	-0.0779	-0.0389	-0.0377	-0.0483
Modified VaR (95%)		-0.0713	-0.0506	-0.0603	-0.0323	-0.0308	-0.0388
Modified CVaR (95%)		-0.0918	-0.0599	-0.1082	-0.0459	-0.0599	-0.0498
Sharpe Ratio (Rf=3,67%)		0,0152	0,0182	-0,0789	-0,0827	-0,1101	-0,0547

Appendix 6 – Summary statistics for yield curve arbitrage strategy

For all tables on appendix 6, the following applies:

'Observations' refer to the number of observations. 'NAs' refers to the number of missing observations. 'T-stat' is the t-statistics and 'SE Mean' is the standard error of the mean. 'LCL Mean' is the lower confidence level of the mean and 'UCL Mean' is the upper confidence level of the mean. 'VaR' is the Value-at-Risk. The 'YCEW' strategy consists of an equally weighted position each month in the individual-maturity yield curve strategies.

Table 5: Summary statistics for the monthly percentage excess returns from the yield curve arbitrage strategies for the sample period from November 1988 to December 2004 with CMS data from Bloomberg™.

	Risk_free	YC2	YC3	YC5	YC7	YCEW
Observations	194	194	194	194	194	194
NAs	0	0	0	0	0	0
Minimum	0.0088	-0.1116	-0.1302	-0.0291	-0.0053	-0.0280
Quartile 1	0.0300	0.0000	-0.0019	-0.0008	-0.0018	0.0029
Median	0.0489	0.0000	0.0152	0.0314	0.0105	0.0161
Arithmetic Mean	0.0440	0.0108	0.0203	0.0266	0.0222	0.0160
t-stat for the Arithmetic Mean	30.246	5.2121	9.8087	12.8225	10.7092	13.0298
Geometric Mean	0.0438	0.0104	0.0199	0.0262	0.0218	0.0158
Quartile 3	0.0553	0.0303	0.0410	0.0401	0.0396	0.0270
Maximum	0.0882	0.0923	0.1068	0.1341	0.1296	0.0699
SE Mean	0.0015	0.0021	0.0021	0.0021	0.0021	0.0012
LCL Mean (0.95)	0.0411	0.0067	0.0162	0.0225	0.0181	0.0136
UCL Mean (0.95)	0.0469	0.0149	0.0244	0.0307	0.0263	0.0184
Variance	0.0004	0.0008	0.0008	0.0008	0.0008	0.0003
Stdev	0.0203	0.0289	0.0289	0.0289	0.0289	0.0171
Skewness	-0.0138	-0.9667	-0.4418	0.9235	1.1884	0.0552
Kurtosis	-0.6379	3.6116	2.8647	1.2631	1.3443	0.0952
Maximum Drawdown		0.4571	0.1973	0.0968	0.0403	0.0981
Historical VaR (95%)		-0.0221	-0.0175	-0.0047	-0.0046	-0.0123
Historical CVaR (95%)		-0.0735	-0.0365	-0.0124	-0.0050	-0.0191
Modified VaR (95%)		-0.0419	-0.0289	-0.0119	-0.0138	-0.0117
Modified CVaR (95%)		-0.0812	-0.0604	-0.0209	-0.0295	-0.0189
Sharpe Ratio (Rf=4,4%)		-0,0053	-0,0018	-0,0012	-0,0012	-0,0048

Table 6: Summary statistics for the monthly percentage excess returns from the yield curve arbitrage strategies for the sample period from November 1988 to December 2011 with CMS data from Bloomberg™.

	Risk_free	YC2	YC3	YC5	YC7	YCEW
Observations	278	278	278	278	278	278
NAs	0	0	0	0	0	0
Minimum	0.0001	-0.1251	-0.1395	-0.0365	-0.0056	-0.0315
Quartile 1	0.0166	0.0000	-0.0013	0.0006	-0.0010	0.0051
Median	0.0411	0.0081	0.0169	0.0233	0.0116	0.0156
Arithmetic Mean	0.0367	0.0125	0.0208	0.0261	0.0219	0.0163
t-stat for the Arithmetic Mean	26.729	7.2296	12.0268	15.097	12.6294	15.6153
Geometric Mean	0.0365	0.0121	0.0204	0.0257	0.0215	0.0161
Quartile 3	0.0509	0.0282	0.0407	0.0420	0.0398	0.0283
Maximum	0.0882	0.1051	0.1164	0.1427	0.1377	0.0764
SE Mean	0.0014	0.0017	0.0017	0.0017	0.0017	0.0010
LCL Mean (0.95)	0.0340	0.0091	0.0174	0.0227	0.0185	0.0142
UCL Mean (0.95)	0.0394	0.0159	0.0242	0.0295	0.0253	0.0183
Variance	0.0005	0.0008	0.0008	0.0008	0.0008	0.0003
Stdev	0.0229	0.0289	0.0289	0.0289	0.0289	0.0174
Skewness	-0.0043	-0.9475	-0.2073	1.0841	1.3330	0.2692
Kurtosis	-0.8255	4.9522	3.2014	1.6547	1.6877	0.4364
Maximum Drawdown		0.4991	0.2111	0.1201	0.0432	0.1087
Historical VaR (95%)		-0.0234	-0.0049	-0.0048	-0.0048	-0.0095
Historical CVaR (95%)		-0.0679	-0.0341	-0.0120	-0.0051	-0.0195
Modified VaR (95%)		-0.0393	-0.0264	-0.0107	-0.0126	-0.0107
Modified CVaR (95%)		-0.0875	-0.0546	-0.0221	-0.0342	-0.0173
Sharpe Ratio (Rf=3,67%)		-0,0036	-0,0012	-0,0009	-0,0008	-0,0035

Table 7: Summary statistics for the monthly percentage excess returns from the yield curve arbitrage strategies for the sample period from November 1988 to December 2004 with CMS data from Thompson Reuters Datastream™.

	Risk_free	YC2	YC3	YC5	YC7	YCEW
Observations	194	194	194	194	194	194
NAs	0	0	0	0	0	0
Minimum	0.0088	-0.1157	-0.0681	-0.0283	-0.0051	-0.0251
Quartile 1	0.0300	0.0000	-0.0019	-0.0002	-0.0017	0.0063
Median	0.0489	0.0000	0.0167	0.0304	0.0123	0.0207
Arithmetic Mean	0.0440	0.0105	0.0235	0.0276	0.0230	0.0169
t-stat for the Arithmetic Mean	30.246	5.0897	11.3466	13.3318	11.081	14.3289
Geometric Mean	0.0438	0.0101	0.0231	0.0272	0.0226	0.0168
Quartile 3	0.0553	0.0303	0.0446	0.0386	0.0380	0.0276
Maximum	0.0882	0.0952	0.1171	0.1364	0.1379	0.0770
SE Mean	0.0015	0.0021	0.0021	0.0021	0.0021	0.0012
LCL Mean (0.95)	0.0411	0.0065	0.0194	0.0235	0.0189	0.0146
UCL Mean (0.95)	0.0469	0.0146	0.0276	0.0317	0.0271	0.0193
Variance	0.0004	0.0008	0.0008	0.0008	0.0008	0.0003
Stdev	0.0203	0.0289	0.0289	0.0289	0.0289	0.0165
Skewness	-0.0138	-0.9709	0.2860	1.0829	1.3140	-0.0644
Kurtosis	-0.6379	3.7503	-0.2226	1.8509	1.9477	0.3060
Maximum Drawdown		0.4222	0.1693	0.0941	0.0412	0.0813
Historical VaR (95%)		-0.0198	-0.0051	-0.0044	-0.0044	-0.0123
Historical CVaR (95%)		-0.0727	-0.0250	-0.0120	-0.0047	-0.0179
Modified VaR (95%)		-0.0421	-0.0216	-0.0090	-0.0114	-0.0103
Modified CVaR (95%)		-0.0824	-0.0304	-0.0199	-0.0312	-0.0184
Sharpe Ratio (Rf=3,67%)		-0,0057	-0,0017	-0,0703	-0,0012	-0,0369

Table 8: Summary statistics for the monthly percentage excess returns from the yield curve arbitrage strategies for the sample period from November 1988 to December 2011 with CMS data from Thompson Reuters Datastream™.

	Risk_free	YC2	YC3	YC5	YC7	YCEW
Observations	278	278	278	278	278	278
NAs	0	0	0	0	0	0
Minimum	0.0001	-0.1299	-0.0881	-0.0358	-0.0054	-0.0333
Quartile 1	0.0166	0.0000	-0.0010	0.0054	-0.0006	0.0054
Median	0.0411	0.0082	0.0187	0.0221	0.0130	0.0168
Arithmetic Mean	0.0367	0.0123	0.0233	0.0267	0.0227	0.0170
t-stat for the Arithmetic Mean	26.729	7.1063	13.478	15.4427	13.1237	16.846
Geometric Mean	0.0365	0.0119	0.0229	0.0263	0.0223	0.0169
Quartile 3	0.0509	0.0255	0.0442	0.0413	0.0401	0.0288
Maximum	0.0882	0.1086	0.1256	0.1461	0.1467	0.0843
SE Mean	0.0014	0.0017	0.0017	0.0017	0.0017	0.0010
LCL Mean (0.95)	0.0340	0.0089	0.0199	0.0233	0.0193	0.0150
UCL Mean (0.95)	0.0394	0.0157	0.0267	0.0301	0.0261	0.0190
Variance	0.0005	0.0008	0.0008	0.0008	0.0008	0.0003
Stdev	0.0229	0.0289	0.0289	0.0289	0.0289	0.0168
Skewness	-0.0043	-1.0199	0.4456	1.2422	1.4342	0.1434
Kurtosis	-0.8255	5.2705	0.5047	2.3791	2.3482	0.5609
Maximum Drawdown		0.4630	0.2074	0.1180	0.0448	0.1031
Historical VaR (95%)		-0.0238	-0.0050	-0.0045	-0.0045	-0.0099
Historical CVaR (95%)		-0.0682	-0.0240	-0.0118	-0.0049	-0.0190
Modified VaR (95%)		-0.0398	-0.0200	-0.0082	-0.0104	-0.0097
Modified CVaR (95%)		-0.0903	-0.0292	-0.0229	-0.0358	-0.0173
Sharpe Ratio (Rf=3,67%)		-0,0039	-0,0011	-0,0558	-0,0009	-0,0280

Appendix 7 – Linear regression analysis for swap spread arbitrage strategy (until 2004)

Table 9: SS linear regression analysis (until 2004)

Linear Regression	SS2			SS3			SS5			SS7			SS10			EWSS		
Factors	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.
Alpha	0,9820	0,4005	0,3932	-12,7220	0,4338	-5,5185	-8,6200	0,5574	-4,8044	-4,8480	0,6671	-3,2344	-3,9730	0,5861	-2,3287	-5,1390	0,6909	-3,5502
MSUSAM													-2,4890	0,0034	-0,0085			
MSWXUS																		
MSEMKF													2,3080	0,0021	0,0049			
USMGUSRI	-2,0370	0,0103	-0,0210							2,3680	0,0298	0,0706						
USMGEXRI																		
ECUSD1M	-9,0600	0,0728	-0,6593															
GOLDBLN																		
TWEXMMTH																		
CREDITaaa				12,3490	0,1241	1,5320				4,3430	0,8111	3,5228	4,9640	0,7207	3,5773	8,1300	0,1443	1,1733
CREDITbaa							7,2850	0,1351	0,9841	-2,3900	0,7541	-1,8023	-2,7150	0,6779	-1,8405			
TED																-2,2350	0,6376	-1,4250
TERM										-2,4230	0,0134	-0,0326						
VALGRTH																		
SMLG																		
MOM																		
VIX																		
INF				2,9050	0,1910	0,5550												
FINANCE	5,6880	0,6815	3,8767													3,2670	0,5439	1,7770
Multiple R^2		0,3842			0,4445			0,2165			0,4885			0,5878			0,5135	
Adjsusted R^2		0,3744			0,4386			0,2125			0,4777			0,5791			0,5059	

Appendix 8 – Linear regression analysis for yield curve arbitrage strategy (until 2004)

Table 10: YC linear regression analysis (until 2004)

Linear Regression Factors	YC2			YC3			YC5			YC7			YCEW		
	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.
Alpha	-3,4700	2,1851	-7,5834	-2,1230	2,3488	-4,9875	5,8630	0,8674	5,0856	5,7580	0,8452	4,8667	-1,1560	1,3624	-1,5753
MSUSAM				2,5970	0,0051	0,0133							2,0370	0,0029	0,0058
MSWXUS															
MSEMKF															
USMGUSRI	3,3850	0,0371	0,1257	2,7270	0,0405	0,1104	4,1310	0,0378	0,1561	4,1150	0,0376	0,1549	4,7470	0,0228	0,1084
USMGEXRI															
ECUSD1M	3,6230	0,2900	1,0507	3,3110	0,3096	1,0251							3,1770	0,1747	0,5549
GOLDBLN										2,6660	0,0044	0,0118			
TWEXMMTH															
CREDITaaa	4,4930	0,3697	1,6610	2,7400	0,3970	1,0879	2,2520	1,0290	2,3179	4,1660	1,0143	4,2255	2,7500	0,6732	1,8515
CREDITbaa							-2,7310	0,9562	-2,6116	-4,4890	0,9434	-4,2354	-2,0410	0,5960	-1,2165
TED	-4,2220	1,4725	-6,2166	-3,5210	1,5678	-5,5197							-3,3090	0,9302	-3,0782
TERM	-2,9660	0,0168	-0,0498	-2,3300	0,0183	-0,0427	-4,0310	0,0170	-0,0687	-4,0070	0,0169	-0,0679	-4,4010	0,0103	-0,0454
VALGRTH	-2,0640	0,0179	-0,0369												
SMLG	-2,1610	0,0192	-0,0416												
MOM															
VIX				2,4240	0,0013	0,0031							2,3620	0,0007	0,0017
INF	-2,6170	0,3059	-0,8005	-2,3590	0,3331	-0,7858	-2,5130	0,2339	-0,5878				-3,1370	0,1880	-0,5897
FINANCE	3,8830	1,4334	5,5662	2,7540	1,5185	4,1825							3,2470	0,8780	2,8511
Multiple R^2		0,2626			0,1715			0,1819			0,2045			0,2675	
Adjsusted R^2		0,2265			0,1310			0,1602			0,1834			0,2274	

Appendix 9 – Linear regression analysis for swap spread arbitrage strategy (until 2011)

Table 11: SS linear regression analysis (until 2011)

Linear Regression Factors	SS2			SS3			SS5			SS7			SS10			EWSS		
	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.
Alpha	-0,2020	0,2720	-0,0548	-0,6040	0,8025	-0,4849	0,3500	0,8563	0,2996	1,7290	0,6381	1,1033	5,2050	0,9045	4,7080	0,0660	0,5897	0,0390
MSUSAM				-3,5500	0,0028	-0,0101				-3,5720	0,0024	-0,0087	-3,7290	0,0028	-0,0106	-3,4580	0,0021	-0,0072
MSWXUS																		
MSEMKF	2,3150	0,0018	0,0041	3,0330	0,0018	0,0054				4,3680	0,0015	0,0066	3,9780	0,0018	0,0071	3,8810	0,0013	0,0050
USMGUSRI																		
USMGEXRI																		
ECUSD1M	-12,1820	0,0518	-0,6315	-4,3130	0,0940	-0,4054	-5,6240	0,0943	-0,5303	-4,8090	0,0693	-0,3334	-5,5130	0,0969	-0,5341	-5,2010	0,0691	-0,3592
GOLDBLN							2,6000	0,0026	0,0067									
TWEXMMTH																		
CREDITaaa				5,2160	0,1483	0,7738	2,2560	0,1590	0,3587	6,2090	0,3805	2,3627	3,3960	0,4441	1,5082	6,0610	0,1090	0,6607
CREDITbaa										-3,5530	0,3464	-1,2307	-2,4870	0,4060	-1,0097			
TED				-3,6780	0,4106	-1,5104				-3,5410	0,2783	-0,9854	-4,4040	0,3423	-1,5076	-5,2620	0,3018	-1,5880
TERM																		
VALGRTH																		
SMLG																		
MOM																		
VIX	2,3750	0,0007	0,0016															
INF													-3,1940	0,1176	-0,3756			
FINANCE	8,7290	0,3654	3,1890	3,6500	0,5628	2,0541										4,0610	0,4136	1,6795
Multiple R^2		0,4641			0,6161			0,4065			0,7238			0,6261			0,6985	
Adjsusted R^2		0,4562			0,6076			0,4000			0,7177			0,6165			0,6918	

Appendix 10 – Linear regression analysis for yield curve arbitrage strategy (until 2011)

Table 12: YC linear regression analysis (until 2011)

Linear Regression Factors	YC2			YC3			YC5			YC7			YCEW		
	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.	t-stat	std.err	est.
Alpha	-2,2940	1,4044	-3,2215	8,0220	0,2574	2,0651	9,9310	0,4772	4,7393	8,5900	0,4988	4,2851	5,6100	0,2323	1,3034
MSUSAM															
MSWXUS															
MSEMKF															
USMGUSRI	2,7740	0,0243	0,0675	3,2440	0,0236	0,0764	3,2410	0,0225	0,0729	3,2000	0,0228	0,0731	3,0540	0,0150	0,0458
USMGEXRI													2,1030	0,0035	0,0074
ECUSD1M	2,3590	0,1645	0,3881										3,0670	0,0456	0,1397
GOLDBLN										2,1390	0,0030	0,0065			
TWEXMMTH															
CREDITaaa										2,8760	0,5259	1,5125			
CREDITbaa	3,6880	0,2199	0,8109				-5,1580	0,0963	-0,4967	-3,8470	0,4549	-1,7499			
TED	-4,0370	0,7362	-2,9719										-3,7840	0,3256	-1,2319
TERM	-2,1260	0,0093	-0,0197	-2,5640	0,0090	-0,0230	-2,9550	0,0086	-0,0253	-2,9280	0,0087	-0,0254	-2,9420	0,0054	-0,0159
VALGRTH															
SMLG															
MOM															
VIX															
INF				-3,0550	0,1496	-0,4570	-3,8850	0,1403	-0,5452	-3,1970	0,1600	-0,5117	-3,5990	0,1024	-0,3686
FINANCE	3,3460	0,9083	3,0395							2,3980	0,5421	1,2998	3,6540	0,4733	1,7290
Multiple R^2		0,1123			0,07314			0,1877			0,1892			0,1849	
Adjsusted R^2		0,0926			0,0630			0,1757			0,1682			0,1638	