The Evaluation of the Trend-Following Directional Change with the Trailing Stop and Major-Trend-Adjusted Strategies on Algorithmic Trading in the Foreign Exchange Markets

Sanhanat Paniangtong

A thesis submitted in partial fulfilment of the requirements for the degree of

Master of Science in Algorithmic Trading

Supervisor: Professor Edward Tsang

Centre for Computational Finance and Economic Agents (CCFEA)

University of Essex

August 2015

ACKNOWLEDGEMENT

First of all, I would like to show my sincere gratitude to my supervisor, Professor Edward Tsang, for his invaluable knowledge, consistent encouragement and unwearying patience. My dissertation would not have been the same without his support.

In addition, I would like to acknowledge all of the CCFEA members for the data contribution and programming advice.

A special thank goes to David Norman for his inspiration to further me to explore systematic trading ideas and software.

Lastly, in particular, I would like to express my heartfelt gratitude to my family for the unconditional support throughout the year.

ABSTRACT

Directional Change is a new way to summarise and capture periodic price activities as well as significant changes in time series using an event-based time scale. Suggested by the scaling law, there exist high profit opportunities in the foreign exchange market thanks to the remarkably long length of currency coastline. This dissertation aims to provide new insights into the directional-change trading strategy in the foreign exchange market using high-frequency data with the implementation of algorithmic trading. We extend the trend-following directional-change trading strategy by incorporating ideas of the trailing stop and trend based on the concept of the scaling law, in an attempt to acquire more statistically uniformly positive results in terms of profitability as well as overall performance. We backtest on historical major currency pairs across multiple directional-change thresholds, and conduct a post-trade analysis to investigate the impact of the trailing stop as well as the effect of trend. Finally, we present a new discovery in the directional-change event strategy suggested by the results of the extended strategies.

TABLE OF CONTENTS

TABLE OF EXHIBITS

1. INTRODUCTION

1.1 ALGORITHMIC TRADING IN THE FOREX MARKET

As Indicated by its name, the Forex market (foreign exchange or FX market) is a market where currencies are exchanged between banks, financial institutions, currency speculators and investors. With an estimated $4 trillion in daily trading transactions, the Forex market is considered one of the most liquid and the fastest growing markets in the world [1]. Most transactions are short-term since the participants aim to quickly generate returns. For successful trading in the Forex market, one requires extensive knowledge in order to predict movements of exchange rates [2].

Aloud, Tsang, Olsen and Dupris in [3] presented an interesting idea of using the directional-change event to characterize price movement and to capture the short-term dynamics of the Forex market. It is suggested that a trading model should be built on the basis of the directional-change event approach, which is believed to be a robust foundation in order to study financial time series.

The finding of Glattfelder, Dupuis and Olsen in [4] indicates that there exist high profit potentials for a currency pair on the tick-by-tick price-curve coastline length, defined by intrinsic time. On average, the profitability is around 1600% per year, which is remarkably long. This means that a coastline offers a great deal of profit opportunities. Moreover, by using scaling laws, Sorin in [5] was also able to observe higher profit opportunities in high-frequency forex data in comparison to data at lower frequency. Another finding in Aloud [6] is that the length of price-curve coastline measured through the directional-change event

approach is remarkably longer than that measured by the physical time. These studies confirm the similar outcomes discovered by Glattfelder et al.

To consistently gain profits in the Forex market, one requires a robust tool to trade currencies. Owing to advanced computational technology, algorithmic trading has become widespread in financial markets over the past decade. Since the algorithm is self-learning and purely empirical, it follows a pre-determined set of trading rules based on computational model without human bias and emotion involved.

Tsang suggests in [7] that an investor could do better with a support of computer trading whenever patterns repeat themselves in the market. Computer trader can consistently operate nonstop all day as well as the Forex market, unlike human traders. According to Giampaoli [8], it is recommended that one should use high-frequency trading to trade in the Forex market whereby a strategy strictly enters and exits positions based on a pre-set rule.

In its simplest form, the high-frequency trading involves extremely quickly moving in and out of trades with the collection of tiny but steady gains. Dempster, Payne, Romahi, and Thompson used intraday high-frequency data for foreign exchange trading in an attempt to maximize return and minimize risk [9]. By using high-frequency data, it indicates significant profit potentials because a trader can earn higher profitability by trading on every price move.

1.2 RESEARCH QUESTION

Sorin in [5] exhibits a performance of the directional change portfolio with regard to annualized Sharp ratio and Sortino ratio. The portfolio usually outperforms the market as it takes advantage on the price overshoot moves. Nonetheless, the coastline trader could encounter market risk, the risk of capital losses arising from the loss-making movement against the trader's favour [10][11]. It can be observed that nearly 40% of the results show negative values, whereas some are crucial. Although the study was not undertaken an analysis of these negative values, it could be implied that the model might have inefficient risk management and lack proper exit strategy. Furthermore, when testing and evaluating a trading system, most prior studies have limited perspective of what contributes to successful investment decisions.

As far as we know, none of the literature has identified a directional-change trading strategies which constantly generates positive results in the case of all exchange rates. This poses a research hypothesis that statistical values of the directional-change portfolio can be uniformly positive [12].

2. LITERATURE REVIEW

This chapter reviews existing findings and literatures pertaining the field of trading strategy. The first part describes recent studies of scaling laws applied to our strategies. The second part deals with the use of risk management. Finally, the third part elaborates on the literature regarding the multiple states of trends.

2.1 THE SCALING LAWS AND THE FX COASTLINE

2.1.1 INTRINSIC TIME AND THE DIRECTIONAL CHANGE

Analysing time series is a key step before building a robust trading model. It is suggested that one should understand financial markets by studying their time scales. Typically, trading activities in financial markets tend to vary depended on the time of day, which normally defined by physical time [8].

Dacorogna, Muller, Olsen, Dave, Ward and Pictet in [13] introduced “intrinsic time”, a new time scale which is independent from the idea of the physical time. Defined by events, intrinsic time is inhomogeneous in time and also replaces the assumption of physical time which fails to capture important events. Muller et al. successfully incorporated intrinsic time scale to a Forex forecasting model, allowing them to capture short-term dynamics and present price movements as well as important information in a significant manner.

Afterwards, Glattfelder et al. [4], Sorin [5], and Aloud [6] highlighted the importance of the intrinsic time because it puts forward not only a new perspective of the Forex market, but

also a key concept to develop a profitable trading model, i.e., the directional-change event approach model.

In the concept of the intrinsic time, Glattfelder et al. exhibited the insights from their finding that the mean absolute price movement in the directional-change event approach between two extreme points (highest and lowest points) can be decomposed into two components : (Let P denote the price and $\triangle P$ denote the price change)

1) Fixed directional-change threshold of $\triangle P_{dc}$

2) Stochastic overshoot event of $\triangle P_{os}$, expressing the price movement beyond a fixed threshold $\triangle P_{dc}$.

This leads to the total move $\triangle P_{tm}$, which represents the absolute price change between two extreme points and can be defined as:

$$\langle | \triangle P_{tm} | \rangle = \langle | \triangle P_{dc} | \rangle + \langle | \triangle P_{os} | \rangle$$

More precisely, an overshoot event begins after a directional change event has been confirmed by a price change of a fixed threshold ($\triangle P_{dc}$). Such threshold defines the minimum price move between two extreme points and characterizes the directional-change event, depending on whether the direction is assumed to be upward or downward. The price direction alternates at each occurrence of the directional-change event. The difference between the previous low (or high) and the price corresponding to that directional-change event determines the overshoot event of $\triangle P_{os}$ [8].

2.1.2 THE SCALING LAW

Glattfelder et al. in [4] discovered twelve new independent scaling laws in time series by using statistical analysis based on the directional-change event approach. The scaling laws

give functional correspondences between occurrences of an observed property measuring at different scales. As the markets can be viewed as a complex system which consists of interacting participants, it seems that high-frequency data in the Forex time series are constrained by the scaling laws [14].

There is a quantitative relationship between the scaling laws discovered by Glattfelder et al. which is worth mentioning.

- A directional-change event ($\triangle P_{dc}$) of size **θ%** is followed by an overshoot event of the same size

$$(\langle \triangle P_{dc} \rangle \approx \langle \triangle P_{os} \rangle)$$

The research suggested that once a directional change event of threshold size θ% has been confirmed, it will be followed by an overshoot of, on average, equal magnitude (θ%) [6].

The most interesting feature is that this relationship not only exposes what uniformly occurs in the Forex market, but also presents that the directional change is observable. These events are independent of the threshold and follow the pattern of the scaling laws, offering tremendous profitable opportunities to traders [15].

2.2 RISK MANAGEMENT AND TRAILING STOP

Dacorogna et al. [16] view that, to acquire more constantly profitable performances, a real-time trading model in the Forex market should have stop-loss algorithm support. With regard to market risk mitigation, Aldridge [10] mentions the trailing stop in order to limit the amount of loss from a losing position. Also, the literature suggests that the performance of the stop-loss-enabled trading strategy needs to be confirmed by a backtesting algorithm.

Paniangtong in [17] describes that the trailing stop offers more striking feature than a regular fixed stop as the trailing feature allows the trailing stop to follow the last current market price by the pre-determined percentage, supposing the price proceeds in profit-making direction. On the contrary, it will not move if the price moves in the unfavourable direction. As soon as the price reaches the trailing-stop level, the position will be automatically closed at the current market price, preventing further risk to the capital. In other words, the trailing stop is self-adjust, moving from limiting downside risks to protecting profits with an automatically executed order.

Durbin [18] suggests that using the trailing stop could be the best possible ideas to protect portfolio value in order to trade in high-frequency trading era. It is pointed out in [12] that using trailing stop tends to increase a chance to outperform the markets whereby it functions as a backup plan**,** securing the capital by determining how much loss can be tolerated and when to exit for the highest possible returns. Having trailing stop built in what-if scenarios, traders can control risks and eliminate emotions from the trading process over time.

Kaminski and Lo in [19] contrast the performance of the stop-loss strategy with other strategy. The results strongly indicate that the stop-loss strategy shows outperformance in all areas. In addition, Bergsveinn and Garib in [20] present empirical results which mirror those of Kaminski and Lo. They point out that stop-loss strategy has a positive marginal impact on portfolio returns.

2.3 TREND

Forex traders adopt history price charts to study the currency market since 1970 by using the foundation of the Dow Theory, focusing on the entire market situation by observing market major trends, i.e, uptrend, downtrend and sideway [21]. Traders can use trend dynamic to ascertain a major trend since it basically holds the notion that prices reveal their fundamentals [1]. James discusses in [22] that a trend-following strategy yields interesting returns, and can be applied systematically to any currency portfolios. By studying history price time series, it helps traders to identify trends and to project the price trends to trade with them rather than against them.

A major trend consists of several minor trends which moves in opposite direction to the major trend and takes shorter period. Another characteristic of the minor trend is that it often moves with more volatility than that of the major move [24]. Supposing the major price trend is downward and there is an upward correction followed by a continuation of the downtrend, these moves are considered to be minor trends.

As Forex traders, observing trends would be great help to determine the value of the exchange rates they are trading. Unfortunately, trends cannot be spotted easily in high-frequency trading [1]. There are a few studies explaining how trends exhibit themselves in the Forex market and high-frequency data.

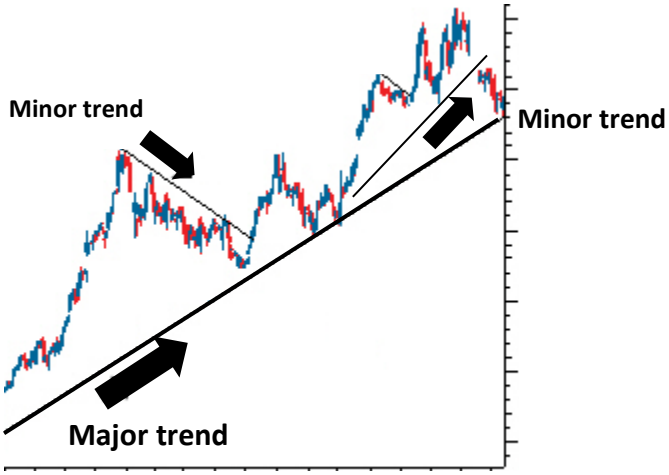

Exhibit 1: The illustration of major and minor trends [23]

Murphy in [25] suggests that minor trends, which are not long-term, can be found in the Forex market. They could be of great importance to Forex traders to pay much attention in order to make profit. Sieczka and Holyst in [26] proposed a model to investigate how trends behave in the high-frequency data. The study concludes that trends in the high-frequency time series show limited lengths. This emphasizes the notion of trends in high-frequency data being short-term.

3. PERFORMANCE INDICATORS

In order to evaluate and compare the performance across the six strategies, five different measures are applied.

- Cumulative return
- Maximum drawdown
- Profit factor
- Winning rate
- Sharpe ratio

By looking at the return alone, it will not allow us to understand strategies' strengths and weaknesses in depth. It is important to review additional metrics in order to justify the potential profitability and the performance of the strategies in more different comprehensive aspects.

3.1 CUMULATIVE RETURN

Cumulative return is simply the total net realized profit (or loss) of all trades made by each strategy per one contract throughout the period, presented in pips. Pip stands for the smallest increment of an exchange rate price movement, either up or down. Most currencies are measured 1 pip as four decimal places (0.0001), which is equal to 10 USD [27]. In other words, the cumulative return in this study is the total pip (or length of the overshoot event coastline) made by each strategy for a certain currency pair per one contract. Also, cumulative return of the extended strategies will be compared to the initial strategy in terms of percentage change.

$$\text{Percentage change in return} = \frac{\text{Cumulative return of each of extended strategy} - \text{Cumulative return of the initial strategy}}{|\ \text{Cumulative return of the initial strategy}\ |} \times 100$$

It is calculated by dividing the difference between cumulative return of each strategy and cumulative return of the initial strategy by the absolute value of cumulative return of the initial strategy. This metric is shown in %. It simply gives a reading of the degree to which the other strategies outperform (or underperform) the initial strategy.

3.2 MAXIMUM DRAWDOWN

Maximum drawdown refers to the largest peak-to-trough loss or decline for a trading period. It can be viewed as "worst-case scenario" for a strategy. The smaller the value of the maximum drawdown, the better strategy is. This metric can help for assessing and measuring the amount of risk incurred by the system. Also, it can determine whether or not a system is practical with respect to an account size by comparing the relative riskiness of one strategy with another [28].

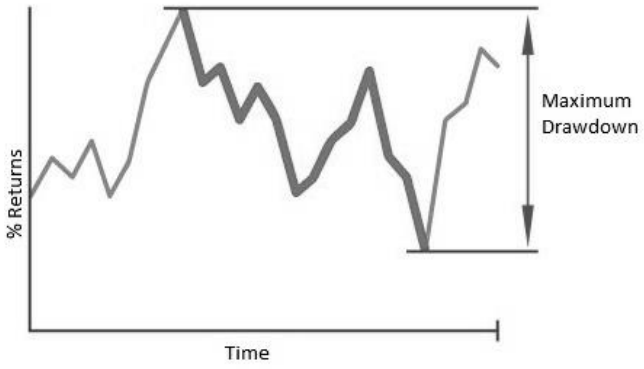

Exhibit 2: The illustration of maximum drawdown **(source: [28])**

3.3 PROFIT FACTOR

Profit factor suggests the real profitability of a series of trades. Profit Factor is simply calculated by dividing gross profit by gross loss.

Profit factor = Gross profit / Gross loss

The metric simply gives a reading of the degree to which gains are greater than losses. It relates the amount of profit per unit of risk. Higher value is better. Normally, traders pick strategies with the profit factor higher than 1, which suggests a profitable system. If gross profit is lesser that gross loss, this leads to a profit factor that is less than 1, suggesting a losing strategy [29][30].

3.4 WINNING RATE

The winning rate, or the probability of winning, can be obtained from comparing the number of winning trades to the number of total trades for a specified period.

Winning rate = Winning trades / Total number of trades

For high-frequency trading, it requires a significantly high winning rate to ensure a winning system due to the fact that the number of winning trades, in general, tends to be close in value to the number of losing trades. That is to say, major trades should be winners because profit from each trade is relatively small [29].

3.5 SHARPE RATIO

The Sharpe ratio or reward-to-variability ratio, developed by William Forsyth Sharpe, is a measure of the risk premium (or excess return) per unit of total risk in a trading strategy. Sharpe ratio is calculated by subtracting the risk-free rate from mean of returns and dividing the result by standard deviation of portfolio returns. It is defined as:

$$SR = \frac{R - Rf}{\sigma} = \frac{E(R - R_f)}{\sqrt{VAR(R - R_f)}}$$

where R = Expected value of returns

R_f = Risk-free rate

σ = Standard deviation of portfolio returns

In our strategies, no risk-free rate is considered as this study is not concerned with optimization between risk-free assets and portfolio. Regarding the expected value of returns (R), it is calculated as arithmetic average of respective means.

The Sharpe ratio is used to describe how much the return of an asset compensates the extra volatility (risk) endured [31]. When compare two strategies, the one with the higher Sharpe ratio are more preferable since it indicates more return for the same risk, and translates into greater risk-adjusted performance. This means that Sharpe ratio indicates to investors whether the returns of a portfolio are obtained through a smart trading strategy or excessive risk [32][33][34].

4. DESIGN OF TRADING STRATEGIES

4.1 TRADING ALGORITHMS

The main objective of these algorithms is to automate decisions, i.e., when to long or short (enter), when to go out of a winning position (exit), when to go out of a losing position (stop). Furthermore, they are built to perform back-tests for currency pairs and to measure coastline trading performances. They are also able to track all of the trading transactions. Each strategy differently spot exit signals by observing the behaviour of a currency on the upside run and on the downside run based on specific rules, whereas entry signals are the same for all strategies. All of complete MATLAB algorithm codes are provided in the enclosed CD.

Strategy 1 exploits the whole idea of trend-following directional-change event trading approach. Its performance will be used for comparison against the other five extended strategies, which combines directional-change event principle with other methodologies (shown in Exhibit 3).

The idea of **strategy 2** is derived from [12] illustrating the way the trailing stop incorporates into the directional-change approach. The trailing stop will be moving from minimizing losses to protecting profits with an automatically executed order, in order to limit the amount of loss and prevent further risk to capital from a losing position, as soon as the price reaches the trailing-stop level.

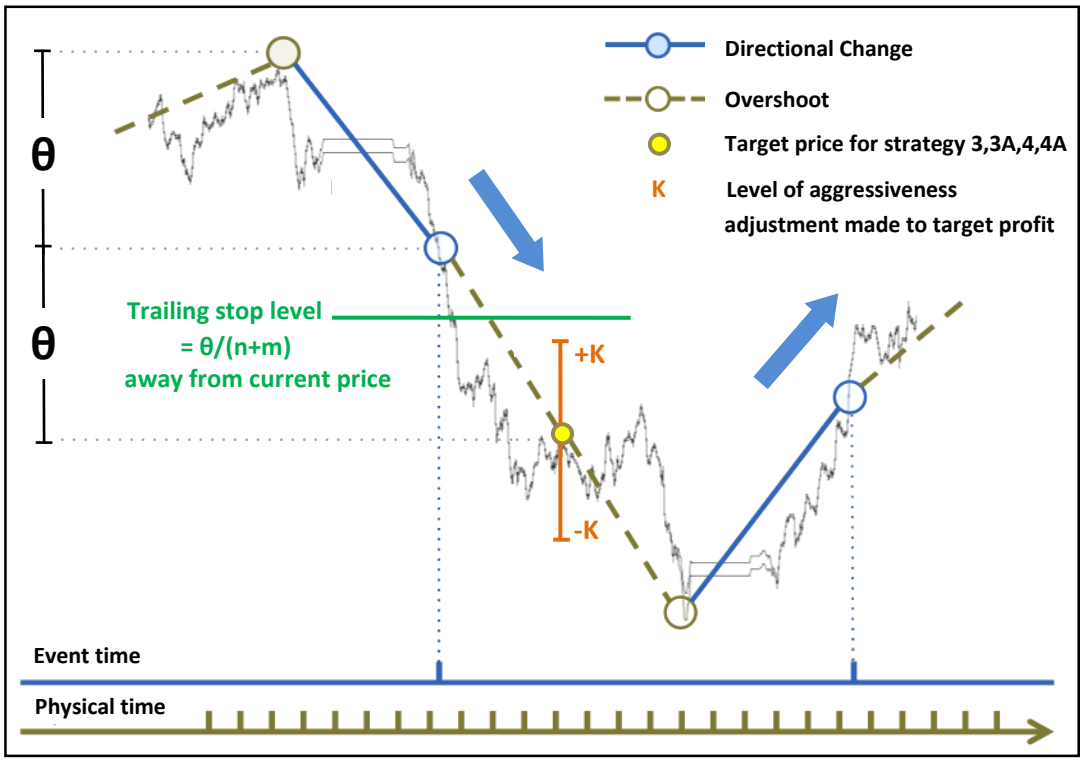

Exhibit 3: The overview of the directional-change strategies, decomposing a price change between two extreme points, and the extended strategy incorporating the ideas of trailing stop and trend (Source: Adapted from [14])

The notions of **strategy 3 and 3A** are inspired by the scaling law and Paniangtong in [17], suggesting a systematic foreign exchange trading portfolio, whereby the profit is made when an overshoot event has proceeded by another threshold, and target profit should be flexibly adjusted corresponding to the current major trend direction. The major trend and the minor trend will be taken into consideration.

By putting the above mentioned strategies all together, this leads to **strategy 4 and 4A** that can be simply explained that profits can be made on the overshoot events, while a trader could adjust the trailing stop and profit target based on the levels of risk appetite and profit objective the trader prefers to be. The higher adjustment indicates more aggressiveness

when being on the same side of the current major trend, whereas it indicates less aggressiveness when being in the opposite direction of the current major trend.

In each strategy, a pseudocode will be firstly illustrated. It is followed by the explanations of how the algorithm works. Each strategy is assigned to eight different fixed thresholds: 0.01%, 0.03%, 0.1%, 0.4%, 0.5%, 0.7%, 0.9% and 1%. Mid-price, an average value of bid price and ask price at a certain time, is used as the current prices in the market.

$$P_t = (Bid_t + Ask_t)/2$$

An order can be either bought (long) or sold (short). It is placed by a market order, which immediately executes at the current mid-price. In the end, the algorithms generate a trading report containing fourteen columns of detail for each transaction:

(i) Trend

(ii) Side (Long,Short)

(iii) Entry Index

(iv) Entry price

(v) Entry rule

(vi) Exit Index

(vii) Exit price

(viii) Exit rule

(ix) Profit target

(x) Return

(xi) Return (%)

(xii-xiii) How a trade exits

(xiv) Extreme value of a trade

4.1.1 STRATEGY 1: Trend-Following Directional Change (TFDC)

Input

- Dataset of currency pair
- Threshold (θ%)

Strategy explanation

Algorithm (i) performs trend-following directional change strategy by taking advantage of the price move, assuming the current move will continue in the same direction. In an upward run, the value of last highest price is updated continuously to the extreme variable. Similarly, in a downward run, the value of the last lowest price is updated continuously to the extreme variable. An upturn event is confirmed when the absolute price change between the current price and the most recent lowest extreme variable is equal to or more than the fixed threshold **θ%**, while an downturn event is confirmed when the absolute price change between the current price and the most recent high extreme variable is equal to or more than the fixed threshold **θ%**.

By way of brief illustration, the algorithm enters long or short positions on the currency being trade once the current price meets the rule.

Algorithm (i): The illustration of the core mechanism for the Strategy 1"*Trend-Following Directional Change (TFDC)"*

Input: data, threshold (θ) ($X = P_1$, $100\% \geq \theta \geq 0.01\%$)
Default input: mode = up, status = no position

if mode is up **then**
    if $P_t \leq X \times (1- \theta)$ **then**
        mode = down
        $X = P_t$
        EXIT LONG
        ENTER SHORT
        status = position being held
    else
        $X = \max(X, P_t)$
    end if
else // mode is down
    if $P_t \geq X \times (1+ \theta)$ **then**
        mode = up
        $X = P_t$
        EXIT SHORT
        ENTER LONG
        status = position being held
    else
        $X = \min(X, P_t)$
    end if
end if
Output: trading report, performance indicators

Trading rules summary

- **1.1 Enter Long & Exit Short**: at price = $\mathbf{P_{ext} \times (1+\theta)}$ (when price increases by threshold θ%; upturn event is confirmed)
- **2.1 Enter Short & Exit Long**: at price = $\mathbf{P_{ext} \times (1-\theta)}$ (when price decreases by threshold θ%; downturn event is confirmed)

Output

- Trading report
- Performance indicators

4.1.2 STRATEGY 2: Trend-Following Directional Change with Trailing Stop (TFTSDC)

Input

- Dataset of currency pair
- Threshold (θ%)
- Trailing stop level (**n**); where **n** = 2 for this strategy

Strategy explanation

Algorithm (ii) performs trend-following directional change strategy which enables a trailing stop behind the price. This strategy aims to protect coastline trader's profits as the current currency price moves in trader's profit-making direction and reaches the next extreme value. As discussed, the trailing stop is self-adjust, offering an advantage of protection against losses with an automatically executed order. It moves from minimizing losses to protecting profits.

The level of trailing-stop of θ/2% is applied, where θ% is direction-change threshold. For example, if an upward directional-change event with threshold of θ% has been confirmed, this accompanies an overshoot event. The trailing stop will follow behind the last highest price by a gap of θ/2%. The trailing stop will be triggered only if the price during the overshoot event touches the trailing-stop level by pulling back from the highest price for θ/2%.

Algorithm (ii): The illustration of the core mechanism for the Strategy 2 "*Trend-Following Directional Change with Trailing Stop (TFTSDC)*"

Input: data,threshold (θ),trailing stop level (n) **(** $x = P_1, 100\% \geq \theta \geq 0.01\%$, stop = θ/n, n > 1 **)**
Default input: mode = up, status = no position

if mode is up **then**
    if status = no position **then**
        if $P_t \leq x \times (1-\theta)$ **then**
            ENTER SHORT
            Update: mode, x, trailing stop level, status = position being held
        else
            $x = \max(x, P_t)$
        end if
    endif
    if status = position being held **then**
        if $P_t \leq x \times (1-\theta)$ **then**
            EXIT LONG, ENTER SHORT
            Update: mode, x, trailing stop level
        else if P_t has reached trailing stop level **then**
            EXIT LONG
            Update: status = no position
        else
            $x = \max(x, P_t)$
            Update: trailing stop level
        end if
    end if
else // mode is down
    if status = no position **then**
        if $P_t \geq x \times (1+\theta)$ **then**
            ENTER LONG
            Update: mode, x, trailing stop level, status = position being held
        else
            $x = \min(x, P_t)$
        end if
    end if
    if status = position being held **then**
        if $P_t \geq x \times (1+\theta)$ **then**
            EXIT SHORT, ENTER LONG
            Update: mode, x, status, trailing stop level
        else if P_t has reached trailing stop level **then**
            EXIT SHORT
            Update: status = no position
        else
            $x = \min(x, P_t)$
            Update: trailing stop level
        end if
    end if
end if
Output: trading report, performance indicators, trailing stop summary

Trading rules summary

- **1.1 Enter Long**: open at price = $\mathbf{P_{ext} \times (1+\theta)}$ (when price increases by threshold θ%, upturn event is confirmed)

  1.2 Exit Long by trailing stop: when the price pulls back from the most recent highest price by **1+(θ/n)**

- **2.1 Enter Short:** open at price = $\mathbf{P_{ext} \times (1-\theta)}$ (when price decreases by threshold θ%; downturn event is confirmed)

  2.2 Exit Short by trailing stop: when the price retraces from the most recent lowest price by **1+(θ/n)**

Output

- Trading report
- Performance indicators
- Trailing stop report

4.1.3 STRATEGY 3: Trend-Following Directional Change with Major-Trend-Adjusted aggressiveness (TADC1/2)

Input

- Dataset of currency pair
- Threshold (θ%)
- Level of aggressiveness (**k**); where $\mathbf{k} = \frac{\theta}{2}$

Strategies explanation

Algorithm (iii) illustrates the pseudocode of **strategy 3**, trend-following directional-change strategies which adopts the ideas of trend based on the concept of the scaling law. **Strategy 3** has two novelties. Firstly, the strategy suggests that a trader should exit a position in order to take profits once the overshoot size has proceeded by the same magnitude of the directional change. This is because, according to the scaling laws based on the intrinsic time framework, an overshoot event of similar size of θ% usually occurs after a directional-change event of size θ%. Secondly, **strategy 3** takes the effects of both major trends and the minor trends into consideration. The overshoot event can be larger or smaller than θ% due to the study of the effects of trends in the high-frequency data and the Forex market in [25] and [26]. As a consequence, the strategy is designed to adjust the level of aggressiveness (**k**) corresponding to the current major trend. The higher level of adjustment in aggressiveness indicates the different amount of target return the trader expects to gain or lose.

The major trend is considered uptrend once the price increases for **2θ%** above the lowest extreme variable, while the major trend is changed to downtrend once the price decreases for **2θ%** below the highest extreme variable. The target profits are expected to be large when a position has been entered on the same side of the current major trend, whereas the program is less aggressive and take smaller profits when being on the opposite side of the current major trend. For instance, the major trend is uptrend, and supposing the price has increased for **θ**% above the lowest price, the program enters a long position and becomes aggressive. It will set a target profit at **2θ+k** above the extreme variable. On the other hand, if price has decreased for **θ**% below the highest variable, the program enters a short position and becomes less aggressive. It will set a profit target at **2θ+k** below the highest extreme variable. However, once the price has decreased for **2θ%** below the highest extreme point, the major trend is changed to downtrend.

Algorithm (iii): The illustration of the core mechanism for the strategy 3&3A"Trend-Following Directional Change with Major-Trend-Adjusted aggressiveness (TADC)"

Input: data,threshold (θ),aggressiveness level (k) **(**$x = P_1, 100\% \geq \theta \geq 0.01\%, \theta \geq k \geq 0$**)**
Default input: mode = up, status = no position, trend = unknown

if trend is unknown **then**
    if P_t changes for 2θ **then**
        Update: x, trend = uptrend or downtrend
    else if Pt changes for θ in the opposite direction of mode **then**
        EXIT A POSITION, ENTER A POSITION
        Update: mode, target price, x, status = position being held
    else if P_t has not reached the target price **then**
        Update: x
    else P_t has reached the target price **then**
        EXIT A POSITION
        Update: x, status = no position
    end if
end if

if trend is known **then**
    if Pt changes for 2θ in the opposite direction to the current trend **then**
        Update: x, trend = uptrend or downtrend
    end if
    if mode is similar to (or different from) trend **then**
        if status = no position **then**
            if P_t changes for θ in the opposite direction to mode **then**
                ENTER A POSITION (LONG OR SHORT)
                Update: mode, target price, x, status = position being held
            else
                Update: x
            end if
        end if
        if status = position being held **then**
            if Pt changes for θ in the opposite direction to mode **then**
                EXIT A POSITION, ENTER A POSITION
                Update: mode, target price, x, status = position being held
            else if P_t has not reached the target price **then**
                Update: x
            else P_t has reached the target price **then**
                EXIT A POSITION
                Update: x, status = no position
            end if
        end if
    end if
end if
Output: trading report, performance indicators, trailing stop summary

Trading rules summary

- **Trend is Uptrend**: whenever price = $\mathbf{P_{ext} \times (1+2\theta)}$ (when price increases by 2θ%)

  Trend is Downtrend: whenever price = $\mathbf{P_{ext} \times (1-2\theta)}$ (when price falls by 2θ%)

- **1.1 Enter Long (& Exit Short)**: at price = $\mathbf{P_{ext} \times (1+\theta)}$ (when price increases by threshold θ%; upturn event is confirmed)

  1.2 Exit Long (Take profit)

  1.2.1 Exit Long by taking profit in uptrend: (being aggressive)

  close at price = $\mathbf{P_{ext} \times (1+2\theta+k)}$

  1.2.2 Exit Long by taking profit in downtrend: (being less aggressive)

  close at price = $\mathbf{P_{ext} \times (1+2\theta-k)}$

  1.2.3 Exit Long by taking profit in unknown trend:

  close at price = $\mathbf{P_{ext} \times (1+2\theta)}$

- **2.1 Enter Short (& Exit Long)**: at price = $\mathbf{P_{ext} \times (1-\theta)}$ (when price decreases by threshold θ%; downturn event is confirmed)

  2.2 Exit Short (Take profit)

  2.2.1 Exit Short by taking profit in uptrend: (being less aggressive)

  close at price = $\mathbf{P_{ext} \times (1-2\theta+k)}$

  2.2.2 Exit Short by taking profit in downtrend: (being aggressive)

  close at price = $\mathbf{P_{ext} \times (1-2\theta-k)}$

  2.2.3 Exit Short by taking profit in unknown trend:

  close at price = $\mathbf{P_{ext} \times (1-2\theta)}$

Output

- Trading report
- Performance indicators

4.1.4 STRATEGY 3A: Strategy 3 with more aggressiveness adjustment (TADC3/4)

Strategy 3A is similar to **strategy 3**, but the only difference is the level of aggressiveness, where **k** = $\frac{3}{4}\theta$. This means that the target profits will be more adjusted to the current major trend than **strategy 3**. The target profits are expected to be greater than the target profits of strategy 3 as the program is more aggressive when being on the same side of the current major trend, whereas, when the program is on the opposite side of the current major trend, the returns will be realized sooner as target profits are more adjusted.

4.1.5 STRATEGY 4: Trend-Following Directional Change with Trailing Stop and Major-Trend-Adjusted aggressiveness (TATSDC1/2)

Input

- Dataset of currency pair
- Threshold (θ%)
- Level of aggressiveness (**k**); where **k** = $\frac{\theta}{2}$
- Trailing stop level (**n**); where **n** = 2 for this strategy
- Trailing stop aggressiveness level (**m**); where **m** = 0.5

Strategies explanation

Putting it all together, algorithm (iv) illustrates two strategies which combine the ideas of algorithm (i), (ii) and (iii). This leads to **strategy 4 and 4A**. In other words, **Strategy 4** is basically the **strategy3** that enables trailing-stop function.

Algorithm (iv): The illustration of the core mechanism for the Strategy 4&4A "Trend-Following Directional Change with Trailing Stop and Major-Trend-Adjusted aggressiveness (TATSDC)"

Input: data,threshold (θ),aggressiveness level (k), trailing stop level (n), trailing stop aggressiveness (m), **(**$x = P_1$,$100\% \geq \theta \geq 0.01\%$, $\theta \geq k \geq 0$, stop = θ/n, $n>1$, $(n-m)> 1$, $n \neq m$, $n>m$ **)**

Default input: mode = up, status = no position, trend = unknown

if trend is unknown **then**
- **if** P_t changes for 2θ **then**
  - Update: x, trend = uptrend or downtrend
- **else if** Pt changes for θ in the opposite direction of mode **then**
  - EXIT A POSITION, ENTER A POSITION
  - Update: mode, target price, x, status = position being held
- **else if** P_t has not reached the target price **then**
  - Update: x
- **else if** P_t has reached the target price **then**
  - EXIT A POSITION
  - Update: x, status = no position
- **else** P_t has reached trailing stop level
  - EXIT A POSITION
  - Update: status = no position
- **end if**

end if

if trend is known **then**
- **if** Pt changes for 2θ in the opposite direction to the current trend **then**
  - Update: x, trend = uptrend or downtrend
- **end if**
- **if** mode is similar to (or different from) trend **then**
  - **if** status = no position **then**
    - **if** P_t changes for θ in the opposite direction to mode **then**
      - stop = $\theta/(n \pm m)$
      - ENTER A POSITION
      - Update: mode, target price, x, trailing stop level, status = position being held
    - **else**
      - Update: x
    - **end if**
  - **end if**
  - **if** status = position being held **then**
    - **if** Pt changes for θ in the opposite direction to mode **then**
      - stop = $\theta/(n \pm m)$
      - EXIT A POSITION, ENTER A POSITION
      - Update: mode, target price, x, trailing stop level
    - **else if** P_t has not reached the target price **then**
      - Update: x, trailing stop level
    - **else if** P_t has reached the target price **then**
      - EXIT A POSITION
      - Update: x, status = no position
    - **else** P_t has reached trailing stop level
      - EXIT A POSITION
      - Update: status = no position
    - **end if**
  - **end if**
- **end if**

end if

Output: trading report, performance indicators, trailing stop summary

Unlike strategy 3 and 3A, if the price moves in opposite direction and triggers the trailing stop level, **strategy 4** proposes an exit in order to protect the capital. A trader can fix the level of aggressiveness (**k**) and trailing stop (**m**) based on the maximum amount he is willing to receive profits as well as to absorb losses. In case the price moves in the loss-making direction and reaches the trailing-stop level, the position will be closed at the current market price to prevent any further losses.

It can be simply explained that profits can be made on the overshoot events, while a trader could adjust the trailing stop level and profit targets based on the levels of risk appetite and profit objective the trader prefers to be. The higher adjustment indicates more aggressiveness when being on the same side of the current major trend, whereas it indicates less aggressiveness when being in the opposite direction of the current major trend.

Trading rules summary

- **Trend is Uptrend**: whenever price = $\mathbf{P_{ext} \times (1+2\theta)}$ (when price increases by 2θ%)

  Trend is Downtrend: whenever price = $\mathbf{P_{ext} \times (1-2\theta)}$ (when price falls by 2θ%)

- **1.1 Enter Long**: open at price = $\mathbf{P_{ext} \times (1+\theta)}$ (when price increases by threshold θ%; upturn event is confirmed)

  1.2 Exit Long (Take profit)

  1.2.1 Exit Long by taking profit in uptrend: (being aggressive)

  close at price = $\mathbf{P_{ext} \times (1+2\theta+k)}$

  1.2.2 Exit Long by taking profit in downtrend: (being less aggressive)

  close at price = $\mathbf{P_{ext} \times (1+2\theta-k)}$

  1.2.3 Exit Long by taking profit in unknown trend:

  close at price = $\mathbf{P_{ext} \times (1+2\theta)}$

1.3 Exit long by trailing stop

1.3.1 Exit Long by trailing stop in uptrend: (being aggressive)

when price pulls back from the highest price by **1+(θ/(n-m))**

1.3.2 Exit Long by trailing stop in downtrend: (being less aggressive)

when price pulls back from the highest price by **1+(θ/(n+m))**

1.3.3 Exit Long by trailing stop in unknown trend:

when price pulls back from the highest price by **1+(θ/n)**

- **2.1 Enter Short:** open at price = $\mathbf{P_{ext} \times (1-\theta)}$ (when price decreases by threshold θ%; downturn event is confirmed)

2.2 Exit Short (Take profit)

2.2.1 Exit Short by taking profit in uptrend: (being less aggressive)

close at price = $\mathbf{P_{ext} \times (1-2\theta +k)}$

2.2.2 Exit Short by taking profit in downtrend: (being aggressive)

close at price = $\mathbf{P_{ext} \times (1-2\theta -k)}$

2.2.3 Exit Short by taking profit in unknown trend:

close at price = $\mathbf{P_{ext} \times (1-2\theta)}$

2.3 Exit Short by trailing stop

2.3.1 Exit short by trailing stop in uptrend: (being less aggressive)

when price retraces from the lowest price by **1+(θ/(n+m))**

2.3.2 Exit short by trailing stop in downtrend: (being aggressive)

when price retraces from the lowest price by **1+(θ/(n-m))**

2.3.3 Exit short by trailing stop in unknown trend:

when price retraces from the lowest price by **1+(θ/n)**

Output

- Trading report
- Performance indicators
- Trailing stop report summary

4.1.6 STRATEGY 4A: Strategy 4 with more aggressiveness adjustment (TATSDC3/4)

Strategy 4A is similar to **strategy 4**, but the only difference is the level of aggressiveness, where $k = \frac{3}{4}\theta$. This means that the target profits will be more adjusted to the current major trend than **strategy 4**.

4.2 STRATEGIES SUMMARY

Strategy	Name	Composition of strategy
1	TFDC	Trend-Following Directional Change
2	TFTSDC	Trend-Following Directional Change Trailing stop (**n**=2)
3	TADC1/2	Trend-Following Directional Change Trend (**k**= θ/2)
3A	TADC3/4	Trend-Following Directional Change Trend (**k**= 3θ/4)
4	TATSDC1/2	Trend-Following Directional Change Trend (**k**= θ/2) Trailing stop (**n**=2 ,**m**=0.5)
4A	TATSDC3/4	Trend-Following Directional Change Trend (**k**= 3θ/4) Trailing stop (**n**=2 ,**m**=0.5)

Exhibit 4: Summary of the composition of each strategy

5. EMPIRICAL TRADING RESULTS

In this study, the inputs are high-frequency Forex datasets during the period 01/12/2012 to 31/12/2013 of 4 currency pairs; EURUSD, AUDUSD, GBPUSD and USDCAD. The quotes are transformed into the mid-price. With 5 metrics across 8 different directional-change thresholds, each strategy produces 160 results for in-depth analysis, comparing the results against the other five strategies.

Transaction costs are ignored because the number of transactions is the same for a specific threshold. The only differences are the exit prices, while the entry prices are the same. Details of the transactions are provided in the trading reports.

5.1 CUMULATIVE RETURNS

Exhibit 5 presents the cumulative returns (in pips) attained at the end of the period by each strategy. The return is based on 1 contract. The performance of the **strategy 1** is used as a benchmark. Green areas suggest superior performances to the **strategy 1**, while red areas indicate inferiority.

Observations

- As can be observed, **strategy 1** (benchmark) yield negative returns in most experiments, while we can note positive returns in a few cases.
- For the extended strategies, about 81% of the areas are highlighted by green color. This is an indication of having higher cumulative returns compared to the initial strategy.

EURUSD (Cumulative return)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-1.369	-0.726	-0.007	-0.049	**0.053**	0.017
0.03%	-1.703	-1.189	**-0.243**	-0.247	-0.355	-0.307
0.1%	-0.760	-0.482	-0.235	**-0.060**	-0.214	-0.135
0.4%	-0.090	-0.043	**0.028**	-0.029	-0.091	-0.052
0.5%	0.060	0.079	0.056	**0.095**	0.005	0.003
0.7%	-0.050	-0.044	-0.058	**-0.023**	-0.027	-0.052
0.9%	-0.026	-0.004	**0.002**	-0.024	-0.010	-0.013
1%	0.091	0.038	0.101	**0.135**	0.034	0.042
Average	-0.481	-0.296	-0.045	**-0.025**	-0.076	-0.062

GBPUSD (Cumulative return)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-2.965	-1.838	**-0.621**	-0.669	-0.585	-0.615
0.03%	-3.262	-2.062	-0.798	**-0.675**	-0.829	-0.730
0.1%	-1.100	-0.861	-0.313	**-0.279**	-0.540	-0.397
0.4%	-0.066	0.070	0.091	**0.120**	0.022	0.037
0.5%	-0.045	-0.008	-0.032	**0.031**	-0.005	-0.002
0.7%	-0.124	-0.029	-0.067	-0.155	-0.029	**-0.028**
0.9%	-0.025	-0.066	0.071	**0.072**	0.001	0.021
1%	0.097	-0.026	0.115	**0.123**	0.038	0.029
Average	-0.936	-0.602	-0.194	**-0.179**	-0.241	-0.211

AUDUSD (Cumulative return)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-0.934	-0.695	**0.291**	0.231	0.262	0.223
0.03%	-2.217	-1.443	**-0.368**	-0.395	-0.407	-0.423
0.1%	-1.251	-0.932	-0.229	**-0.178**	-0.368	-0.295
0.4%	-0.051	-0.098	**0.054**	-0.020	-0.042	-0.047
0.5%	-0.003	-0.025	-0.002	**0.039**	0.008	0.012
0.7%	-0.053	-0.049	0.124	**0.126**	0.004	0.035
0.9%	-0.192	-0.031	**0.080**	0.049	0.027	0.021
1%	-0.057	-0.010	0.044	**0.051**	-0.044	-0.052
Average	-0.595	-0.410	**-0.001**	-0.012	-0.070	-0.066

USDCAD (Cumulative return)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-1.582	-1.173	**-0.341**	-0.404	-0.400	-0.452
0.03%	-2.039	-1.304	-0.574	**-0.506**	-0.565	-0.532
0.1%	-0.701	-0.536	-0.182	**-0.103**	-0.336	-0.231
0.4%	-0.110	-0.063	**0.005**	-0.001	-0.040	-0.038
0.5%	-0.100	-0.042	-0.043	-0.051	-0.033	**0.014**
0.7%	-0.151	-0.009	-0.057	-0.049	**-0.005**	-0.014
0.9%	-0.110	-0.026	**0.045**	0.002	-0.004	-0.038
1%	-0.111	**0.031**	-0.021	0.016	0.001	0.022
Average	-0.613	-0.390	-0.146	**-0.137**	-0.173	-0.159

Exhibit 5: The cumulative return (presented in pips) attained by each strategy (bold font suggests the most favorable result for a specific threshold, green cell suggests better performance compared to strategy1)

- However, for EURUSD, GBPUSD and AUDUSD, there are noticeable experiments for which cumulative returns of the extended strategies are lower than **strategy 1**.
- For USDCAD, none of the extended strategy yields lower return than the initial strategy.
- By quantifying the number of the highest cumulative returns over the four currencies across six models, another observation is that all strategies, except for **strategy 1**, can yield at least one highest cumulative return. (The highest cumulative return for a specific threshold is highlighted in bold)
    - **Strategy 3A** holds the greatest number, 16 out of 36.
    - **Strategy 3** holds 11 out of 36.
    - **Strategy 4** holds 2 out of 36. Similar observation is noted for **strategy 4A**.
    - **Strategy 2** holds 1 out of 36.
    - **Strategy 1** is the only strategy holding none of the highest cumulative return.

However, when taking a closer look at USDCAD, **strategy 3A** holds fewer number than **strategy 3**.

- For EURUSD, GBPUSD and USDCAD, the highest average cumulative return belongs to **strategy 3A**, but belongs to **strategy 3** for AUDUSD. The lowest average return belongs to **Strategy 1** for all of four currencies.

Additionally, the bar charts in Exhibit 6 compare and show the degree to which the performances of the other five strategies are greater (lower) than the benchmark.

Observations

- As we can observe, the extended trading strategies on average exceed the benchmark for all currencies.
  - **Strategy 2** shows the improvement in cumulative returns by 35% on average.
  - **Strategy 3** shows the improvement in cumulative returns by 86% on average.
  - **Strategy 3A** shows the improvement in cumulative returns by 88% on average.
  - **Strategy 4** shows the improvement in cumulative returns by 80% on average.
  - **Strategy 4A** shows the improvement in cumulative returns by 82% on average.
- We also observe dramatic improvement over 200% in five experiments. The observations were noted by **strategy 3**, **3A and 4A**.
- However, as indicated by threshold 0.5%, 0.9% and 1%, it is not entirely true that these strategies will result in improvements.

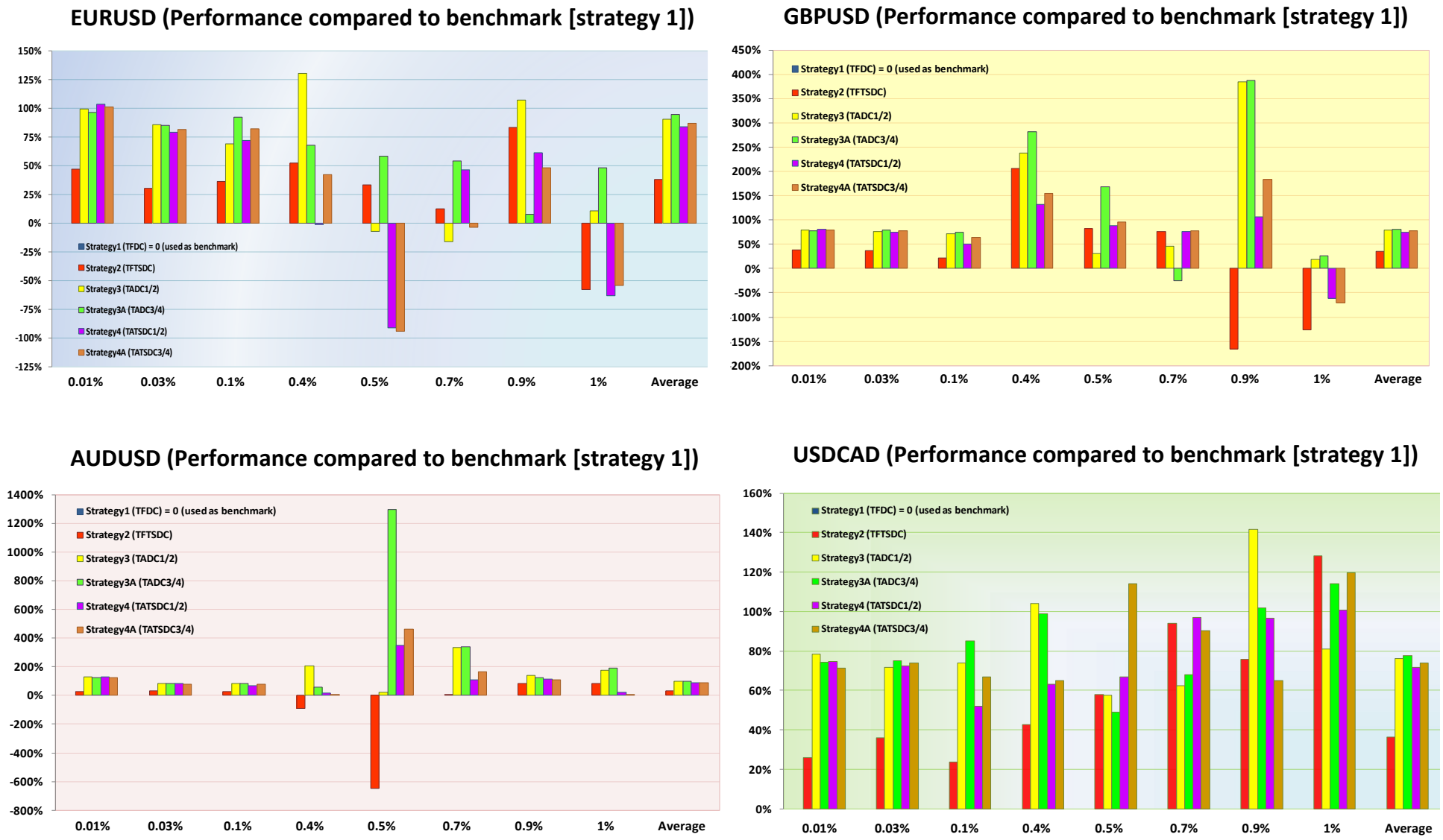

Exhibit 6: Bar chart comparing performance of strategy 2,3,3A,4 and 4A with the initial strategy (strategy1) in terms of profitability and the average value for each threshold

When looking at the Exhibit 7 consisting of line graphs depicting the cumulative returns (in pips) attained by each strategy. The graphs indicate changes in the returns during the whole trading period. (The graphs of the other thresholds are provided in the appendix).

Observations

- In most circumstances, we notice that the cumulative returns of **strategy 1** (benchmark) go down markedly, usually being in the lower half of each graph. With the more trade, the clearer direction we can note.
- The returns of **strategy 2** normally share the same trend with the initial strategy but generally stay on the higher level as they fall by smaller amount. However, in some experiments, they can be in the bottom of the graph.
- The cumulative returns of **strategy 3 and 3A** bear less relation to the initial strategy. They can fall steadily, remain constant, or even show inverse proportion to the initial strategy, as we can observe in AUDUSD, regardless of the threshold size.
- In most cases, the maximum cumulative returns can be found in either **strategy 3 or 3A**, which often is exhibited in the upper half of each graph.
- For smaller thresholds, **strategy 4 and 4A** share similar trends with **strategy 3 and 3A**, seemingly unrelated to the **strategy 1**. However, for larger thresholds, the performances become in the middle, corresponding more closely to the initial strategy.
- The returns of **strategy 4 and 4A** appear to be so paralleled that do not show very distinct difference between one another until the number of trades is high enough.

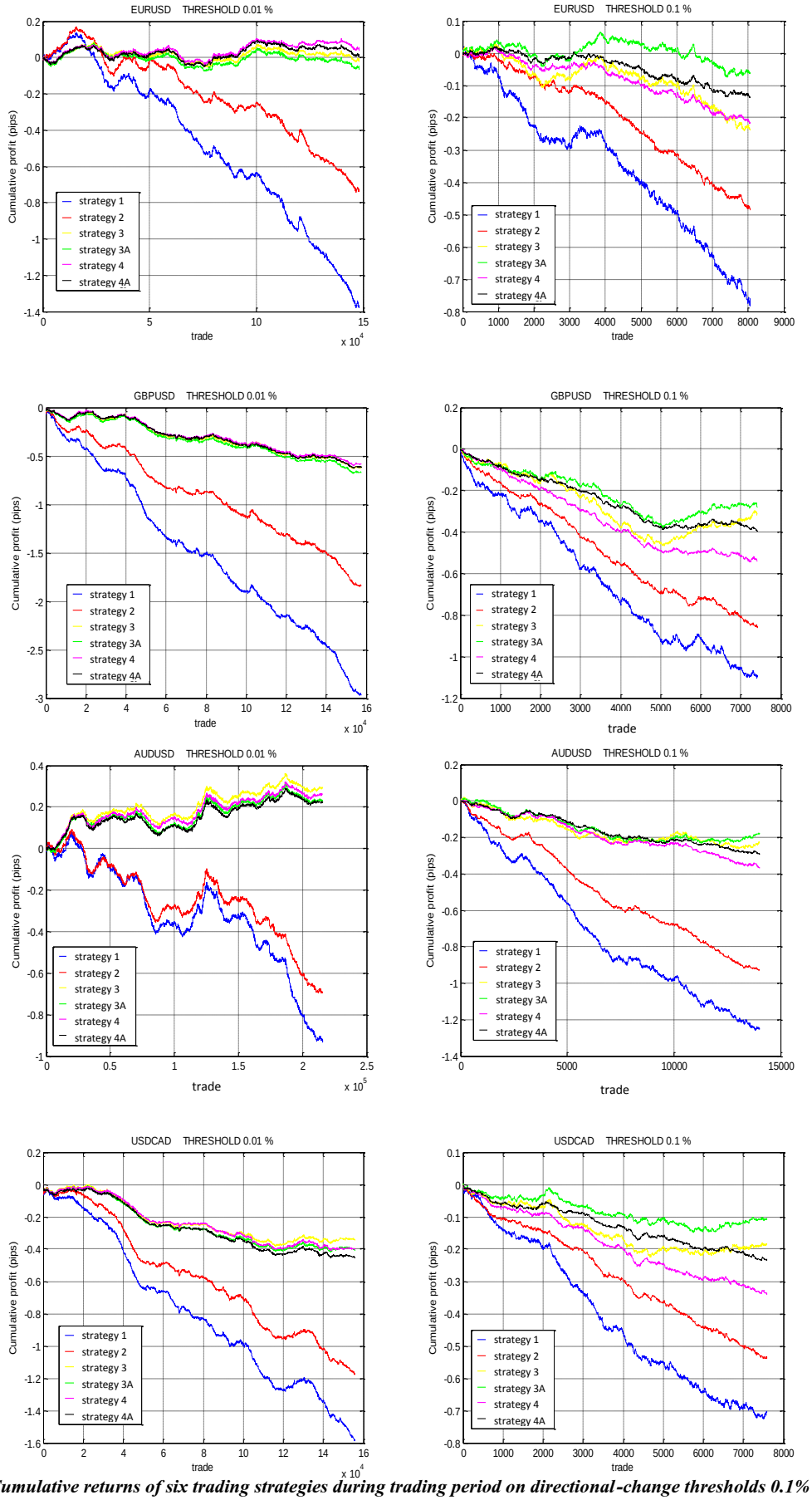

Exhibit 7: Cumulative returns of six trading strategies during trading period on directional-change thresholds 0.1% and 0.01%

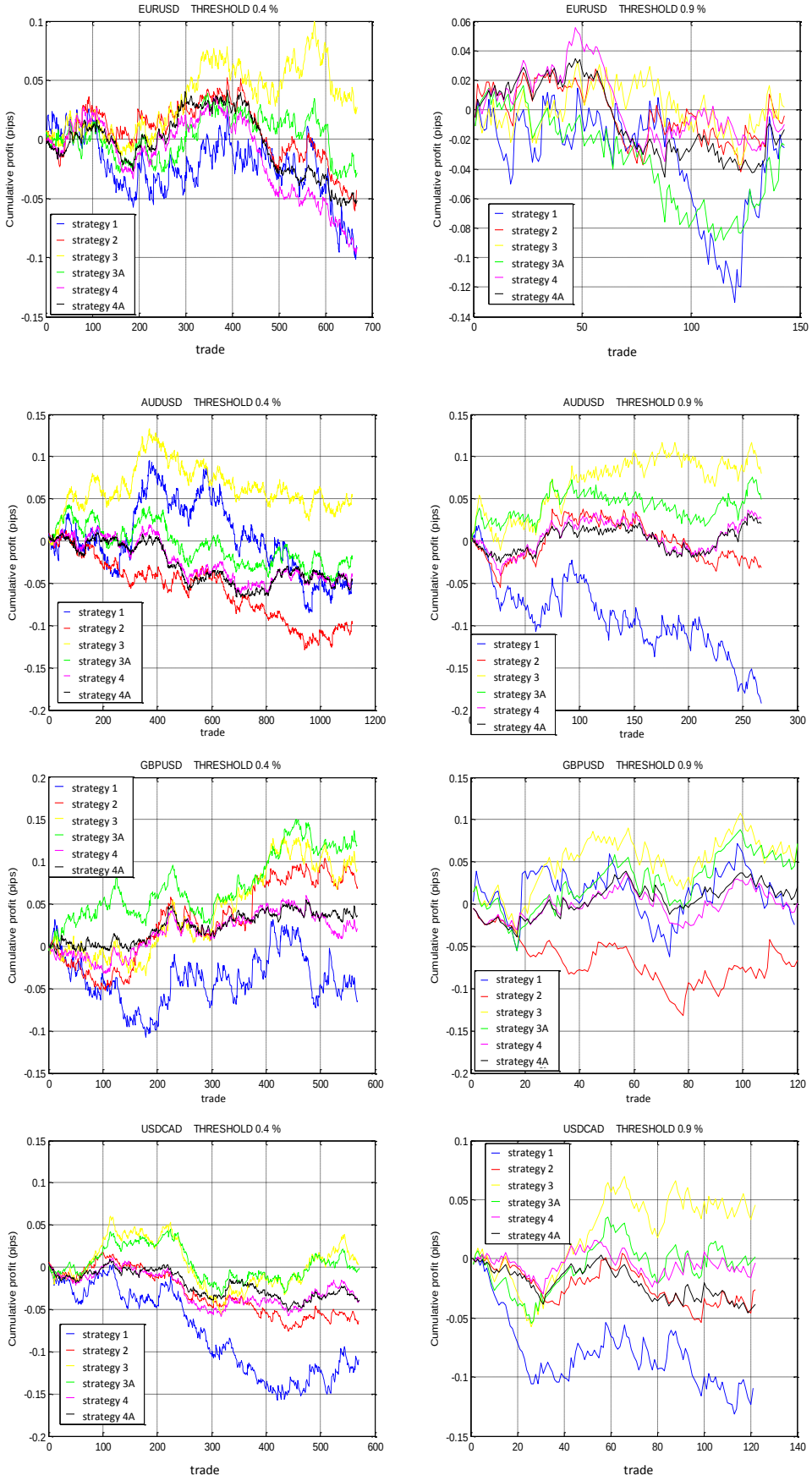

Exhibit 7 (continued): Cumulative returns of six trading strategies during trading period on directional-change thresholds 0.4% and 0.9%

5.2 MAXIMUM DRAWDOWN

Exhibit 7 also identifies the maximum and the minimum of a cumulative return during the trading period, allowing us to point out whether each strategy is robust enough to maintain its cumulative returns. This leads to Exhibit 8, summarising the maximum drawdowns.

Observations

- The values of the extended strategy in most cases are smaller than the value of the initial strategy.
- **Strategy 3A** holds three most favourable maximum drawdowns for EURUSD, **strategy 4** holds those for AUDUSD, and so does **strategy 4A** for GBPUSD.
- **Strategy 3A and 4A** each hold two most favourable average values of maximum drawdown.
- **Strategy 2, 3 and 4** fail to present the most favourable maximum drawdown for some thresholds.
- Also, **strategy 3** rarely holds the most favourable value of maximum drawdown.

EURUSD (Maximum drawdown)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	1.517	0.911	0.137	0.153	**0.107**	0.115
0.03%	1.817	1.279	0.337	**0.324**	0.425	0.369
0.1%	0.803	0.487	0.268	**0.140**	0.236	0.158
0.4%	0.127	0.112	0.078	**0.072**	0.133	0.099
0.5%	0.109	**0.059**	0.087	0.060	0.080	0.065
0.7%	0.122	0.078	0.126	0.078	**0.067**	0.070
0.9%	0.145	**0.069**	0.070	0.105	0.091	0.080
1%	0.097	0.072	0.045	0.033	0.035	**0.030**
Average	0.592	0.383	0.144	**0.121**	0.147	0.123

GBPUSD (Maximum drawdown)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	2.968	1.849	0.629	0.679	**0.599**	0.626
0.03%	3.271	2.065	0.828	**0.693**	0.832	0.733
0.1%	1.101	0.860	0.468	**0.383**	0.541	0.397
0.4%	0.140	0.059	0.062	0.070	0.051	**0.037**
0.5%	0.134	0.106	0.118	0.088	0.078	**0.067**
0.7%	0.203	**0.058**	0.138	0.199	0.070	0.063
0.9%	0.122	0.127	0.073	0.077	0.065	**0.051**
1%	0.067	0.077	0.076	0.056	**0.036**	0.038
Average	1.001	0.650	0.299	0.281	0.284	**0.252**

AUDUSD (Maximum drawdown)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	1.011	0.787	0.104	0.110	**0.102**	0.105
0.03%	2.236	1.446	0.418	0.450	**0.417**	0.433
0.1%	1.268	0.935	0.280	**0.246**	0.371	0.296
0.4%	0.180	0.142	0.109	0.092	0.082	**0.077**
0.5%	0.163	0.074	0.109	0.108	**0.046**	0.062
0.7%	0.173	0.083	0.077	0.057	0.067	**0.045**
0.9%	0.210	0.074	0.066	0.055	0.052	**0.042**
1%	0.111	**0.052**	0.074	0.064	0.074	0.086
Average	0.669	0.449	0.155	0.148	0.151	**0.143**

USDCAD (Maximum drawdown)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	1.587	1.176	**0.382**	0.416	0.408	0.453
0.03%	2.041	1.307	0.576	**0.507**	0.568	0.535
0.1%	0.726	0.538	0.226	**0.149**	0.339	0.235
0.4%	0.162	0.094	0.117	0.079	0.070	**0.061**
0.5%	0.169	0.074	0.061	0.108	0.080	**0.055**
0.7%	0.223	**0.058**	0.135	0.106	0.085	0.076
0.9%	0.133	0.059	0.067	0.061	**0.039**	0.049
1%	0.124	0.051	0.048	0.039	0.056	**0.024**
Average	0.645	0.420	0.202	**0.183**	0.206	0.186

Exhibit 8: Maximum drawdown presented in pips (bold font suggests the most favorable result for a specific threshold, green cell suggests better performance compared to strategy1)

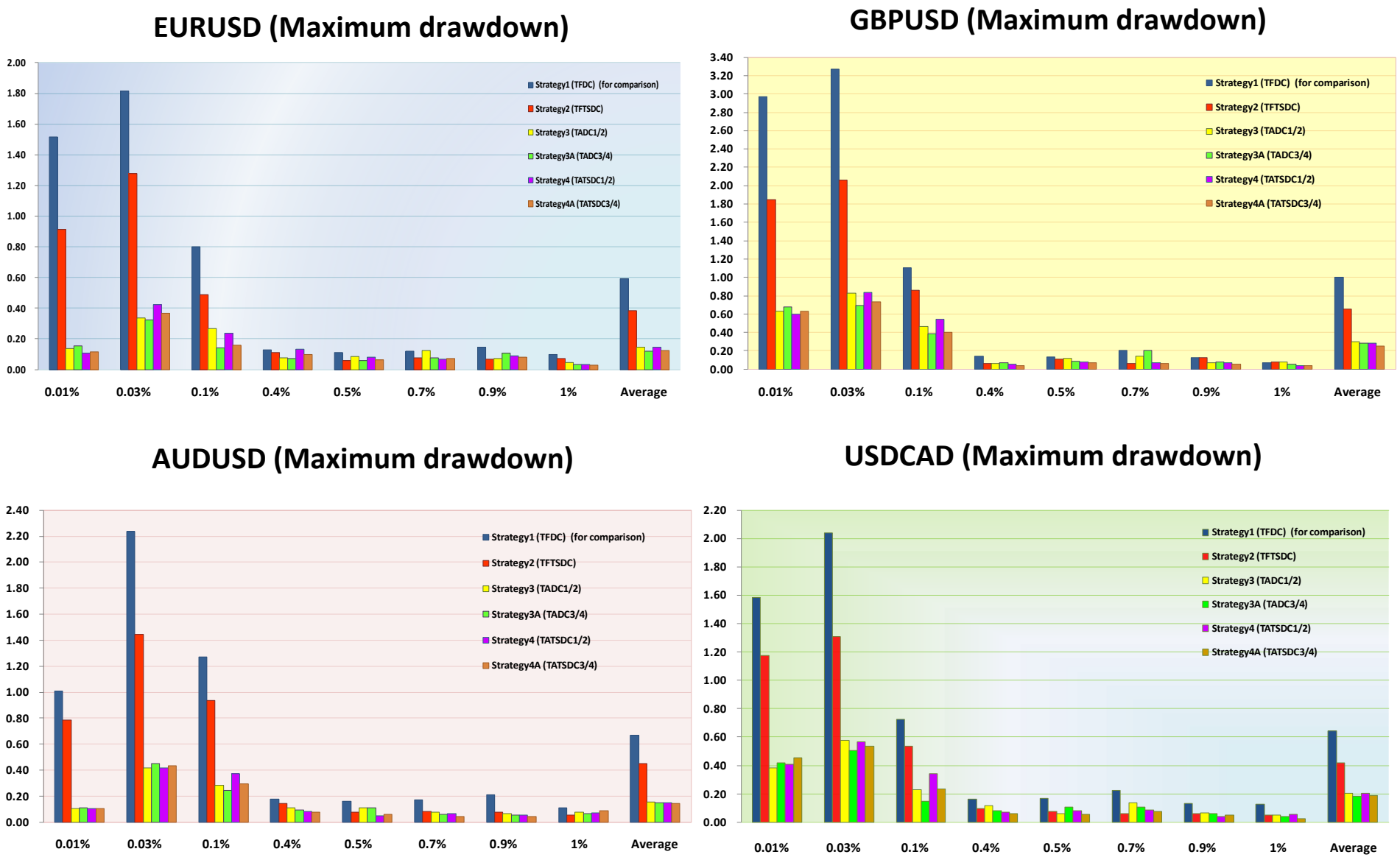

Exhibit 9: Bar chart comparing maximum drawdown and the average value of individual strategies for each threshold

5.3 PROFIT FACTOR

The profit factors higher than 1 signifies having higher amount of profit gained on trades in relation to amount of loss. Exhibit 10 reveals the results in terms of profit factor.

- **Strategy 1** fails to attain profit factors higher than 1 in most experiments.
- 81% of the experiments, highlighted by the green areas, indicate that the extended strategies generate higher profit factors than the initial strategy.
- However, lower measures than the initial strategy can be seen in every strategy. They can be consistently observed in **strategy 2**, producing 13 times in total. Similar observations were noted in **strategy 4 and 4A**, having 7 times on each.
- For USDCAD, none of the strategy is able to attain average profit factors higher than 1.
- **Strategy 3A** achieves the highest number of profit factor higher than 1, resulting in average profit factors higher than 1 for EURUSD, AUDUSD and GBPUSD.
- The highest values of the profit factors are often attained by **strategy 3 and 3A**.

EURUSD (Profit factor)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.931	0.955	1.000	0.997	**1.004**	1.001
0.03%	0.865	0.862	**0.973**	0.968	0.951	0.953
0.1%	0.854	0.842	0.942	**0.980**	0.925	0.943
0.4%	0.938	0.946	**1.023**	0.968	0.884	0.923
0.5%	1.055	1.142	1.063	**1.161**	1.010	1.008
0.7%	0.944	0.906	0.920	**0.955**	0.938	0.867
0.9%	0.961	0.988	**1.003**	0.944	0.971	0.955
1%	1.184	1.142	1.250	**1.557**	1.125	1.192
Average	0.967	0.973	1.022	**1.066**	0.976	0.980

GBPUSD (Profit factor)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.877	0.906	**0.964**	0.960	0.962	0.959
0.03%	0.780	0.797	**0.925**	0.925	0.903	0.904
0.1%	0.806	0.749	**0.930**	0.916	0.832	0.854
0.4%	0.954	1.090	1.077	**1.146**	1.029	1.057
0.5%	0.961	0.987	0.967	**1.046**	0.991	0.997
0.7%	0.863	0.935	0.913	0.746	**0.938**	0.928
0.9%	0.961	0.818	1.131	**1.176**	1.005	1.070
1%	1.201	0.909	1.290	**1.457**	1.144	1.119
Average	0.926	0.899	1.025	**1.046**	0.975	0.986

AUDUSD (Profit factor)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.961	0.965	**1.017**	1.014	1.017	1.014
0.03%	0.860	0.873	**0.967**	0.960	0.956	0.950
0.1%	0.817	0.773	**0.956**	0.954	0.903	0.907
0.4%	0.972	0.903	**1.038**	0.980	0.955	0.941
0.5%	0.998	0.968	0.998	**1.048**	1.011	1.019
0.7%	0.950	0.918	1.143	**1.218**	1.006	1.071
0.9%	0.788	0.936	**1.111**	1.093	1.059	1.053
1%	0.925	0.975	1.073	**1.128**	0.891	0.852
Average	0.909	0.914	1.038	**1.050**	0.975	0.976

USDCAD (Profit factor)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.898	0.908	**0.970**	0.963	0.960	0.954
0.03%	0.789	0.806	**0.917**	0.914	0.899	0.894
0.1%	0.812	0.756	0.937	**0.951**	0.839	0.866
0.4%	0.885	0.875	**1.006**	0.998	0.920	0.911
0.5%	0.870	0.894	0.934	0.895	0.919	**1.042**
0.7%	0.749	0.968	0.885	0.869	**0.984**	0.942
0.9%	0.751	0.881	**1.126**	1.006	0.984	0.825
1%	0.731	**1.172**	0.939	1.068	1.003	1.142
Average	0.811	0.908	**0.964**	0.958	0.938	0.947

Exhibit 10: Profit factor attained by each strategy (bold font suggests the most favorable result for a specific threshold, green cell suggests better performance compared to strategy1)

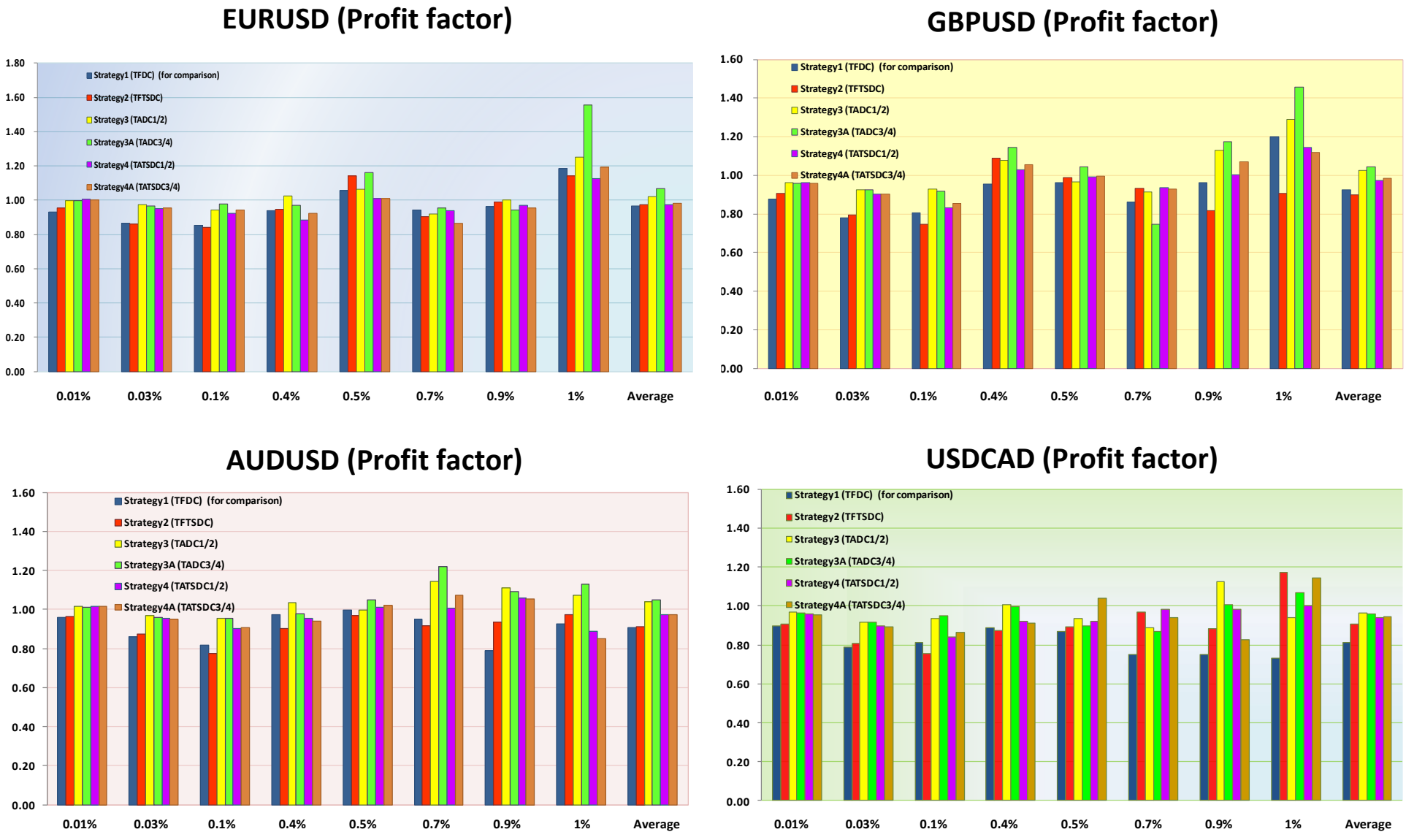

Exhibit 11: Bar chart comparing profit factor and the average value of individual strategies for each threshold

5.4 WINNING RATE

Exhibit 12 and Exhibit 13 depict the comparisons of the winning rate across six strategies.

One immediate observation is that the results share similar trend over the four currencies.

- **Strategy 3A** holds all of the highest winning rates of 69% on average.
- **Strategy 3** comes next with 59% winning rate on average.
- This is followed by **strategy 4A** and **4** with on average 56% and 43%, respectively.
- We can note that **strategy 2** is the only strategy which cannot generate a higher winning rate than **strategy 1**. For this reason, both **strategy 1 and 2** lie last with the same winning rate of 36% on average. **Strategy 2** also quantifies fewer winning rates than **strategy 1**.

EURUSD (Winning rate)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.347	0.340	0.609	**0.620**	0.530	0.544
0.03%	0.340	0.334	0.620	**0.679**	0.493	0.568
0.1%	0.337	0.332	0.591	**0.711**	0.422	0.578
0.4%	0.364	0.346	0.588	**0.692**	0.376	0.533
0.5%	0.365	0.372	0.588	**0.733**	0.393	0.562
0.7%	0.342	0.338	0.552	**0.698**	0.392	0.543
0.9%	0.385	0.343	0.559	**0.671**	0.392	0.552
1%	0.426	0.389	0.620	**0.778**	0.435	0.593
Average	0.363	0.349	0.591	**0.698**	0.429	0.559

GBPUSD (Winning rate)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.343	0.340	0.609	**0.628**	0.527	0.549
0.03%	0.331	0.331	0.617	**0.684**	0.491	0.574
0.1%	0.338	0.317	0.578	**0.695**	0.388	0.547
0.4%	0.369	0.370	0.589	**0.723**	0.400	0.572
0.5%	0.373	0.364	0.568	**0.714**	0.415	0.561
0.7%	0.366	0.365	0.571	**0.670**	0.389	0.562
0.9%	0.378	0.358	0.567	**0.683**	0.400	0.525
1%	0.438	0.400	0.611	**0.744**	0.411	0.544
Average	0.367	0.356	0.589	**0.693**	0.428	0.554

AUDUSD (Winning rate)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.353	0.348	0.599	**0.609**	0.534	0.546
0.03%	0.348	0.343	0.625	**0.674**	0.512	0.574
0.1%	0.348	0.339	0.601	**0.712**	0.432	0.582
0.4%	0.376	0.372	0.601	**0.717**	0.421	0.580
0.5%	0.369	0.388	0.589	**0.726**	0.411	0.586
0.7%	0.370	0.362	0.599	**0.744**	0.387	0.559
0.9%	0.341	0.378	0.607	**0.730**	0.419	0.573
1%	0.353	0.362	0.604	**0.749**	0.394	0.563
Average	0.357	0.362	0.603	**0.708**	0.439	0.570

USDCAD (Winning rate)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	0.344	0.340	0.603	**0.622**	0.526	0.548
0.03%	0.333	0.334	0.616	**0.680**	0.496	0.576
0.1%	0.337	0.328	0.584	**0.707**	0.401	0.566
0.4%	0.360	0.368	0.577	**0.706**	0.401	0.571
0.5%	0.362	0.354	0.559	**0.678**	0.359	0.545
0.7%	0.330	0.358	0.544	**0.672**	0.417	0.559
0.9%	0.314	0.393	0.566	**0.648**	0.393	0.508
1%	0.333	0.380	0.540	**0.710**	0.400	0.590
Average	0.339	0.357	0.573	**0.678**	0.424	0.558

Exhibit 12: Winning rate attained by each strategy (bold font suggests the most favorable result for a specific threshold, green cell suggests better performance compared to strategy1)

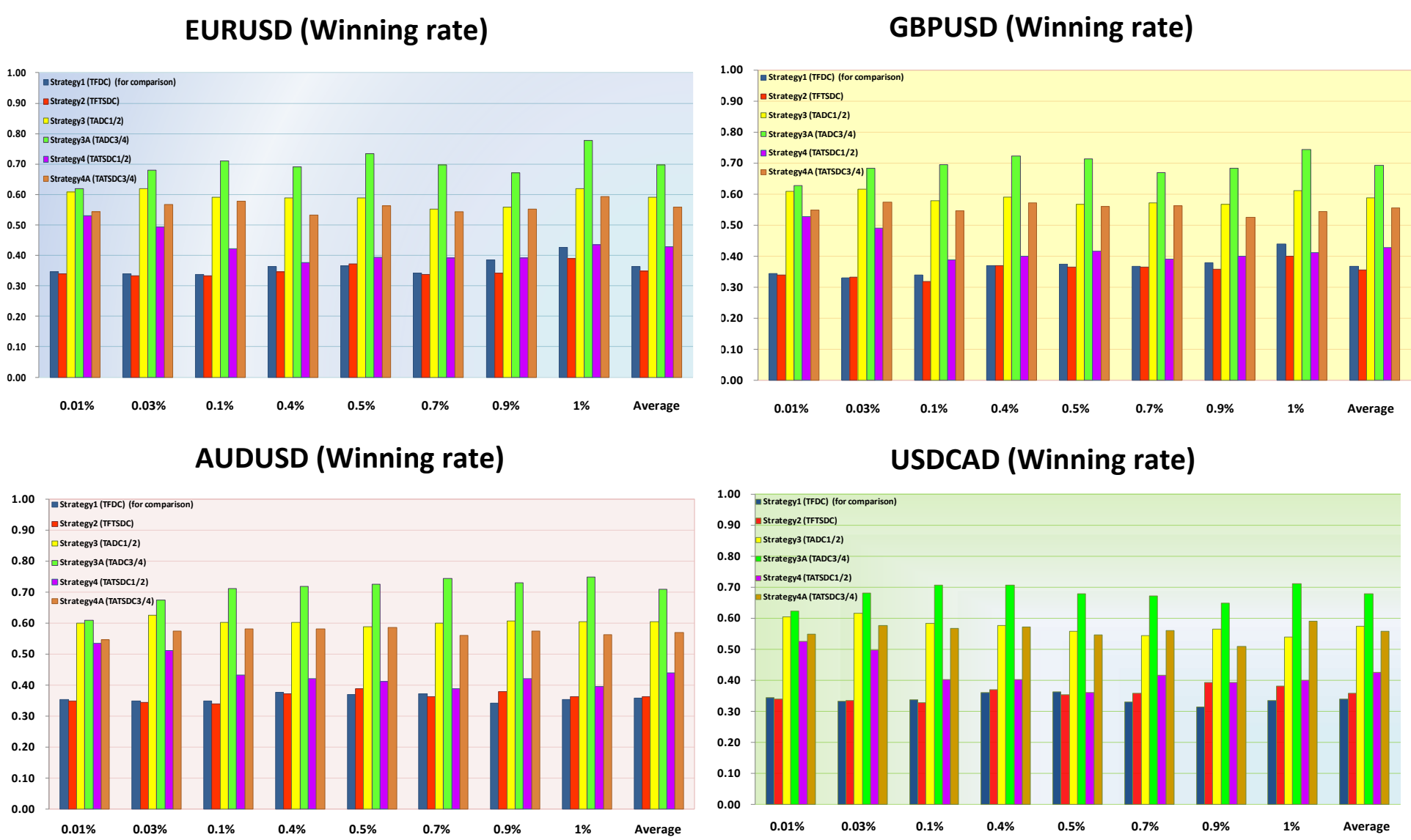

Exhibit 13: Bar chart comparing winning rate and the average value of individual strategies for each threshold

5.5 SHARPE RATIO

As indicated by Exhibit 14, for EURUSD, the highest average Sharpe ratio of all belongs to **Strategy 4A**. The result is in line with AUDCAD and GBPUSD, while the highest Sharpe ratio for USDCAD belongs to **strategy 3**.

Taking a closer look at the average measures (Exhibit 15), illustrating clear pictures of performance comparison across the six strategies, we can group them into 3 groups:

- **Strategy 1 and 2** generate a few positive ratios, whereas most are negative. Their average performances are the lowest two.
- Penultimately, **strategy 3 and 3A** distinctly possess two highest average measures. The results are confirmed across all 4 currencies. We can observe consistent positive ratios for EURUSD, GBPUSD and AUDUSD; however, those for USDCAD are still negative.
- **Strategy 4 and 4A** perform in the middle. Their average Sharpe ratios are not lower than the first group, but do not show much of the improvement.

EURUSD (Sharpe ratio)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-0.024	-0.015	-0.000	-0.001	**0.002**	0.000
0.03%	-0.051	-0.050	**-0.011**	-0.012	-0.020	-0.018
0.1%	-0.057	-0.060	-0.026	**-0.008**	-0.033	-0.023
0.4%	-0.024	-0.020	**0.010**	-0.012	-0.052	-0.032
0.5%	0.019	0.049	0.028	**0.057**	0.004	0.003
0.7%	-0.022	-0.038	-0.038	**-0.018**	-0.027	-0.060
0.9%	-0.016	-0.004	**0.002**	-0.022	-0.013	-0.019
1%	0.066	0.051	0.101	**0.166**	0.049	0.072
Average	-0.013	-0.011	0.008	**0.019**	-0.011	-0.010

GBPUSD (Sharpe ratio)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-0.044	-0.032	**-0.014**	-0.015	-0.014	-0.015
0.03%	-0.088	-0.078	-0.032	**-0.029**	-0.040	-0.037
0.1%	-0.080	-0.105	**-0.032**	-0.033	-0.077	-0.062
0.4%	-0.017	0.030	0.034	**0.052**	0.012	0.023
0.5%	-0.015	-0.005	-0.015	**0.017**	-0.004	-0.001
0.7%	-0.054	**-0.026**	-0.042	-0.118	-0.028	-0.032
0.9%	-0.014	-0.078	0.055	**0.062**	0.002	0.027
1%	0.066	-0.038	0.113	**0.138**	0.055	0.044
Average	-0.031	-0.041	0.008	**0.009**	-0.012	-0.007

AUDUSD (Sharpe ratio)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-0.013	-0.011	**0.006**	0.005	0.006	0.005
0.03%	-0.053	-0.046	**-0.013**	-0.015	-0.017	-0.019
0.1%	-0.074	-0.093	-0.019	**-0.017**	-0.042	-0.037
0.4%	-0.011	-0.038	**0.017**	-0.008	-0.019	-0.025
0.5%	-0.001	-0.013	-0.001	**0.018**	0.005	0.008
0.7%	-0.020	-0.033	0.060	**0.075**	0.003	0.027
0.9%	-0.093	-0.026	**0.048**	0.034	0.025	0.022
1%	-0.030	-0.010	0.032	**0.046**	-0.052	-0.074
Average	-0.037	-0.034	0.016	**0.017**	-0.012	-0.012

USDCAD (Sharpe ratio)

Threshold	Strategy1	Strategy2	Strategy3	Strategy3A	Strategy4	Strategy4A
0.01%	-0.036	-0.031	**-0.012**	-0.014	-0.015	-0.017
0.03%	-0.085	-0.075	-0.035	**-0.033**	-0.042	-0.042
0.1%	-0.077	-0.102	-0.028	**-0.019**	-0.075	-0.057
0.4%	-0.046	-0.049	**0.003**	-0.001	-0.036	-0.039
0.5%	-0.052	-0.044	-0.031	-0.044	-0.035	**0.017**
0.7%	-0.112	-0.012	-0.055	-0.054	**-0.007**	-0.025
0.9%	-0.117	-0.046	**0.054**	0.002	-0.007	-0.080
1%	-0.124	**0.053**	-0.029	0.025	0.001	0.053
Average	-0.081	-0.038	**-0.017**	-0.017	-0.027	-0.024

Exhibit 14: Sharpe ratio attained by each strategy (bold font suggests the most favorable result for a specific threshold, green cell suggests better performance compared to strategy1)

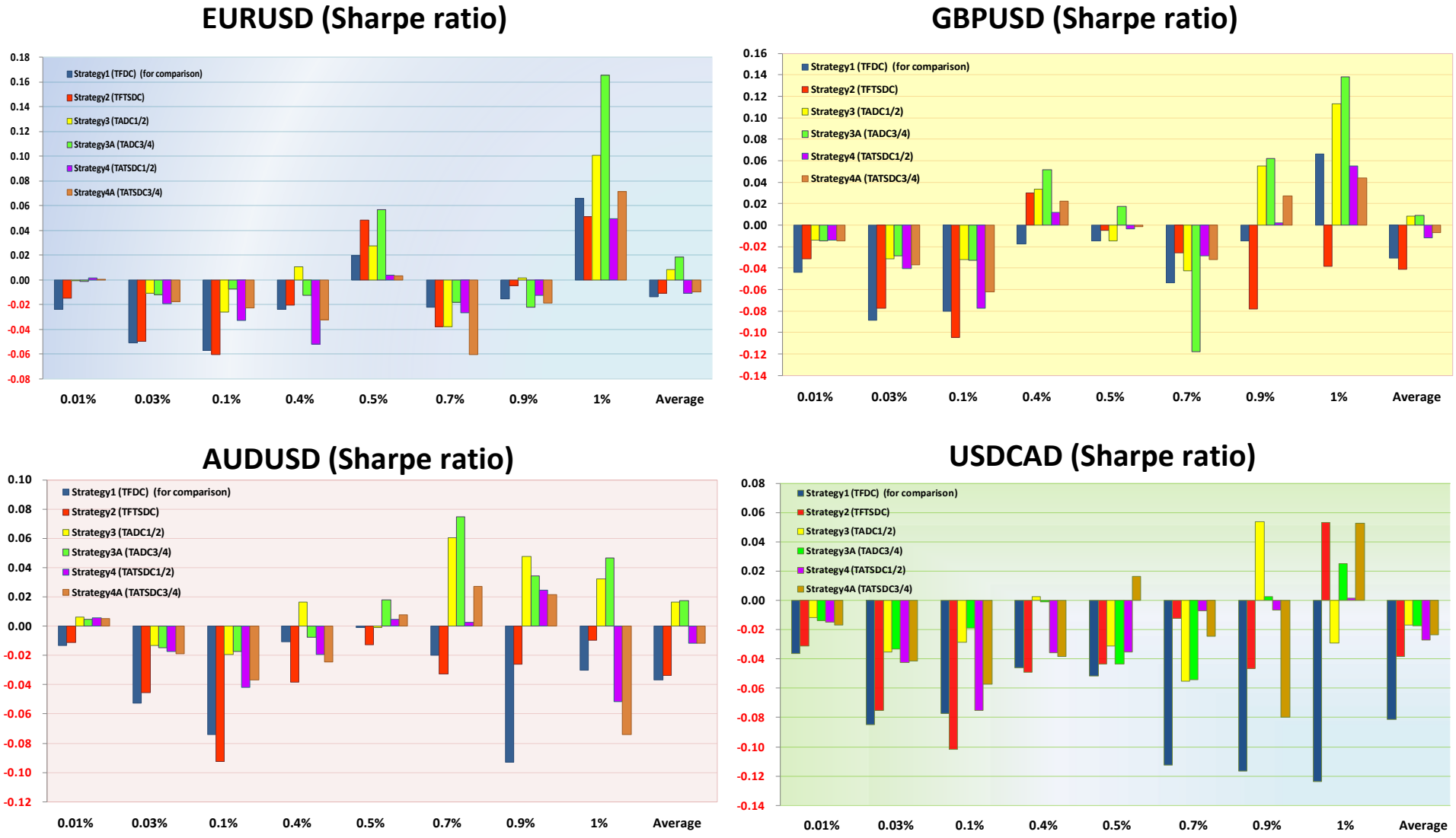

Exhibit 15: Bar chart comparing Sharpe ratio and the average value of individual strategies for each threshold

6. ANALYSIS AND DISCUSSION

6.1 EVALUATION OF THE SIX STRATEGIES

- ***STRATEGY 1: Trend-Following Directional Change (TFDC)***

Overall, **strategy 1** is outperformed by the extended strategies as presented in Exhibit 16, summarising and comparing the averaged performances across 4 currencies against those of each strategy. As indicated in Exhibit 7, the results point to the highest losses and maximum drawdown, meaning that trend-following directional-change approach tends to produce a significant decline during the tested period and does not robust enough to maintain its returns. Also, the consistently underperforming test-statistics, such as winning rate (Exhibit 13) and profit factor (Exhibit 17), would imply that the more **strategy 1** trades, the more loss it is likely to generate. In terms of Sharpe ratio (Exhibit 14), **strategy 1** shows negative values in most experiments, and none of the highest ratio belongs to this strategies. As Sharpe ratios measure excess return per unit of risk, when considering this evidence, it can be implied that **strategy 1** results in a risky trading.

The evidence suggests that the performance for **strategy 1** is rather inconsistent, although larger thresholds seem to help the strategy become more robust in terms of cumulative return and maximum drawdown. Therefore, we assume that using trend-following approach alone with the directional change could not ensure a satisfactory profitability.

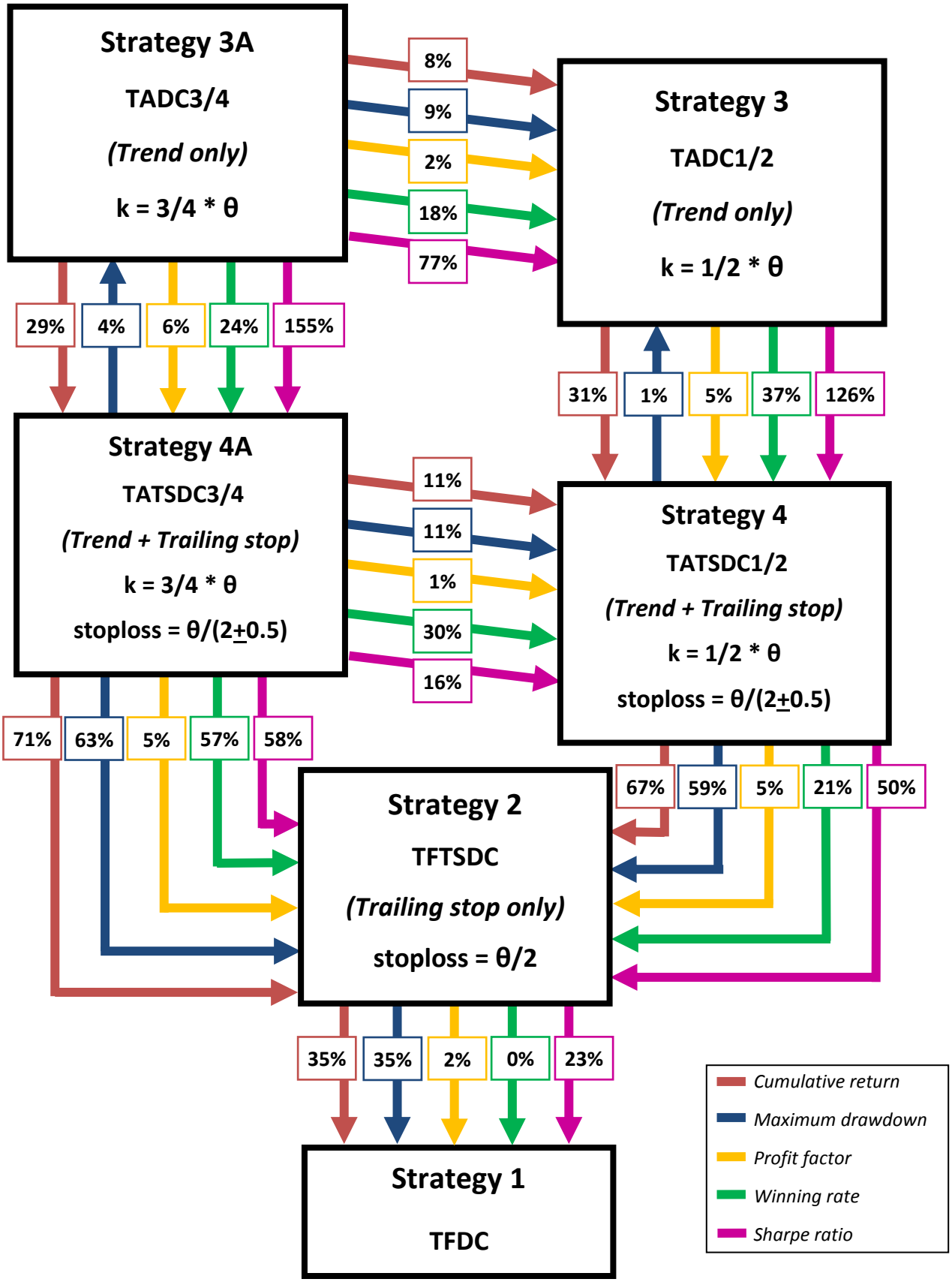

Exhibit 16: The summary of strategies performances averaged by 4 currencies across 8 thresholds, where A --[x]--> B indicates A outperforms B by x%

- ***STRATEGY 2: Trend-Following Directional Change with Trailing Stop (TFTSDC)***

As expected, by incorporating trailing stop into the directional-change strategy, it leads to the improvements in the results as indicated by Exhibit 16. **Strategy 2** produces better performances than **strategy 1** in terms of cumulative returns and Sharpe ratio, it can be implied that using trailing stop is capable of reducing losses from trading. The lower measures of maximum drawdown also identifies in Exhibit 9 that the amount of risk incurred by the strategy becomes smaller.

However, the performances of **strategy 2** still share similar trend with **strategy 1**. There were many experiments for which profit factor do not show much of the improvement compared to the initial system (Exhibit 11). We can also note that **strategy 2** is the only strategy which fails to generate higher average winning rate (Exhibit 12). As shown in the Exhibit 16, the evidences suggest that both of **strategy 1** and **strategy 2** are outperformed by the other extended strategies in all areas.

For these reasons, it would imply that **strategy 2** does *not* significantly perform better than **strategy 1**. Nevertheless, it is a safer idea to incorporate trailing stop into the directional-change strategy, while trailing stop alone still fails to advantage a strategy to achieve the goal in a term of consistently profitable system.

- ***STRATEGY 3: Trend-Following Directional Change with Major-Trend-Adjusted aggressiveness (TADC1/2)***
- ***STRATEGY 3A: Strategy 3 with more aggressiveness adjustment (TADC3/4)***

As indicated by Exhibit 16, **strategies 3 and 3A** appear to be the two most robust among the extended strategies. The cumulative returns present greater performances in Exhibit 7 as the graphs bear less relation to the initial strategy. They can fall steadily but by smaller amount, or remain constant, or even show inverse proportion to the initial strategy. As we can observe in Exhibit 6, the extended trading strategies capably exceed the performance of the initial strategy, by nearly 90% improvement, not to mention unexpected improvement over 200% in some cases. As a result, the Trend-Following Directional Change strategies with Major-Trend-Adjusted aggressiveness are capable of turning negative yields into positive yields.

Statistically, the profit factors higher than 1 can be commonly found in **strategy 3 and 3A** (Exhibit 10). This signifies clear indication of having high ratios of profit gained on trades in relation to the amount of loss. As Sharpe ratio measures excess return per unit of risk, when considering this evidence (Exhibit 15), it can be implied that both **strategy 3 and 3A** result in less risky strategies, the returns are obtained through a smart trading.

However, it is unintelligible to assume which one can generate consistently higher profitability as one performs better than the other in one experiment, whereas it is outperformed in another experiment. The evaluation becomes clearer when the winning rate and maximum drawdown are used as tiebreakers in order to clear up ambiguity when the other metrics of

several strategies are close. This validates the importance of applying multiple metrics for the strategy evaluation.

Being subject to a large percentage of winning trades (Exhibit 13), **strategy 3A** shows strong indication of being more robust and profitable system than **strategy 3**. As for high-frequency trading, it requires a significantly high winning rate metric to ensure a profitable system thanks to the fact that the number of winning trades generally seems to be close in value to the number of losing trades. In other words, most of the trades should be profitable as each trade yields relatively small profit.

Furthermore, maximum drawdown points to that fact that **strategy 3**, which is initially believed to be robust, also rarely holds the most favourable maximum drawdown (Exhibit 8). This means that **strategy 3** is not robust enough to maintain its returns during the trades because it has quite a larger decline in cumulative returns, compared to the other extended strategies.

In brief, the evidences suggest that the Trend-Following Directional Change strategies with Major-Trend-Adjusted aggressiveness significantly statistically *out*performs both of the initial strategy (**strategy 1**) and the trailing-stop-enabled strategy (**strategy 2**). It can be concluded that trends have significant effects on the overshoot events because higher performance can observed when profit targets are adjusted to the current major trend. The higher aggressiveness adjustment in target profits made to the strategy seems to result in more consistently robust strategy (**strategy 3A**), exhibiting a fewer signs of inferiority. However, the lower aggressiveness adjustment in target profit made to the strategy likely leads to less robust strategy (**strategy 3**), holding less favourable measures.

- ***STRATEGY 4: Trend-Following Directional Change with Trailing Stop and Major-Trend-Adjusted aggressiveness (TADC1/2)***
- ***STRATEGY 4A: Strategy 4 with more aggressiveness adjustment (TATSDC3/4)***

Confirmed by four currencies, the evidences in Exhibit 16 suggest that **strategy 4A** performs in a more excellent way than **strategy 4**. This result correlates with the earlier result suggested by **strategy 3 and 3A** such that the higher level of aggressiveness in profit target adjusted to the current major trend, the more favourable results the strategy can produce.

However, both **strategy 4 and 4A** are outperformed by **strategy 3 and 3A**. As indicated by Exhibit 6 and 7, the cumulative returns share similar values with **strategy 3 and 3A**, while **strategy 4 and 4A** perform in the middle for larger thresholds, corresponding more closely to the initial strategy. Similar indications are noted when looking at winning rate, profit factor and Sharpe ratio. Still, the maximum drawdowns can show slight improvement.

Quite interestingly, the combination of trend and trailing stop does not maximize the performance and profitability. This intrigues us to conduct further analysis to investigate the impact of the trailing stop as well as the effect of trend on the directional-change strategy.

6.2 SUB-DC ANALYSIS

We conduct further analysis by taking an advantage of the trailing stop to detect price movement on the overshoot event. We name a price retracement smaller than θ% as “Sub-DC”.

EURUSD		Trailing-stop enabled		Trailing-stop disabled
		Strategy 4B	Strategy 4C	Strategy 4D
		stoploss=θ/2	stoploss=3θ/4	stoploss= n/a
Positions closed by trailing stop	0.1%	76%	59%	n/a
	0.4%	82%	68%	
	0.7%	81%	69%	
	0.9%	80%	67%	
	1%	79%	66%	
	Average	79%	66%	
Winning rate	0.1%	0.34	0.37	0.42
	0.4%	0.35	0.35	0.39
	0.7%	0.35	0.38	0.40
	0.9%	0.35	0.38	0.42
	1%	0.39	0.40	0.44
	Average	0.35	0.37	0.42

GBPUSD		Trailing-stop enabled		Trailing-stop disabled
		Strategy 4B	Strategy 4C	Strategy 4D
		stoploss=θ/2	stoploss=3θ/4	stoploss= n/a
Positions closed by trailing stop	0.1%	78%	63%	n/a
	0.4%	81%	67%	
	0.7%	83%	68%	
	0.9%	84%	72%	
	1%	83%	66%	
	Average	82%	67%	
Winning rate	0.1%	0.32	0.35	0.41
	0.4%	0.37	0.38	0.41
	0.7%	0.36	0.37	0.40
	0.9%	0.36	0.33	0.41
	1%	0.40	0.42	0.46
	Average	0.36	0.37	0.42

AUDUSD		Trailing-stop enabled		Trailing-stop disabled
		Strategy 4B	Strategy 4C	Strategy 4D
		stoploss=θ/2	stoploss=3θ/4	stoploss= n/a
Positions closed by trailing stop	0.1%	75%	57%	n/a
	0.4%	80%	64%	
	0.7%	82%	67%	
	0.9%	82%	68%	
	1%	84%	73%	
	Average	81%	66%	
Winning rate	0.1%	0.35	0.38	0.44
	0.4%	0.38	0.39	0.42
	0.7%	0.36	0.38	0.41
	0.9%	0.38	0.38	0.38
	1%	0.36	0.37	0.38
	Average	0.37	0.38	0.41

USDCAD		Trailing-stop enabled		Trailing-stop disabled
		Strategy 4B	Strategy 4C	Strategy 4D
		stoploss=θ/2	stoploss=3θ/4	stoploss= n/a
Positions closed by trailing stop	0.1%	78%	63%	n/a
	0.4%	84%	69%	
	0.7%	84%	73%	
	0.9%	89%	76%	
	1%	84%	72%	
	Average	84%	71%	
Winning rate	0.1%	0.34	0.35	0.40
	0.4%	0.37	0.34	0.39
	0.7%	0.36	0.36	0.36
	0.9%	0.39	0.33	0.35
	1%	0.38	0.33	0.33
	Average	0.37	0.34	0.37

Exhibit 17: Comparison of positions closed during the overshoot events, and winning rate between trailing-stop-enabled and trailing-stop-disable strategy

We extend **strategy 4** in order to build three new models, having target price at 2θ. The trailing stop level of the first model is $\frac{\theta}{2}$, and that of the second model is $\frac{3}{4}\theta$, while the last one is trailing-stop-disabled. We have done the experiments on 4 currencies over 5 thresholds. Taking a closer look in Exhibit 17 at EURUSD only, the results suggest 2 important notes:

- Firstly, about 80% of trades are closed by the trailing stop of $\frac{\theta}{2}$, and more than half of the trades are closed by the trailing stop of $\frac{3}{4}\theta$.
- Secondly, the winning rates of the trailing-stop-enabled models are lower than the trailing-stop-disabled model.

The results experimented on four currencies are in line. The evidences suggest that, for the directional-change strategy, the trailing stop tends to stop out the trade prematurely instead of letting profit run. This explains why the combination of trailing stop and trend does not maximize the performance and profitability.

We also discover that the price on an overshoot event does not move in a straight line, but it is likely to retrace before reaching the target price at 2θ.

- There are 82% chances on average that a Sub-DC of $\frac{\theta}{2}$ will occur during an overshoot event.
- There are 68% chances on average that a Sub-DC of $\frac{3}{4}\theta$ will occur during an overshoot event.

CONCLUSION AND FUTURE RESEARCH SUGGESTIONS

Directional change is the approach summarising and capturing significant changes in the market, where prices alternate between upward trend and downward trend. In each trend, there is a directional-change event followed by an overshoot event (Chapter 2).

In this thesis, we have investigated how directional changes can be used to build trading strategies. By incorporating the ideas of the trailing stop and trend based on the concept of the scaling law into the trend-following Directional Change strategy, we have invented five new trading strategies: **Strategies 2, 3, 3A, 4 and 4A** (Chapter 4).

We have thoroughly assessed their performance in the foreign exchange market by backtesting over historical 4 major currency pairs across 8 directional-change thresholds, and compare the results against each strategy (Chapters 5 and 6). Experiments suggest that the strategies that we invented were successful (summarized in Exhibit 16). The evidences indicate that our extended strategies show statistical outperformance in terms of cumulative return, maximum drawdown, profit factor, winning rate and Sharpe ratio. The results are in line across all currencies. **Strategy 2** (Trend-Following Directional Changes with Trailing Stop) can improve profitability and performance in most experiments, while **strategy 3 and 3A** (Trend-Following Directional Changes with Major-Trend-Adjusted aggressiveness) outperforms the initial strategy by a significant margin. The higher level of aggressiveness in target profit adjusted to the major trend, the more favourable results the strategy can produce. This presents strong indication that trends have significant effects on the currency price during the overshoot events. Quite interestingly, **strategy 4 and 4A** (Trend-Following Directional Changes with the combination of

Trailing Stop and Major-Trend-Adjusted aggressiveness) does not maximize the performance and profitability. We conduct further analysis by taking an advantage of the trailing stop to investigate price movements during the overshoot events (shown in Exhibit 17). We have discovered that there are 82% and 68% chances on average that the price on an overshoot event will retrace by $\frac{\theta}{2}$ and $\frac{3}{4}\theta$, respectively. For the trend-following directional-change strategy, the trailing stop tends to exit the trade prematurely instead of letting profit run.

We conclude a few perspectives for future research:

- One might study the impacts of the threshold size. As indicated by larger thresholds, our results find that the extended strategies perform differently. This shows an implication that the size of the threshold matters.
- The strategies adopt the idea of trend following only. One could study and devise a contrarian trading strategy with the combination of trailing stop and trend on different adjustment of profit target.
- It has been proven that all of the extended strategies can yield highest cumulative return, suggesting that every strategy has potential to maximize the profitability if equipped with efficient risk management methodology.

REFERENCES

[1] Qirici, M., Franco, S., Baidan, J. and Nesbitt, C. (2013). FOREX Trading and Investment, WORCESTER POLYTECHNIC INSTITUTE, MA, USA.

[2] Gregoriou, G.N., (2015), Chapter 3 & 14 Trading Model, *Handbook of high frequency trading*. Keynes, UK, Academic Press.

[3] Aloud, M., Tsang, E.P.K., Olsen, R. and Dupuis, A. (2012). A directional-change events approach for studying financial time series, Economics: The Open-Access, E-Journal Open-Assessment. http://dx.doi.org/10.5018/economics-ejournal.ja.2012-36

[4] Glattfelder, J., A. Dupuis, and R. Olsen (2011), Patterns in high-frequency FX data: discovery of 12 empirical scaling laws, Quantitative Finance, 11(4), 599–614.

[5] Voicu, S., Directional Change Trading Strategies in the Foreign Exchange Markets, Centre for Computational Finance and Economic Agents (CCFEA), University of Essex, U.K., 2012.

[6] Aloud,M., Modelling the High-Frequency FX Market: An Agent-Based Approach, School of Computer Science and Electronic Engineering, University of Essex, U.K., 2013.

[7] Tsang, E.P.K. (2009). Forecasting - where computational intelligence meets the stock market. Frontiers of Computer Science in China, Springer, Vol.3, No.1, March 2009, 53-63 Earlier version filed as Working Paper WP026-08, Centre for Computational Finance and Economic Agents (CCFEA), University of Essex.

[8] Giampaoli, I., Ng, W., Constantinou, N. Periodicities of Foreign Exchange Markets and the Directional Change Power Law, School of Computer Science and Electronic Engineering, University of Essex, U.K., 2013.

[9] Dempster, M. A. H., Payne, T. W., Romahi, Y. & Thompson, G. W. P. (2001). *Computational Learning Techniques Using Popular Technical Indicators for Intraday FX Trading*, IEEE Transactions on Neural Networks, special issue on Computational Finance, 2001, No. 4, Vol. 12, 744-754

[10] Aldridge,I., (2013), Chapter 14 Risk management of HFT, *High-frequency trading a practical guide to algorithmic strategies and trading system*, Canada, Wiley.

[11] Elder, A.,(2008), Chapter5 Selling on a stop, *Sell and Sell Short*, New Jersey, USA, Wiley Trading

[12] Paniangtong, S. (2015). Project proposal "The Rule-based Directional Change Trading Model with Trailing Stop in the Foreign Exchange Markets", Centre for Computational Finance and Economic Agents (CCFEA), University of Essex, U.K.

[13] Müller, U. A., Dacorogna, M. M., Dave, R. D., Pictet, O. V., Olsen, R. B. and J. Ward (1995). A challenge to econometricians - Fractals and intrinsic time, Working Papers 1993-08-16, Olsen and Associates.

[14] Olsen. "Strategy Highlights". Internet: https://www.olseninvest.com/customer/overview.vm [accessed on 29 Jun 2015].

[15] Tsang, E.P.K., New ways to understand financial markets. Centre for Computational Finance and Economic Agents (CCFEA), University of Essex, U.K., 2010.

[16] Dacorogna, M., Gancay,R., Muller,U., Olsen,R., Pictet,O., (2001), *Chapter 11 Trading Model*, An introduction to High-frequency finance. California,USA. ,Academic Press.

[17] Paniangtong, S. (2015). "A High-Frequency Trading Model in Foreign Exchange Markets, Assignment CF968 Design a trading model", Centre for Computational Finance and Economic Agents (CCFEA), University of Essex, U.K.

[18] Durbin, M., (2010), Preface & Chapter 1, All About High-Frequency Trading, USA, Mc Graw Hill.

[19] Kaminski, K. & Lo, A.W., (2007) When Do Stop-Loss Rules Stop Losses? Ljubljana Meetings Paper European Finance Association 2007. Available at: http://ssrn.com/abstract=968338

[20] Bergsveinn, S. and Garib, Y. (2009). PERFORMANCE OF STOP-LOSS RULES VS. BUY-AND-HOLD STRATEGY, SCHOOL OF ECONOMICS AND MANAGEMENT, LUND UNIVERSITY, Sweden.

[21] Paul, Neely J Christopher and Weller A. Technical Analysis in the Foreign Exchange Market. St Louis, 2 May 2011.

[22] James, J. “Trend Models Can simple trend strategies work long term?”, Investor Risk Advisory Group CitiFX, London, Citibank N.A.

[23] Investopedia. “Technical Analysis: The Use Of Trend ”. Internet: http://www.investopedia.com/university/technical/techanalysis3.asp, [accessed on 03 Jul 2015].

[24] Langager, C. and Murphy, C. “Dow Theory: The Three-Trend Market”. Internet: http://www.investopedia.com/university/dowtheory/dowtheory2.asp, [accessed on 03 Jul 2015].

[25] John, M (1999). Technical Analysis of the Financial Market: A comprehensive Guide. New York: Penquin.

[26] Sieczka, P. and Hołyst, J.A. (2008). Statistical properties of short term price trends in high frequency stock market data, Faculty of Physics and Center of Excellence for Complex Systems Research, Warsaw University of Technology, Koszykowa 75, Warsaw, Poland.

[27] DefineAZ. “Pip”. Internet: http://defineaz.com/en/economy/pip.html, [accessed on 01 Jul 2015].

[28] Khan, S. “Maximum Drawdown in VBA”. Internet: http://investexcel.net/maximum-drawdown-vba/, [accessed on 03 Jul 2015].

[29] Folger, G. “Interpreting A Strategy Performance Report ”. Internet: http://www.investopedia.com/articles/fundamental-analysis/10/strategy-performance-reports.asp, [accessed on 03 Jul 2015].

[30] Nqoos, J. “The Science of Strategy Evaluation”, chapter8. Internet: *www.trading-naked.com/library/Chap8.pdf*, [accessed on 03 Jul 2015].

[31] Cremer, G. and Freund, Y. AUTOMATED TRADING WITH BOOSTING AND EXPERT WEIGHTING, Center for Computational Learning Systems, Columbia University, NY, USA.

[32] Kablan, A. and Ng, W.L. (2011). Intraday high-frequency FX trading with adaptive neuro-fuzzy inference systems. Financial Markets and Derivatives Int. J., 2011, Vol. 2, Nos. 1/2, Centre for Computational Finance and Economic Agents (CCFEA), University of Essex, U.K.

[33] Sila, J. (2014). Application of technical analysis on algorithmic trading, Faculty of Social Sciences Institute of Economic Studies, Charles University, Prague.

[34] Harish, K.S. (2004). Evolutionary Algorithms in Optimization of Technical Rules for Automated Stock Trading, Faculty of the Graduate School of the University of Texas at Austin, USA.

APPENDIX

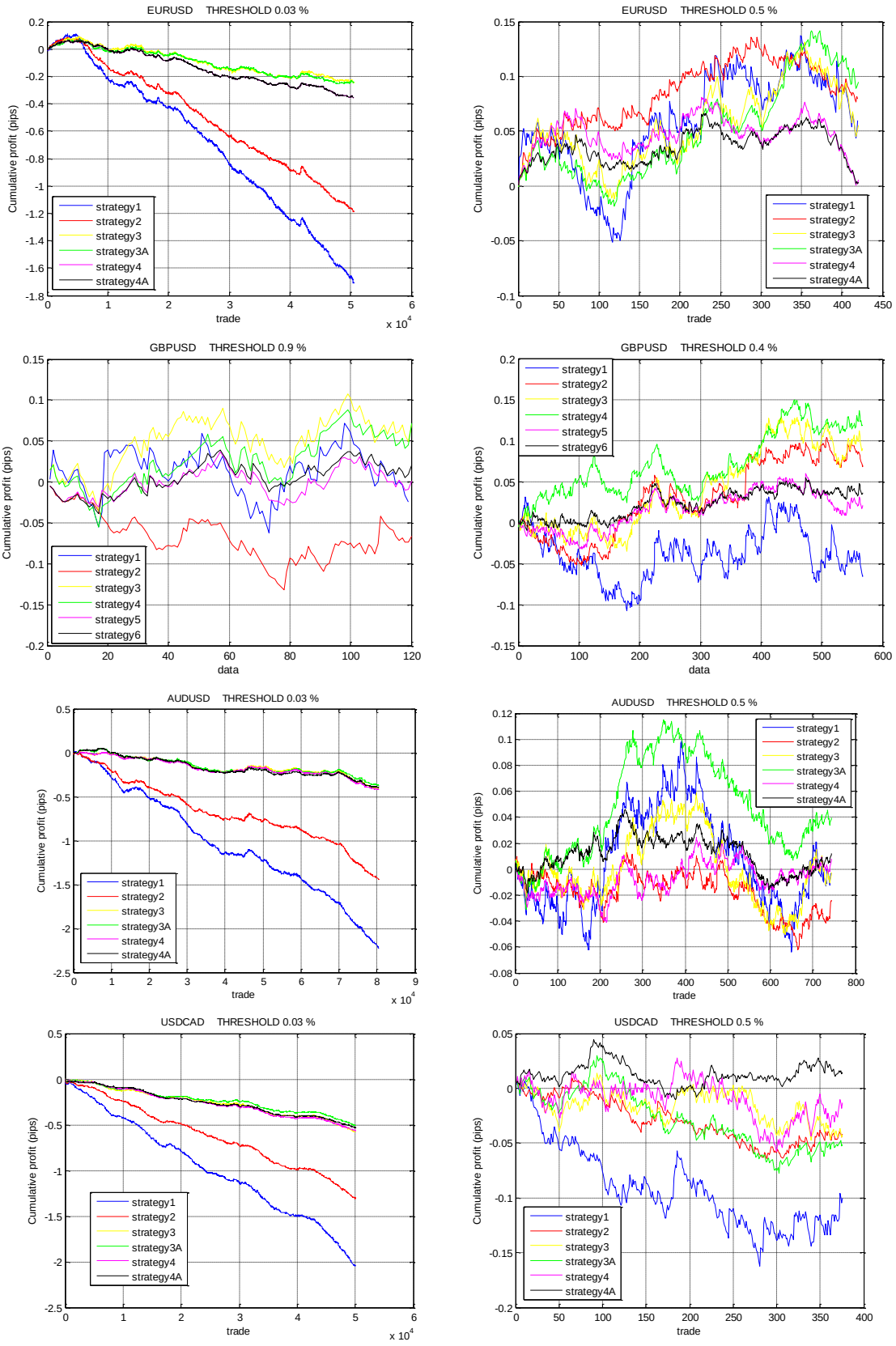

Exhibit 18: Cumulative returns of six trading strategies during trading period on directional-change thresholds 0.03% and 0.5%

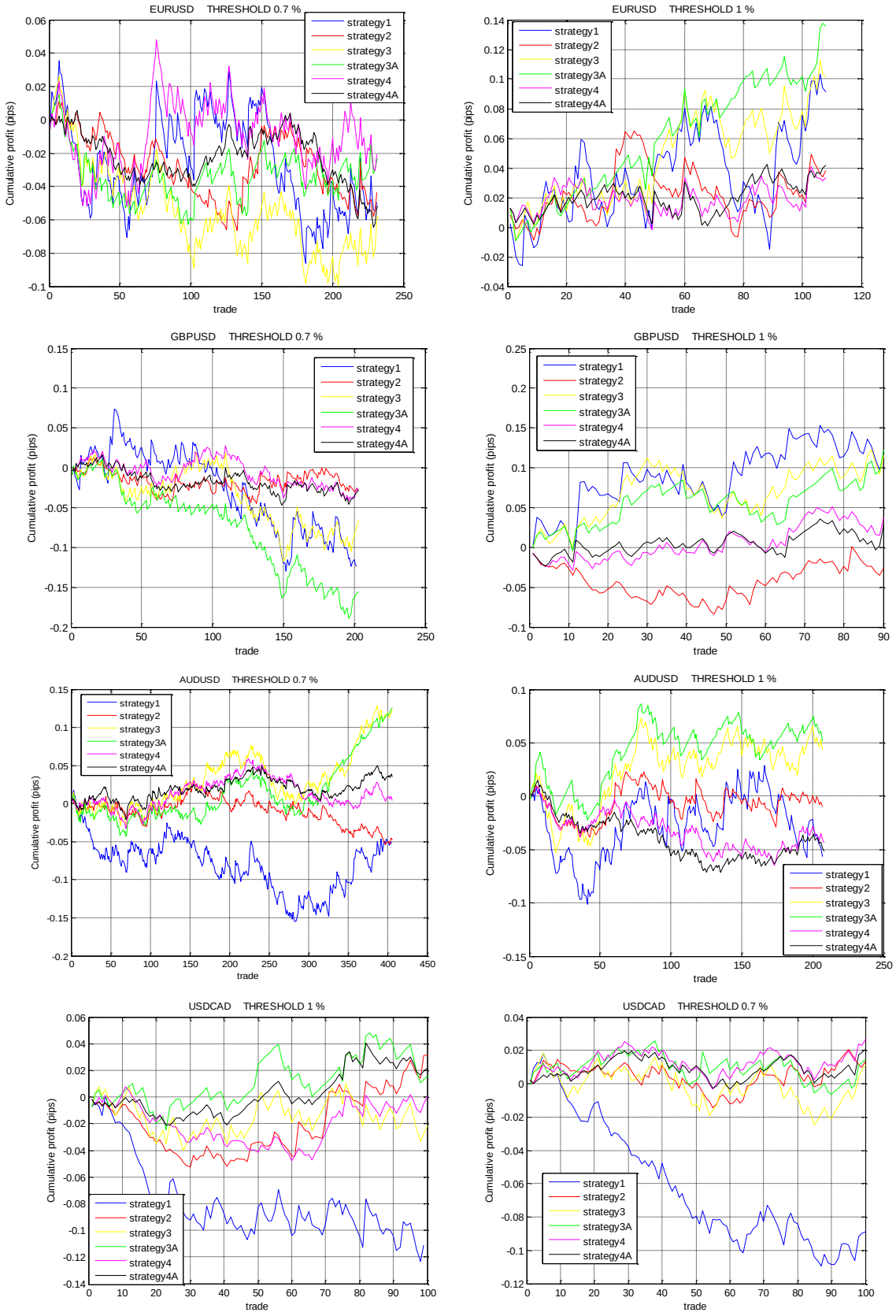

Exhibit 18(continued): Cumulative returns of six trading strategies during trading period on directional-change thresholds 0.07% and 1%

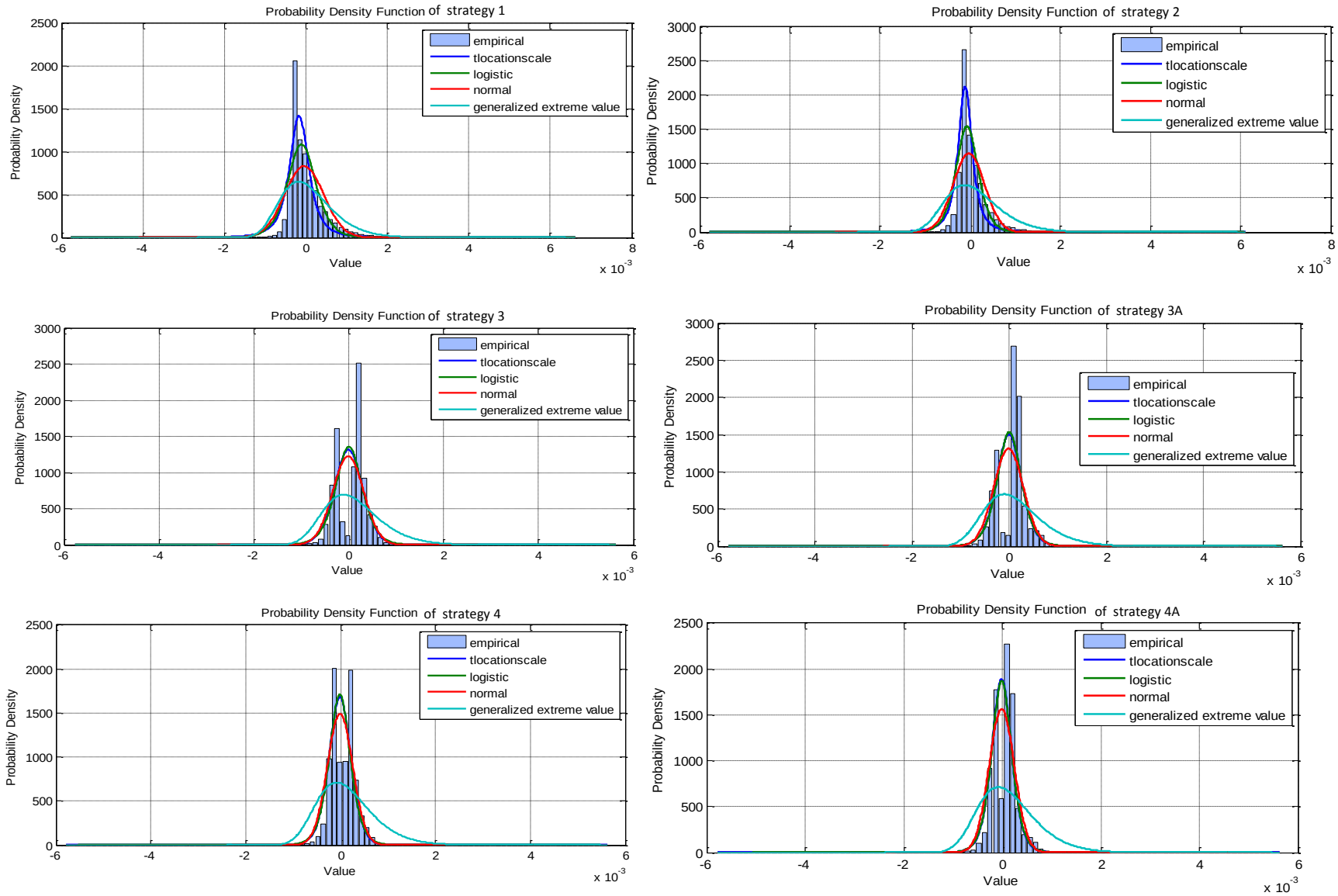

Exhibit 19: Probability density function of return for each strategy (experimented on USDCAD threshold 0.03%)

Trend	Side	Entry Index	Entry Price	Entry Rule	Exit Index	Exit Price	Exit Rule	Profit target	Net Profit	Profit (%)	Exit by profit taking	Exit by Trailing stop
Unknown	Short	8121	1.53839	2.1	12046	1.545595	2.33	1.52321	-0.00720	-0.00468	-	1.54560
Unknown	Long	23670	1.538915	1.1	24231	1.532455	1.33	1.55415	-0.00646	-0.00420	-	1.53246
Uptrend	Short	58041	1.576745	2.1	58174	1.583235	2.31	1.57291	-0.00649	-0.00412	-	1.58324
Uptrend	Long	67411	1.58095	1.1	74954	1.57729	1.31	1.60773	-0.00366	-0.00232	-	1.57729
Uptrend	Short	75460	1.571435	2.1	75657	1.567605	2.21	1.56807	0.00383	0.00244	1.56761	-
Uptrend	Long	78353	1.580715	1.1	88562	1.58819	1.31	1.60804	0.00747	0.00473	-	1.58819
Uptrend	Short	89022	1.582935	2.1	92664	1.579075	2.21	1.57917	0.00386	0.00244	1.57908	-
Downtrend	Long	108753	1.57806	1.1	108771	1.58039	1.22	1.58007	0.00233	0.00148	1.58039	-
Uptrend	Short	135037	1.5901	2.1	135945	1.586045	2.21	1.58612	0.00406	0.00255	1.58605	-
Uptrend	Long	147521	1.596495	1.1	149207	1.58739	1.31	1.62403	-0.00910	-0.00570	-	1.58739
Uptrend	Short	153135	1.582105	2.1	153660	1.58896	2.31	1.57811	-0.00686	-0.00433	-	1.58896
Uptrend	Long	156037	1.59833	1.1	169255	1.62575	1.21	1.62561	0.02742	0.01716	1.62575	-
Uptrend	Short	182776	1.613435	2.1	183780	1.61808	2.31	1.60948	-0.00465	-0.00288	-	1.61808
Downtrend	Long	219695	1.543105	1.1	219752	1.5371	1.32	1.54609	-0.00600	-0.00389	-	1.53710
Uptrend	Short	229397	1.5439	2.1	230056	1.54675	2.31	1.54024	-0.00285	-0.00185	-	1.54675
Uptrend	Long	233402	1.556025	1.1	234591	1.54743	1.31	1.58294	-0.00860	-0.00552	-	1.54743
Uptrend	Short	248666	1.561695	2.1	249857	1.557715	2.21	1.55798	0.00398	0.00255	1.55772	-
Uptrend	Long	259566	1.56437	1.1	267184	1.561445	1.31	1.59120	-0.00292	-0.00187	-	1.56145
Uptrend	Short	268475	1.55597	2.1	268600	1.55179	2.21	1.55252	0.00418	0.00269	1.55179	-
Downtrend	Long	280234	1.55544	1.1	283598	1.558765	1.22	1.55872	0.00333	0.00214	1.55877	-
Uptrend	Short	293922	1.55746	2.1	294281	1.55352	2.21	1.55368	0.00394	0.00253	1.55352	-
Uptrend	Long	298748	1.561995	1.1	306085	1.56542	1.31	1.58859	0.00343	0.00219	-	1.56542
Uptrend	Short	307553	1.56024	2.1	307831	1.55586	2.21	1.55632	0.00438	0.00281	1.55586	-
Uptrend	Long	310556	1.564835	1.1	314422	1.55564	1.31	1.59170	-0.00920	-0.00588	-	1.55564
Uptrend	Short	388264	1.61396	2.1	389165	1.620305	2.31	1.61019	-0.00635	-0.00393	-	1.62031
Downtrend	Long	418011	1.61391	1.1	420148	1.610815	1.32	1.61782	-0.00310	-0.00192	-	1.61082
Downtrend	Short	421389	1.60157	2.1	426994	1.596395	2.22	1.57331	0.00518	0.00323	1.59640	-
Downtrend	Long	429510	1.607625	1.1	429631	1.612655	1.22	1.61157	0.00503	0.00313	1.61266	-
Downtrend	Short	441792	1.601315	2.1	445582	1.59684	2.22	1.57301	0.00448	0.00279	1.59684	-
Downtrend	Long	471798	1.599115	1.1	471861	1.60294	1.22	1.60291	0.00382	0.00239	1.60294	-
Uptrend	Short	516438	1.614145	2.1	519297	1.61692	2.31	1.61010	-0.00277	-0.00172	-	1.61692
Uptrend	Long	526471	1.62296	1.1	529456	1.62648	1.31	1.65102	0.00352	0.00217	-	1.62648
Uptrend	Short	530100	1.62112	2.1	530647	1.61717	2.21	1.61732	0.00395	0.00244	1.61717	-
Downtrend	Long	541077	1.61559	1.1	542041	1.61104	1.32	1.61941	-0.00455	-0.00282	-	1.61104
Downtrend	Short	549143	1.601355	2.1	550941	1.59705	2.22	1.57319	0.00431	0.00269	1.59705	-
Downtrend	Long	570712	1.583295	1.1	570927	1.57785	1.32	1.58718	-0.00545	-0.00344	-	1.57785
Downtrend	Short	572741	1.571925	2.1	578010	1.579795	2.32	1.54415	-0.00787	-0.00501	-	1.57980
Downtrend	Long	582488	1.579985	1.1	582699	1.582825	1.22	1.58281	0.00284	0.00180	1.58283	-
Downtrend	Short	586787	1.56837	2.1	587842	1.56436	2.22	1.54066	0.00401	0.00256	1.56436	-
Downtrend	Long	602166	1.53031	1.1	602474	1.525145	1.32	1.53224	-0.00517	-0.00338	-	1.52515
Downtrend	Short	606121	1.50766	2.1	606127	1.507505	2.22	1.48939	0.00015	0.00010	1.50751	-
Downtrend	Long	618248	1.514135	1.1	618332	1.517875	1.22	1.51774	0.00374	0.00247	1.51788	-

Exhibit 20: Example of trade report (of GBPUSD threshold 1%) containing fourteen details for each transaction