Profiling Financial Market Dynamics under Directional Changes

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Abstract,

Market prices are traditionally sampled in fixed time-intervals; for example, daily closing prices are often used to record price movements. Directional change (DC) is an alternative way to record price movements. Instead of sampling at fixed intervals, DC is data-driven: price changes dictate when one records a price. With this new approach, we need to develop the new ways to extract information out of data. In this paper, we have introduced a set of indicators for capturing information from data that record DCs. We will demonstrate that the indicators could help us construct DC profiles of markets. We will also demonstrate the usefulness of such profiles in foreign exchange (EUR/USD) and gold markets.

1 Introduction

Market dynamics are traditionally captured by a time series. The observer decides how often the data is sampled. For example, the daily closing prices have been widely used: the transaction price at the end of each trading day is sampled. The sampled prices form a summary of the market over the whole period.

Guillaume et al. (1997) introduced the concept of "directional changes" as an alternative way to sample data. In this approach, sample points are data-driven: that means the observer lets the data determine when to have a sample of the market. This will be explained in detail in the next section. The basic idea is that the observer decides a threshold which he/she considers significant in price changes: for example, he/she may consider a price change of 5% significant. The market is seen to be in alternating uptrends and downtrends. It is considered to have changed from a downtrend to an uptrend if the price data points are sampled when the market changes direction by the predefined threshold.

In further research about DC, Glattfelder et al. (2011) presented twelve new empirical scaling laws related to foreign exchange data series across thirteen currency exchange rates based on directional change theory. Kablan and Ng (2011) also developed a new method of capturing

volatility using the directional-change event approach. Aloud et al (2012) pointed out that the length of the price-curve coastline defined by directional change events shows a long coastline of price changes.

In time series analysis, researchers have developed useful indicators, such as return and volatility, to summarize market price changes. However, DC is a relatively new concept. In this paper, we would like to propose potentially useful indicators for profiling markets under DC. We would also like to assess the usefulness of these profiles in summarizing real market data. And we believe summarizing markets under DC will provide us with some different information about the market, compared with time series analysis.

The remainder of the paper is organised as follows. Section 2 describes the concept of directional change and its component events. Section 3 gives a definition of summarizing the market in the directional change approach. The specification with regard to the indicators from directional-change event, is presented in Section 4. Section 5 shortly illustrate the specification of the programme that produces the DC summary. Section 6 offers an example of profiling EUR/USD market, Section 7 provides the explanation and discussion of the example. This paper is concluded within Section 8.

2 Directional changes

2.1 Directional Change (DC) event

According to Tsang (2010), a DC event can take one of two forms - a downturn DC event or an upturn DC event. Besides that, there is a period called downward run which lies in the gap between a downturn DC event and the next upturn DC event, while an upward run lies between an upturn DC event and the next downturn DC event. A downturn DC event terminates an upward run, and starts a downward run, whereas an upturn DC event terminates a downward run and starts an upward run, as it is shown in figure 1.

During a downward run, a last low price P_l is continuously updated to the minimum of P_t (the current market price) and P_l (the last low price). Similarly, during an upward run, a last high price P_h is continuously updated to the maximum of P_t (the current market price) and P_h (the Last High price) (Tsang 2010). At the beginning of the sequence, the last high price P_h and

last low price P_l are set to the initial market price P_{t0} at the beginning of the sequence (Tsang 2010).

A downturn DC event is an event when the absolute price change between the current market price P_t and the last high price P_h is lower than a fixed threshold (a percentage) θ:

$$P_t \leq P_h \times (1- \theta) \quad (1)$$

The starting point of a downturn DC event is a downturn point which is the point at which the price last peaked - P_h. The end of a downturn DC event is a downturn DC point which is the point at which the price has dropped from the last downturn point by the threshold θ (Tsang 2010).

In a downward run, an upturn DC event is an event when the absolute price change between the current market price Pt and the last low price P_l is higher than a fixed threshold θ:

$$P_t \geq P_l \times (1+ \theta) \quad (2)$$

The starting point of an upturn DC event is an upturn point, which is the point at which the price last troughed - P_l. The end of an upturn DC event is an upturn DC point which is the point at which the price has risen from the last upturn point by the threshold θ.

2.2 Overshoot (OS) Event

A downturn DC event is followed by a downward overshoot event, which is ended by the next upturn DC event, which is itself followed by an upward overshoot event, which is ended by the next DC downturn event (Tsang 2010), as it is shown in figure 1. The overshoot event (OS) therefore represents the time interval of price movement beyond the DC event.

Under the DC framework, price movement is summarized in a four-events cycle:

… → Downturn DC Event→

Downward Overshoot Event →

Upturn DC Event →

Upward Overshoot Event →

Downturn DC Event→ …

2.3 Total Move (TM)

A total price movement (TM) price movement is constituted by a downturn event and a downward overshoot event follows, or an upturn event and an upward overshoot event follows (Glattfelder et al, 2011), as it is shown in figure 1.

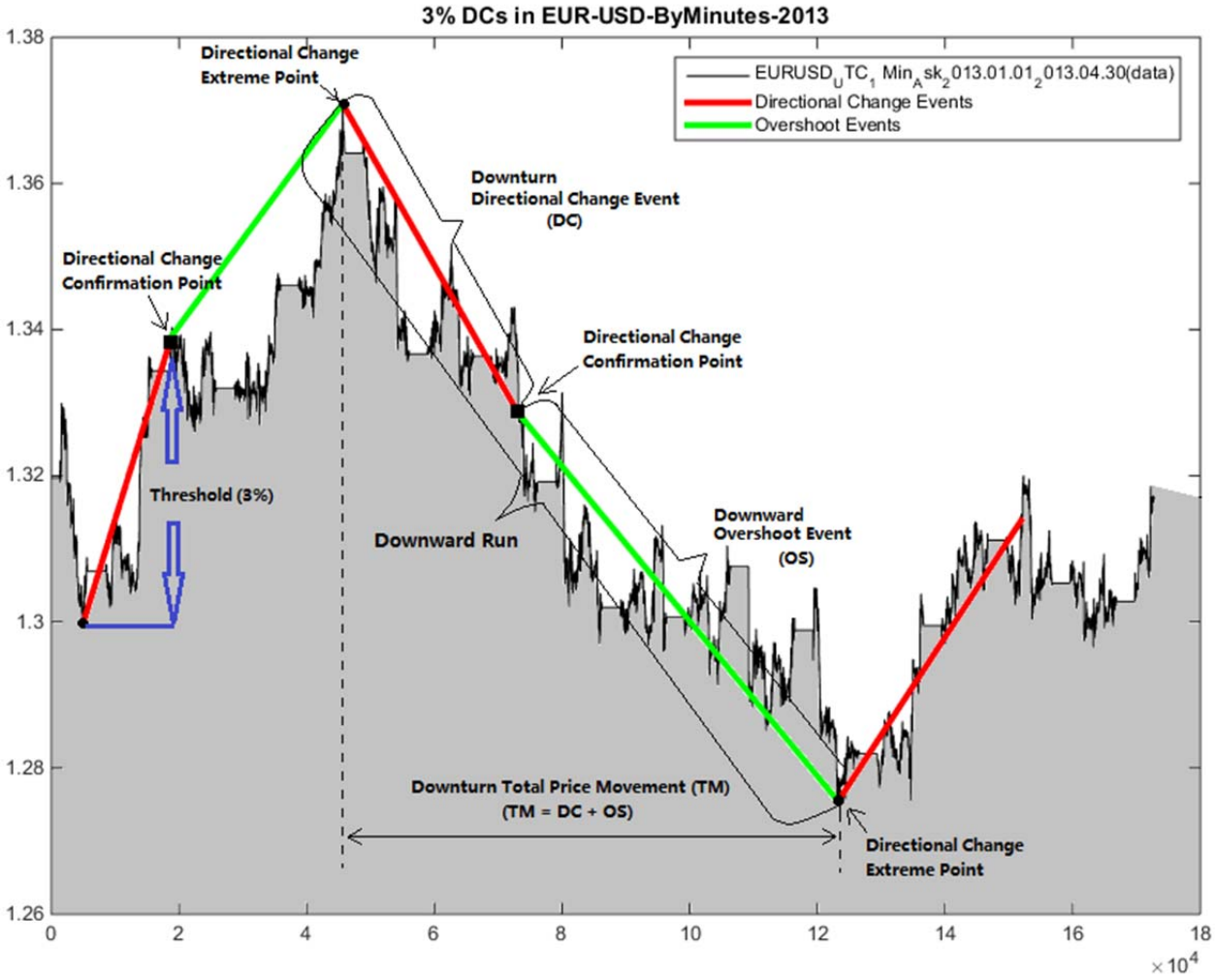

Figure 1: Directional Changes in EUR/USD (threshold = 3%)

3 Summarizing time series with DCs

In this section, we shall propose a procedure for summarizing market price movements with DC. The first step for summarizing time series with DC theory is to locate the significant points of each DC event: Directional Change Extreme Point (EXT), Directional Change Confirmation Point (DCC) and Theoretical Directional Change Confirmation Point (DCC*).

Directional Change Extreme Point (EXT) is the starting point that is an Upturn Point or Downturn Point. It can be also seen as the end of one TM event (Figure 2). Directional Change Confirmation Point (DCC) is the point at which to confirm one DC event. For an Upturn Event, it is the first point that rises past $P_{EXT} \times (1+ \theta)$. And for a Downturn Event, it is the first point that drops past $P_{EXT} \times (1- \theta)$ (Figure 2).

The Theoretical Directional Change Confirmation Point (DCC*) is the minimal or maximum directional change confirmation price for an upturn or downturn directional change event. It does not really exist in the real market. The reason we use DCC* rather than DCC, it is because in reality, EXT point and DCC point can be the same point under a fixed threshold. This will cause trouble for the indicator calculation in the next step. The price of DCC* is defined in the following way:

In an uptrend: $P_{DCC\uparrow^*} = P_{EXT} \times (1+ \theta) \leq P_{DCC\uparrow}$;

In a downtrend: $P_{DCC\downarrow^*} = P_{EXT} \times (1+ \theta) \geq P_{DCC\downarrow}$,

Here P_{EXT} is the price of directional change extreme point (EXT). P_{DCC} is the price of directional change confirmation point (DCC), θ is the fixed threshold. ↑and ↓ here represents Upturn and Downturn event. Therefore $P_{DCC\uparrow^*}$ is the DCC* price of an upturn directional change event and $P_{DCC\downarrow^*}$ is the DCC* price of a downturn directional change event.

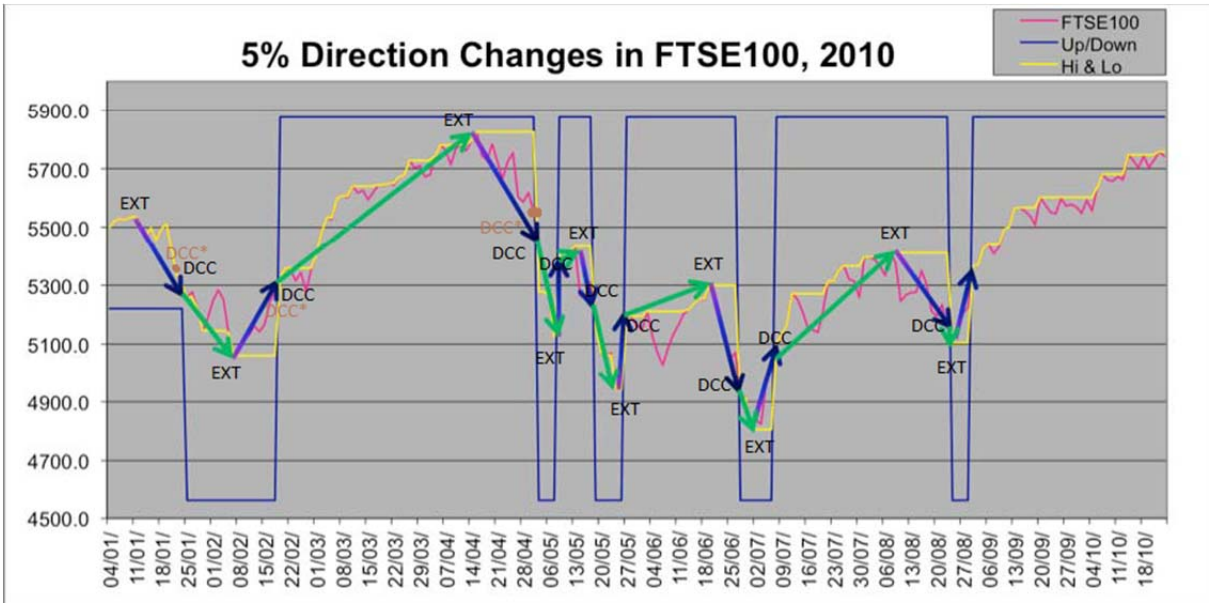

Figure 2: EXT, DCC and DCC* in DC summarizing the FTSE100

After the DCC, DCC* and EXT points have been located, the second step is to define useful indicators for directional change summarizing. These indicators are all calculated from the value of the points and the time intervals. For instance, some indicators are to define the market trend, another indicator is used to measure the directional change trading volatility, or the risk. The introduction of these indicators will be described in next section. All these indicators will be generated from our programme TR1, after the sample data was introduced into it.

The programme TR1 will generate two files: the DC-Data file and the Profile Summary File. The DC-Data file includes all details of every point and indicators of it, which is machine readable for testing the correctness of Profile Summary File. The Profile Summary File is converted from the DC-Data file, while it only has a few indicators in it. These few indicators show the whole of the market price movements. Users will be able to obtain the market characteristics in directional change terms more easily. This is the whole process of summarizing time series with directional changes.

4 Useful indicators in directional change

DC is a new way of summarizing price changes. In order to analyse price dynamics, we need to extract useful information from DC summaries. In this section, we propose indicators which could be useful for extracting information. With these indicators, we aim to construct profiles for price changes summarized under the DC framework.

4.1 Number of directional change events (N_{DC})

N_{DC} is the total number of DC events that happened over the profiled period, which measures the frequency, or volatility of DC events. Based on the same threshold, the time period which has higher N_{DC} value is more volatile than other time periods. By recording the N_{DC} within the profiled period, DC provides us another way to measure the volatility of market price movements.

4.2 Overshoot Values at Extreme Points (OSVEXT)

The magnitude of an overshoot is the price change from the last directional change confirmation price (DCC) to the current price. We define Overshoot Value (OSV) for measuring the magnitude of an overshoot. Instead of using the absolute value of the price change, we would like this measure to be relative to the threshold, θ. Therefore, we define OSV as follows:

$$OSV = ((P_c - P_{DCC}) \div P_{DCC}) \div \theta \quad (3)$$

Here P_c is the current price, P_{DCC} is the last directional change confirmation price, θ is the threshold. At DC confirmation, $P_c = P_{DCC}$, so OSV = 0.

Overshoot values at extreme points (OSV_{EXT}) is an indicator for measuring the magnitude of an overshoot based on the price distance between fixed points. It measures how far the overshoot goes from the theoretical directional change confirmation point (DCC*) to the next extreme point (EXT). We define OSV_{EXT} as follows:

$$OSV_{EXT} = ((P_{EXT} - P_{DCC*}) \div P_{DCC*}) \div \theta \quad (4)$$

Here P_{EXT} is the price at the extreme point that ends the current trend, P_{DCC*} is the price of the theoretical directional change confirmation point of the current trend, θ is the threshold.

The reason we use DCC*, rather than DCC, to calculate OSV_{EXT}, it is because in reality, EXT point and DCC point can be the same point under a fixed threshold. In other words, P_{EXT} may equals to P_{DCC}, $OSV_{EXT} = 0$. Especially if the sample is in a low volatile period, OSV_{EXT} can be a bunch of zero, which will make OSV_{EXT}'s calculation meaningless, and make problems for DC market profiling.

4.3 Time for completion of a trend (T)

DC is defined based on events, so it uses intrinsic, as opposed to physical, time (Glattfelder et al 2011). However, that does not mean that it ignores physical time. The amount of physical time that a trend takes to complete is a significant piece of information. We define an indicator T as the time that it takes between the extreme points that begin and end a trend (Figure 3).

Figure 3: Example: T, P_{EXT} and θ in EUR/USD, θ = 3%, P_{EXT} is the price at directional change extreme point (solid black squares), T is the time that it takes between two consecutive directional change extreme points.

4.4 Total Price Movements Value at Extreme Points (TMV_{EXT})

Total price movements value at extreme points (TMV_{EXT}) measures the price distance between the extreme points that begin and end a trend, normalized by θ, which is the threshold used for generating the directional change summary. It measures the maximum possible profit for each trend. TMV_{EXT} is defined by:

$$TMV_{EXT_i} = \frac{P_{EXT\_i+1} - P_{EXT\_i}}{P_{EXT_i} * \theta} \quad (5)$$

Here P_{EXT_i} represents the price at the i-th directional change extreme point, P_{EXT_i+1} represents the price at the (i+1)-th directional change extreme point, θ is the threshold used (Figure 2).

4.5 Number of directional change events in Sub-threshold (Sub-N_{DC})

N_{DC} measures the volatility of market price movements over the profiled period. However, the price movement is not smooth from the last EXT point to next EXT point. There still exist some price fluctuations in every DC trend. These price fluctuations are also important information of the market which is not able to be observed by N_{DC}. So here we introduced another indicator - Sub-N_{DC}. By choosing another smaller threshold, Sub-N_{DC} measures the total number of DC events that happened in each DC trend based on the smaller threshold. For example, as Figure 4 shows, compared with the threshold 3%, we set another smaller threshold, called sub-threshold, which is 1%. Based on the same sub-threshold, the DC trend which has higher Sub-N_{DC} value is more volatile than other DC trends.

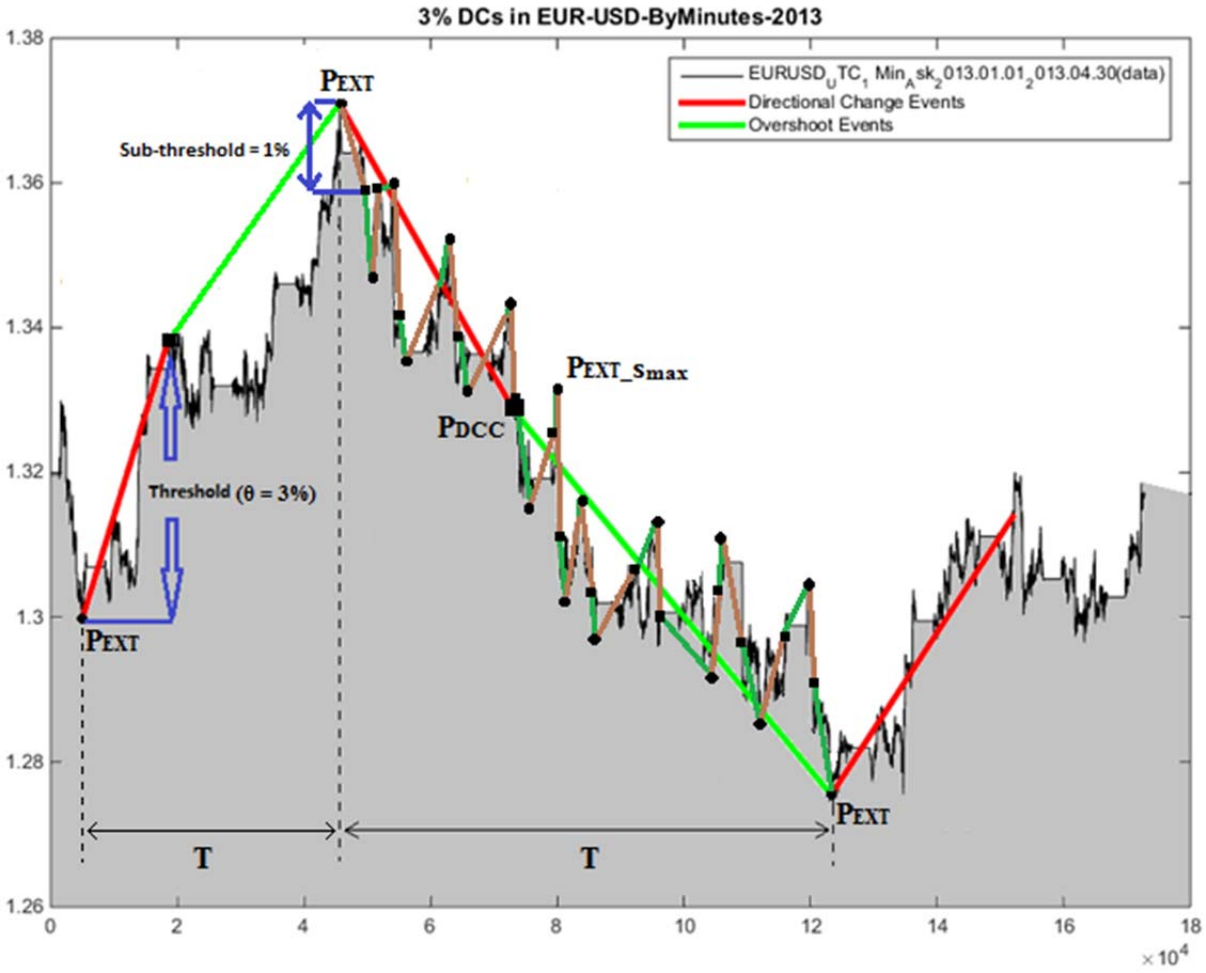

Figure 4: Using sub-threshold 1%, we found 17 DC events between two EXT points. So Sub-N_{DC} is 17 in this DC trend.

4.6 Undershoot Value at Extreme Points (USV_{EXT_s})

Undershoot Value at Extreme Points (USV_{EXT_s}) is also based on the sub-threshold. It measures the highest price change in each DC trend according to the sub-threshold. In a downward DC trend, USV_{EXT_s} is defined by:

$$USV_{EXT\_s} = \begin{cases} \frac{P_{EXT\_smax} - P_{DCC*}}{P_{DCC*} \times \theta}, & P_{EXTs\_max} - P_{DCC*} > 0 \\ 0, & P_{EXTs\_max} - P_{DCC*} \leq 0 \end{cases} \quad (6)$$

Here $P_{EXT\_s_{max}}$ is the highest price at the DC extreme point, which is based on sub-threshold. As Figure 4 shows. P_{DCC*} is the price of the theoretical directional change confirmation point of the current trend which is based on the threshold, θ is the threshold.

In a upward DC trend, USV_{EXT_s} is defined by:

$$USV_{EXT\_s} = \begin{cases} \frac{P_{DCC*} - P_{EXT\_smin}}{P_{DCC*} \times \theta}, & P_{DCC*} - P_{EXTs\_min} > 0 \\ 0, & P_{DCC*} - P_{EXTs\_min} \leq 0 \end{cases} \quad (6)$$

Here $P_{EXT\_s_{min}}$ is the lowest price at the DC extreme point, which is based on sub-threshold. As Figure 4 shows. P_{DCC*} is the price of the theoretical directional change confirmation point of the current trend which is based on the threshold, θ is the threshold.

Compared with Sub-N_{DC} which measures the frequency of price changes in each DC trend, USV_{EXT_s} measures the magnitude of price changes in the trend. Based on the same sub-threshold, the DC trend which has higher USV_{EXT_s} value is more volatile than other DC trends.

4.7 Time independent Coastline (C_{DC})

Since TMV_{EXT} represents the maximum possible profit of each TM event, we define the length of the price-curve coastline under DC (θ) as the sum of all absolute value of TMV_{EXT} over the profiling period:

$$C_{DC} = \sum_{i=1}^{N(\theta)} \left| TMV_{EXT_i} \right| \quad (7)$$

Here θ is the threshold (in %), N (θ) is the total number of DC events over the profiling period under θ and TMV_{EXT_i} is the Total Price Movements Value at each directional change extreme point.

The calculation of C_{DC} only pays attention to price changes; time is ignored. It shows us the maximum possible profit available from the profiled period.

4.8 Time-adjusted return of DC (R_{DC})

We define time-adjusted return of DC (R_{DC}) to measure the return in each upturn or downturn event, i.e. the ratio between each TM event and time interval (T). A high R_{DC} means the profit can be earned in a short time period. Since TMV_{EXT} measures the number of thresholds in up/downtrend. We define R_{DC} as:

$$R_{DC} = \frac{|TMV_{EXT}| * \theta}{T} \quad (8)$$

Here TMV_{EXT} is total price movement value at extreme points and T is the time interval between each EXT, θ is the threshold used. Here R_{DC} measures the percentage of price rising/dropping per time unit.

One could define a coastline based on time-adjusted returns R_{DC}. For example, one could take the accumulative (unsigned) returns to represent coastline. However, its equivalence in time series is unfamiliar to researchers. Therefore, while it is potentially useful, we leave this option open at this stage.

4.9 Summary on contrast between time series and DC

DC is still in its infancy. It is still limited in what we can use DC indicators to profile market dynamics. But useful information can be gained from the research so far. This has been explained in the above subsections. Here is a summary.

The returns that time series look at are returns over fixed period of time, while the returns that DC looks at (R_{DC}) are returns over directional change events. Given the same number of data points, DC coastlines are often longer than time series coastlines for the same period, because by definition, DC captures the extreme points (Aloud et at 2012).

The five indicators (N_{DC}, TMV_{EXT}, T, Sub-N_{DC} and USV_{EXT}) introduced in DC provide five additional measures of volatility. The introduction of overshoot enabled (Glattfelder et al 2011) to observe power laws in the foreign exchange market. Table 1 summarizes the indicators discussed so far.

	Time Series Indicators	**Directional Change Indicators**
Return: Different angles on returns	Returns measured in each (fixed) period	Percentage of price changes measured in each trend. Since they are sampled in irregular times, this percentage must be time adjusted for comparison
Coastlines: DC coastlines are often longer than time series coastlines (Aloud et at 2012)	Accumulation of Returns	C_{DC}: maximum possible returns over the profiled period
Volatility: Time series and DC provide different perspectives on volatility	Variance on Returns	N_{DC}: measures the frequency of DCs TMV_{EXT}: measures the scale of price changes T: measures the time that it takes to complete a trend Sub-N_{DC}: measures the frequency of DCs in each DC trend USV_{EXT}: measures the scale of price changes in each DC trend
Statistical observations: Different observations made possible by different indicators	Many observations, such as fat tails and volatility clustering	Power law found on overshoot event, which is made possible by the introduction of overshoot value at extreme points (Glattfelder et al 2011)

Table 1: Contrast between time series indicators and DC-based indicators.

5 TR1: Profiling time series

TR1 is a program that reads in time-stamped prices (which we call the Input Data File) and output a profile of the input data. The profile includes two parts. First, TR1 outputs a file that

contains all the data points at extreme points and directional change confirmation points. We call this the DC-Data File. Secondly, TR1 outputs a summary of the profile. We call it the Profile Summary File. The full specification of TR1 is in Appendix I.

The Profile Summary File is summarized from the DC-Data file, which only has a few indicators in it. These indicators show the information of the whole market price movements, such as the market trend, and the price curve volatility. Compared with time series analysis, users are able to have a different understanding of the market price movements in directional change term more easily.

5.1 Input to TR1

The Input file is a csv file with one record per data point, timed.

5.2 Output of TR1

The program will produce two files: (1) “DC-Data File” and (2) “Profile Summary File”.

DC-Data file contains:

Header: It contains information for reproducing the results, which include the program version, input and output files and the threshold used for computing the DCs. The full specification of the Header and the Body (below) can be found in Appendix I.

Body: It contains a chronological report of all the trends in the whole period which has been summarized. This includes the extreme point, and directional change confirmation point of each trend, together with indicators OSV_{EXT}, TMV_{EXT}, T, R_{DC}, Sub-N_{DC} and USV_{EXT} as defined in Section 4.

Profile Summary File contains:

Header: It is the same one as the DC-Data file.

Body: It contains market information that concludes from the indicators in the DC-Data file. This includes the number of directional changes (N_{DC}) and the median value of OSV_{EXT}, TMV_{EXT}, T, R_{DC}, Sub-N_{DC} and USV_{EXT} for DC uptrends, downtrends, and the whole trends.

Snapshot profile – it only contains market information at the ending point in DC-Data file. This includes the final time and price displayed in the Input Data File, together with the spot indicators OSV, TMV, T and R_{DC} as defined in Section 4.

6 Example: PROFILING THE EUR/USD MARKET

The DC-Data file will be fully displayed in appendix II, which is used to check the correctness of Profile Summary File in table 1.

Figure 5 shows the price movements of second-by-second FOREX market data for EUR/USD, which is spans from October 1, 2009 to October 30, 2009. It also shows the highest and lowest price points. Figure 6 shows the one-month data is summarized that in the DC method, under a fixed threshold 0.4%. Table 2 is the DC Profile file, and table 3 is the Snapshot file.

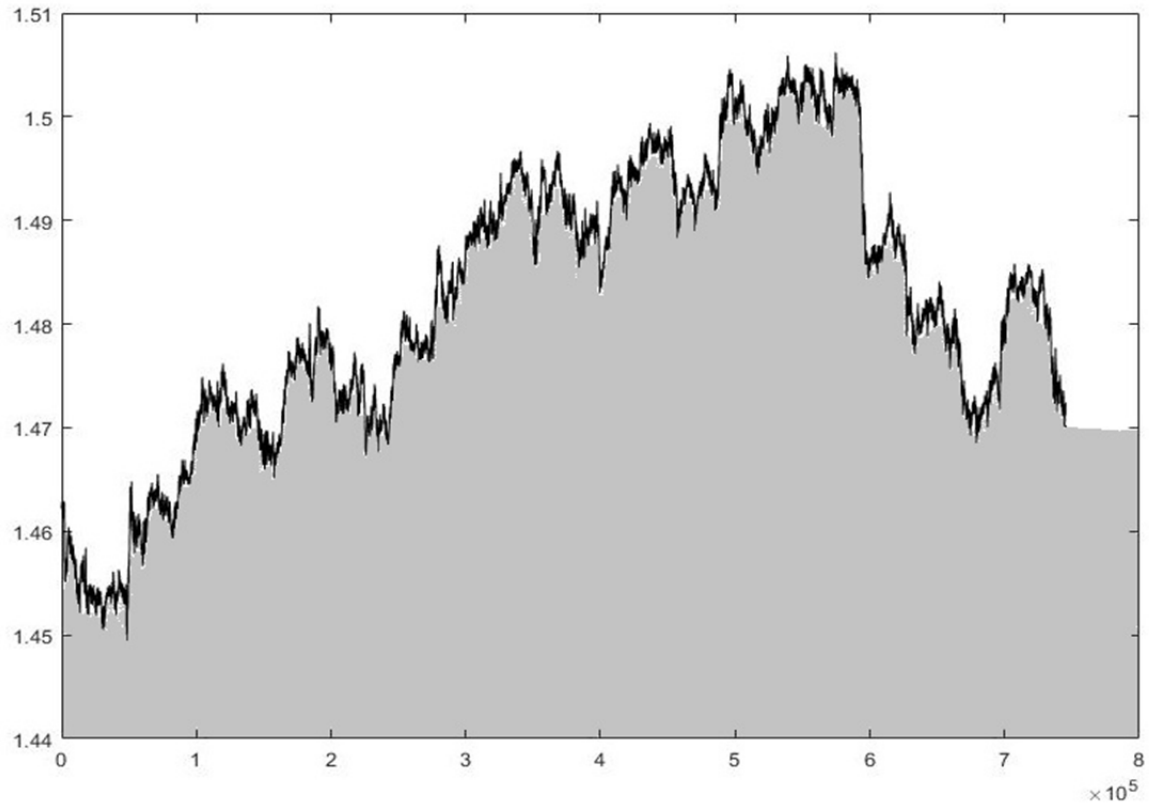

Figure 4: Price movements of second-by-second market data for EUR/USD, spanning October 1, 2009 to October 30, 2009, which includes around 745,466 data points.

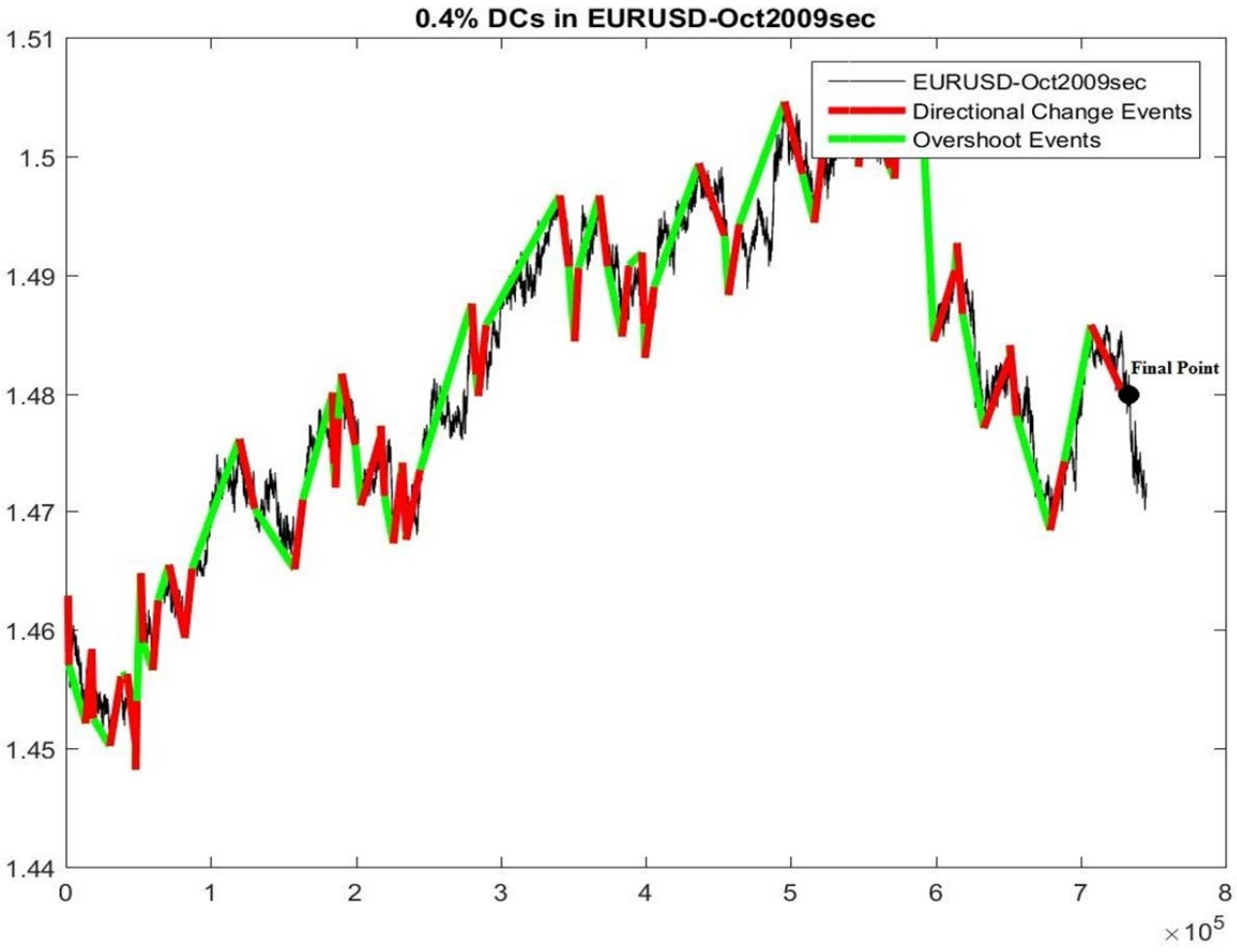

Figure 5: Price movements of second-by-second market data for EUR/USD, spanning October 1, 2009 to October 30, 2009, determined by a fixed threshold 0.4%. The total price movements between two consecutive extreme points are decomposed into directional change events (red lines) and an overshoot events (green lines).

Profile Summary File:

Program_ID:TR1.3	
Author: Ran Tao	
Date	2016.03.03 22:20:37
File_input	EURUSD-Oct2009sec
Threshold(Theta)	0.004
Sub-Threshold	0.001
Tstart	01/10/2009,00:00:00
Tfinal	30/10/2009,16:58:58
TL	745266
NDC	43
PC	1.015654
MedianOSV_overall	0.669948
MedianOSV_up	0.644839
MedianOSV_down	0.695057
MedianT_overall	37378
MedianT_up	44389
MedianT_down	25740
MedianR_DC_overall	1.79E-07
MedianR_DC_up	1.48E-07
MedianR_DC_down	2.46E-07
LenC	77.42177
MeanLenC	1.843376
MedianSub_NDC	13
MedianUSV	0.166625

Table 2: Profile Summary File of second-by-second market data for EUR/USD, spanning October 1, 2009 to October 30, 2009, determined by a fixed threshold 0.4%

Snapshot	
Tfinal	30/10/2009,16:58:58
Pfinal	1.4722
SPC	1.006701
SOSV	-1.28396
STMV	-2.28833
ST	38042
SR_DC	6.02E-05

Table 3: Snapshot at the final point of second-by-second market data for EUR/USD, spanning October 1, 2009 to October 30, 2009, determined by a fixed threshold 0.4%

Table 2 is an example of DC market summary. It summarizes the 745266 seconds (TL) in the one month period in the EUR/USD market under a threshold of 0.4%. The market price

movement is going up as the price change (PC) from first extreme point (EXT) to the last extreme point is slightly greater than 1 (1.015654). It shows that there are 43 DC events (N_{DC}). The median time that each trend takes is 37378 seconds (MedianT_overall). The uptrends take more time, which is 44389 seconds per trend (MedianT_up). While the downtrends only take 25740 seconds (MedianT_down). Downtrends shows more frequency in price changes.

The median range of price change is 0.669949 (MedianOSV_overall). The price change in up trends (MedianOSV_up = 0.644839) is smaller than down trends (MedianOSV_down = 0.695057). So the downtrends have more potential profit and less risk for the DC traders.

The profile can also tell us about the time-adjusted return (R_{DC}) in up and downtrends. MedianR_DC_up is $1.79 \times 10^{-}7$, or 0.0646% per second. MedianR_DC_up (1.48×10^{-7}) is smaller than MedianR_DC _down (2.46×10^{-7}). In other words, the price rises 0.053% (0.053% = $1.48 \times 10^{-7} \times 3600$) per hour while drops 0.089% (0.089% = $2.46 \times 10^{-7} \times 3600$) per hour in each trend. This profile shows that downtrends have higher return than uptrends in EUR/USD market.

The price-curve coastline (LenC) is 77.42177. This means the profit that one can potentially make in the profiling period is 77.42177 × threshold (0.4%) = 30.9687%. It represents the highest possible profit that one could make according to the DC profile. Furthermore, the profile shows that the MeanLenC is 1.843376. This means on average threshold (0.4%) × 1.843376 =0.7373504% of potential profit can be earned in each trend.

The sub-threshold we choose for this DC profile is 0.1% (Sub-Threshold). So the median DC events based on the sub-threshold that happened in each trend is 13 (MedianSub_N_{DC}). The median undershoot value at extreme points is 0.166625 (MedianUSV).

7 Discussion

Based on the DC profile, we make a comparison between the same period's EUR/USD market and GOLD/USD market to test the DC market summary. The fixed threshold is 0.4% and sub-threshold is 0.1%.

	EUR/USD	GOLD/USD
Threshold(Theta)	0.004	0.004
Sub-Threshold	0.001	0.001
Tstart	01/10/2009,00:00:00	01/10/2009,00:36:58
Tfinal	30/10/2009,16:58:58	30/10/2009,17:14:58
TL	745266	129314
NDC	43	54
PC	1.015653838	1.029225
MedianOSV_overall	0.669947899	1.366657
MedianOSV_up	0.644839122	1.703172
MedianOSV_down	0.695056677	1.354507
MedianT_overall	37378	15846
MedianT_up	44389	13806
MedianT_down	25740	21060
MedianR_DC_overall	1.7941E-07	5.35E-07
MedianR_DC_up	1.47982E-07	7.17E-07
MedianR_DC_down	2.46345E-07	5.24E-07
LenC	77.42177291	141.8471
MeanLenC	1.843375546	2.676361
MedianSub_NDC	13	3
MedianUSV	0.166624722	0.192552

Table 4: the profile comparison between EUR/USD market and GOLD/USD market from October 1, 2009 to October 30, 2009 (Threshold 0.4%, Sub-Threshold 0.1%)

The results in Table 4 shows the differences between two markets under DC summarizing. It shows profiles that summarize the minute-by-minute transaction prices October 1, 2009 to October 30, 2009 in both the EUR/USD and the GOLD/USD market. Both profiles were created under a threshold of 0.4%.

The profiles in Table 4 suggest that the GOLD/USD market is more volatile than the EUR/USD market. First of all, GOLD/USD market has more frequency in price changes than EUR/USD market. 54 DC events were observed in the GOLD/USD market (see row N_{DC}

under column 2 in Table 4), which is greater than 43 for EUR/USD. GOLD/USD market also has more Sub-N_{DC} than EUR/USD market. The median DC events based on the sub-threshold that happened in each trend is 13, which is greater than 3 for EUR/USD market (see row MedianSub_N_{DC} under column 3 in Table 4). Secondly, the physical time that it takes to complete a trend in GOLD/USD market is much shorter than EUR/USD market. The median time for GOLD/USD market to end a trend is 15846 seconds. While EUR/USD market takes 37378 seconds. Finally, compared with EUR/USD market, GOLD/USD market has greater price changes. The median overall value of OSV_{EXT} of the market is 1.366657(row MedianOSV_overall in Table 4), which is greater than the same period's EUR/USD market (0.669947899). GOLD/USD market also has greater undershoot value, which is 0.192552 (row MedianUSV in Table 4). While the undershoot value for EUR/USD market is 0.166624722. So the DC volatility in GOLD/USD market is much higher than EUR/USD market.

GOLD/USD market also has a higher time-adjusted return (R_{DC}). R_{DC} for GOLD/USD market is 5.35×10^{-7} (see row MedianR_DC_overall in Table 4). In other words, 0.1924% per second. This is than EUR/USD market, which is 0.0646% per second. Furthermore, GOLD/USD market has more potential profit (row LenC in Table 4) in DC trading. It has a much longer price-curve coastline ($141.8471 \times 0.4\% = 53.7388\%$), or potential profit than the same period's EUR/USD market ($77.42177 \times 0.6\% = 30.9687\%$).

However, the downtrends in EUR/USD market shows more price changes than uptrends, which is opposite in GOLD/USD market. In EUR/USD market, the price change in up trends (MedianOSV_up = 0.644839) is smaller than down trends (MedianOSV_down = 0.695057). While in GOLD/USD market, the price change in up trends (MedianOSV_up = 1.703172) is greater than down trends (MedianOSV_down = 1.354507). Besides that, the downtrends in EUR/USD market has higher value of time-adjusted return than uptrends. The price rises 0.053% per hour while drops 0.089% per hour in each trend, as indicated in Section 6.While for GOLD/USD market, the uptrends has higher value of time-adjusted return than downtrends. The price rises 0.2582% ($0.2582\% = 7.17 \times 10^{-7} \times 3600$) per hour while drops 0.188% ($0.188\% = 5.24 \times 10^{-7} \times 3600$) per hour in each trend.

8 Conclusion and Further Research

In this paper, we have introduced DC as an alternative way to summarize price changes. It is different from the traditional time series. It provides a different angle for capturing and analysing price changes.

We need to extract information from the data. In this paper, we have introduced a set of indicators for capturing information from data. For example, R_{DC} captures the time-adjusted return of a completing trend. The coastline captures the potential profit in trading in a time period under the observed threshold. This is useful information that we do not often find in time series analysis.

These indicators could help us construct DC profiles of markets. We have produced a program, which we called TR1, to produce DC profiles. Given market data and a threshold, TR1 produces a DC profile which contains the indicators introduced in this paper. TR1 helps its users to extract information from data, so that further research about the market can be conducted.

We have demonstrated how DC profiles could be used to summarize price changes in the high frequency EUR/USD and GOLD/USD markets. Through these indicators, we can discover useful information about the profiled period. For example, in the profiled EUR/USD market, price rises slowly in uptrends and drops quickly in downtrends. The opposite was observed in the GOLD/USD market. Besides, the profiled GOLD/USD market has a longer coastline than EUR/USD. Such observations could have implications for which market to trade in, and whether to trade more in bull or bear markets.

With the indicators presented in this paper, we hope to open doors to further research in the DC framework. One obvious direction is to discover new indicators for DC profiles. The more useful indicators one defines, the more information we can extract from the data. Another direction is to combine directional change analysis with the traditional time series analysis to explore synergy. Since they are two different methods to observe the same market, they may provide complementary market information.

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Appendix I – Specification of TR1

TR1 is a program that reads in time-stamped prices (which we call the Input Data File) and output a profile of the input data. The profile includes two parts. First, TR1 outputs a file that contains all the data points at extreme points and directional change confirmation points. We call this the DC-Data File. Secondly, TR1 outputs a summary of the profile. We call it the Profile Summary File.

Following is the specification of TR1.

Input Data File

This is a csv file with one record per data point, where each record comprises the following fields:

- TimeStamp: Time stamp, which could include the date and time of a Trade
- TradePrice: Price of a trade

Output: The program will produce two files: (1) "DC-Data File" and (2) "Profile Summary File".

Output 1: DC-Data File

This is a csv file with two parts:

(**Header**, **Body**)

Header: it contains information that enables other researchers to reproduce the results:

- Program_ID: Program and version: e.g. TR1.0 v.1.0
- Author: Ran Tao
- Date on which the DC-Data File was produced
- File_input: Name of the Input Data File
- Theta: Threshold used to run the program
- Tstart: First T_{Trade} displayed in the Input Data File; i.e. start of the data series
- Tfinal: Final T_{Trade} displayed in the Input Data File; i.e. end of the data series
- Link to the Working Paper <Edward will give you a link>

Body: it is a table with one record per extreme point; each record comprises the following fields:

- T_{EXT}: Date_Time at extreme point
- P_{EXT}: Price at extreme point

- T_{DCC}: Date_Time at DC Confirmation (DCC) point
- P_{DCC}: Price at DCC point
- DCC*: Minimum price at DCC point
- OSV_{EXT}: The OSV at extreme point T_{EXT}
- T: The time taken by the current trend, i.e. the difference between the current $T_{\_EXT}$ and the next $T_{\_EXT}$
- TMV_{EXT}: Total Price movements value at extreme point $T_{\_EXT}$
- R_{DC}: (= $TMV_{EXT} \div T$) the time-adjusted return of the trend
- Sub-N_{DC}: The total number of directional changes in each TM event based on the sub-threshold
- USV_{EXT}: The USV at extreme point T_{EXT}

Output 2: Profile Summary File

This is a csv file with name-value pairs. It contains three parts: (1) Header, (2) Profile for the whole period; and (3) Snapshot Profile.

Part 1: Header: it contains information that provides information for reproducing the results:

- Program and version: e.g. TR1.0 v.1.0
- Author: Ran Tao
- Date on which the DC-Data File was produced
- File_input: Name of the Input Data File
- Theta: Threshold
- Tstart: First T_{Trade} displayed in the Input Data File; i.e. start of the data series
- Tfinal: Final T_{Trade} displayed in the Input Data File; i.e. end of the data series

Part 2: Profile for the whole period:

- TL: Length of the time period covered by the Input Data File, also represents the time units in total, e.g. minutes.
- N_{DC}: The total number of directional changes over the profiled period
- PC: Price change – the spot percentage increase/decrease in price at the last extreme point (EXT) from the first extreme point in the DC-Data File
- MedianOSV = (MedianOSV_overall, MedianOSV_up, MedianOSV_down)

    - MedianOSVoverall: median of absolute value of OSV_{EXT} collected in the DC-Data File
    - MedianOSVup: median value of OSV_{EXT} collected for the up-trends only
    - MedianOSVdown: median of absolute value of OSV_{EXT} collected for the down-trends only
- MedianT = (MedianT_overall, MedianT_up, MedianT_down)
    - The median value of T collected, the median value of T in the up trends and in the down trends
- $MedianR_{DC}$ = ($MedianR_{DC}$_overall, $MedianR_{DC}$_up, $MedianR_{DC}$_down)
    - The median value of R_{DC} collected, the median value of R_{DC} in the up trends and in the down trends
- C_{DC} = Length of Coastline defined by directional change events ($\sum_{i=1}^{N(\theta)} TMV_{EXT_i}$)
    - the median value of TMV_{EXT} collected in the DC-Data File
- MedianSub-N_{DC}: The median value of Sub-N_{DC} collected in the DC-Data File
- MedianUSV_{EXT}: The median of absolute value of USV_{EXT} collected in the DC-Data File

Part 3: Snapshot profile: information at T_final

- T_{final}: Final TimeStamp displayed in the Input Data File; i.e. the date and time at the end of the data series
- P_{final}: Final TradePrice displayed in the Input Data File; i.e. price at the end of the data series
- SPC: Price change – the spot percentage increase/decrease in price at the current point from the beginning of the period covered by the Input Data File
- SOSV: The Spot OSV at the final trend of the period
- STMV: The Spot TMV at the final trend of the period
- ST: The Spot time taken in the current trend
- SR_{DC}: The Spot R_{DC} at the current point

Appendix II – Sample DC-Data File

DC-Data file is a file that contains all the data points at extreme points and directional change confirmation points. It also includes the indicators, such as OSV_{EXT}, which is calculated from

the data points. The DC-Data file is machine readable for testing the correctness of the Summary Profile and calculating new indicators if needed.

Table 6 shows a sample DC-Data File. This file contains two parts: the Header and the Body. The Header starts from the beginning to end of the row that starts with "Tfinal" (the first eight lines in Table 5). It contains sufficient information to reproduce the results. Table 5 it shows the version of the program run (which is TR1.3) and the date and time (2016.03.03 22:20:37, which reads 3rd March 2016 at time 22:22:37) at which the program was executed. It shows the name of the Input Data File ("EURUSD-Oct2009sec") and the threshold being used (0.004, i.e. 0.4%, as shown in row 5 column 2). The sub-threshold is 0.001 (row 6 column 2).It also shows the time of the first transaction and the final transaction recorded in the Input Data File (01/10/2009,00:00:00and 30/10/2009,16:58:58, respectively).

The Body is the table that starts with "T_EXT" (row 10 in this example) and finishes at the end of the file. Each row records a Directional Change event. For example, the first extreme point recorded is at "01/10/2009, 01:24:56". The transaction price recorded was 1.4629(column 2). At "01/10/2009, 01:49:28" (row 10, column 3), the transaction price was 1.457 (column 4). Since this price is 0.4% higher than the extreme price (1.4629), it confirmed an upward directional change from the extreme point. The table also records the minimum price that must be reached before one could confirm an upward directional change. This is called PDCC* (column 5). In the first event (row 11), PDCC* is 1.4629× (1+0.4%) = 1.457048.

With PEXT and PDCC*, we calculate overshoot value at extreme points. OSV_{EXT} = ((1.4521-1.457048) ÷ 1.457048) ÷ 0.004 = - 0.84905 (column 6, row 11). With PEXT and PDCC, we calculate total price movements at extreme points. TMV_{EXT} = ((1.4521-1.4629) ÷ 457048) ÷ 0.004 = - 1.84565 (column7, row 11). Time interval (column 8) records the time units between each T_EXT, such as 25740 (column 8, row 11). The next column is RDC, which measures the time-adjusted return of upturn/downturn trend. RDC = |TMVEXT| × threshold / T = 1.84565 × 0.004 ÷ 25740 = 2.87× 10^{-7} (column 10, row 11). The last two columns records Sub-N_{DC} and the undershoot value at extreme points (USV_{EXT}) in each trend.

Program_ID:TR1.3										
Author: Ran Tao										
Date	2016.03.03 22:20:37									
File_input	EURUSD-Oct2009sec									

Threshold(Theta)	0.004									
Sub-Threshold	0.001									
Tstart	01/10/2009,00:00:00									
Tfinal	30/10/2009,16:58:58									
T_EXT	PEXT	T_DCC	PDCC	PDCC*	OSVEXT	TMVEXT	T	R_DC	sub_NDC	USV
01/10/2009,01:24:56	1.4629	01/10/2009,01:49:28	1.457	1.457048	-0.84905	-1.84565	25740	2.87E-07	23	0
01/10/2009,08:33:56	1.4521	01/10/2009,10:55:30	1.4582	1.457908	0.084299	1.084636	8496	5.11E-07	3	0.257218
01/10/2009,10:55:32	1.4584	01/10/2009,11:35:24	1.4525	1.452566	-0.40728	-1.40565	33300	1.69E-07	19	0
01/10/2009,20:10:32	1.4502	02/10/2009,02:21:42	1.4561	1.456001	0.051374	1.051579	31129	1.35E-07	13	0.154533
02/10/2009,04:49:22	1.4563	02/10/2009,08:32:52	1.4504	1.450475	-0.39208	-1.39051	13484	4.12E-07	9	0.12065
02/10/2009,08:34:06	1.4482	02/10/2009,09:03:04	1.454	1.453993	1.858194	2.865626	7320	1.57E-06	13	0.481433
02/10/2009,10:36:06	1.4648	02/10/2009,11:21:52	1.4589	1.458941	-0.40111	-1.39951	19054	2.94E-07	15	0.222764
02/10/2009,15:53:40	1.4566	04/10/2009,20:34:46	1.4625	1.462426	0.525428	1.52753	37650	1.62E-07	17	0.153854
05/10/2009,02:22:24	1.4655	05/10/2009,08:54:52	1.4596	1.459638	-0.05789	-1.05766	24070	1.76E-07	7	0.13702
05/10/2009,09:03:34	1.4593	05/10/2009,12:02:24	1.4652	1.465137	1.887673	2.895224	94725	1.22E-07	43	0.085316
06/10/2009,11:22:20	1.4762	06/10/2009,20:26:22	1.4702	1.470295	-0.88336	-1.87983	96693	7.78E-08	35	0.289058
07/10/2009,14:14:04	1.4651	07/10/2009,19:29:18	1.471	1.47096	1.553339	2.559552	67407	1.52E-07	23	0.152961
08/10/2009,08:57:34	1.4801	08/10/2009,09:21:12	1.4741	1.47418	-0.36963	-1.36815	4180	1.31E-06	7	0.152627
08/10/2009,10:07:14	1.472	08/10/2009,11:10:18	1.4779	1.477888	0.644839	1.647418	8710	7.57E-07	17	0.16916
08/10/2009,12:32:24	1.4817	08/10/2009,20:05:32	1.4757	1.475773	-0.89329	-1.88972	37106	2.04E-07	13	0.118582
08/10/2009,22:50:50	1.4705	09/10/2009,07:28:40	1.4764	1.476382	0.155448	1.156069	31249	1.48E-07	1	0.304799
09/10/2009,07:31:42	1.4773	09/10/2009,09:04:50	1.4713	1.471391	-0.69506	-1.69228	17996	3.76E-07	13	0.067963
09/10/2009,12:31:38	1.4673	11/10/2009,17:28:26	1.4732	1.473169	0.174929	1.175629	22843	2.06E-07	7	0.220613
11/10/2009,18:53:30	1.4742	11/10/2009,21:17:10	1.4683	1.468303	-0.11973	-1.11925	8822	5.07E-07	9	0.204317
11/10/2009,21:20:32	1.4676	12/10/2009,05:02:40	1.4736	1.47347	2.397334	3.406923	124182	1.1E-07	33	0.0509
13/10/2009,07:50:28	1.4876	13/10/2009,09:30:16	1.4816	1.48165	-0.31208	-1.31084	9276	5.65E-07	9	0.21935
13/10/2009,10:25:04	1.4798	13/10/2009,13:46:58	1.4858	1.485719	1.847725	2.855116	143276	7.97E-08	49	0.168269
15/10/2009,02:13:04	1.4967	15/10/2009,05:46:58	1.4907	1.490713	-1.05875	-2.05452	21322	3.85E-07	7	0.268328
15/10/2009,08:08:26	1.4844	15/10/2009,09:36:26	1.4906	1.490338	1.067275	2.071544	46296	1.79E-07	19	0.419368
15/10/2009,21:00:02	1.4967	16/10/2009,02:30:54	1.4907	1.490713	-0.99167	-1.98771	41007	1.94E-07	25	0.134164
16/10/2009,08:23:38	1.4848	16/10/2009,11:06:00	1.4908	1.490739	0.194669	1.195447	38227	1.25E-07	9	0.218013
18/10/2009,19:02:10	1.4919	18/10/2009,20:16:58	1.4859	1.485932	-0.49336	-1.49139	5612	1.06E-06	3	0.504734
18/10/2009,20:35:42	1.483	19/10/2009,01:30:48	1.489	1.488932	1.757636	2.764666	92893	1.19E-07	55	0.100743
19/10/2009,22:24:00	1.4994	20/10/2009,10:17:12	1.4933	1.493402	-0.85416	-1.85074	48119	1.54E-07	9	0.133922
20/10/2009,11:46:04	1.4883	20/10/2009,16:56:20	1.4943	1.494253	1.731099	2.738023	94421	1.16E-07	39	0.200769
21/10/2009,13:59:58	1.5046	21/10/2009,23:37:22	1.4985	1.498582	-0.69759	-1.6948	53215	1.27E-07	15	0.13346
22/10/2009,04:46:54	1.4944	22/10/2009,08:18:00	1.5006	1.500378	0.920168	1.923849	55998	1.37E-07	17	0.166625
22/10/2009,20:20:12	1.5059	23/10/2009,02:34:38	1.4998	1.499876	-0.12941	-1.12889	22561	2E-07	7	0.16668
23/10/2009,02:36:14	1.4991	23/10/2009,05:48:48	1.5051	1.505096	0.000598	1.0006	11554	3.46E-07	13	0.099661
23/10/2009,05:48:48	1.5051	23/10/2009,15:39:06	1.499	1.49908	-0.16337	-1.16271	51565	9.02E-08	5	0.033354
25/10/2009,20:14:40	1.4981	25/10/2009,22:00:18	1.5041	1.504092	0.350311	1.351712	7464	7.24E-07	13	0.232698
25/10/2009,22:19:04	1.5062	26/10/2009,10:53:08	1.5001	1.500175	-2.62889	-3.61838	58753	2.46E-07	17	0.099988
26/10/2009,14:38:18	1.4844	27/10/2009,02:06:56	1.4904	1.490338	0.396286	1.397871	44389	1.26E-07	7	0.301945

27/10/2009,02:58:10	1.4927	27/10/2009,05:11:10	1.4867	1.486729	-1.61919	-2.61272	38186	2.74E-07	39	0.100893
27/10/2009,13:34:36	1.4771	28/10/2009,02:53:28	1.4831	1.483008	0.184018	1.184754	48033	9.87E-08	7	0.370868
28/10/2009,02:55:16	1.4841	28/10/2009,05:34:02	1.4781	1.478164	-1.65131	-2.6447	62842	1.68E-07	37	0.033826
28/10/2009,20:22:38	1.4684	29/10/2009,03:48:18	1.4743	1.474274	1.95459	2.962408	65891	1.8E-07	43	0.237405
29/10/2009,14:40:52	1.4858	30/10/2009,07:54:40	1.4798	1.479857						0.219616

Table 5: DC Data File produced by TR1 (see specification in Section 5) based on second-by–second data in EUR/USD market from October 1, 2009 to October 30, 2009 (Threshold 0.4%, Sub-Threshold 0.1%)

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