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A STUDY ON THE INFLUENCE OF THE DISCRETISATION UNIT ON THE EFFECTIVENESS OF MODELLING CURRENCY EXCHANGE RATES USING THE BINARY-TEMPORAL REPRESENTATION

An exchange rate can be expressed in the form of a binary-temporal representation. Such a representation is based on a discretization of movements in the exchange rate, in which to each change in the value - equal to a given discretization unit – two parameters are allocated: a binary value, consistent with the direction of change in the exchange rate (increase 1, decrease 0) and duration. Statistical examination proves the existence of dependencies between the parameters of previous changes and the direction of future changes. To model the exchange rate using the applied binary-temporal representation, an appropriate model was developed that enables estimation of the probability of the direction of future changes in the currency exchange rate based on the parameters of historical changes. This article presents an analysis of the influence of the chosen discretization unit on the quality of exchange rate modelling. For this purpose, software was written in MQL4 and C++. As a result of the study, an optimal value for the discretization unit and the optimal parameters of the model providing the highest efficiency were determined. The input data used in the analysis involved tick data for the AUD/NZD exchange rate for a five-year time frame 2012–2017.

Keywords: *foreign exchange market, technical analysis, decision support for currency market investment, modelling of currency exchange rates*

1. Introduction

Currency exchange rates tend to display a great deal of variability over time (they can change literally every second). Hence, the values of exchange rates are typically

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presented by broker platforms in the form of a candlestick chart. The candlestick representation is thus the most common form used in technical analysis and research studies [3, 7, 11, 15]. It is also used in determining the values of relevant indicators and, in visual methods, in the technical analysis of a given currency exchange rate. The application of a candlestick representation, in which the parameters of the candlestick are dependent on the imposed time frame, may lead, however, to a significant decrease in the quality and accuracy of modelling. One intrinsic problem is that the use of the candlestick representation causes information on the sequence and the number of changes ”inside” the candlestick to be lost. With this in mind and on the basis of the idea of binarization of the currency exchange rate, well known from the point and figure method developed at the beginning of the XX century [5], a binary method was proposed [18]. This was followed by a binary-temporal representation [17], which is an expanded version of the binary representation including the duration of individual changes. This particular method for presenting the currency exchange rate enables all the binary-temporal information pertaining to changes that have occurred within a required range to be recorded.

Most of these traditional methods of technical analysis use the candlestick representation (visual methods, indicators, etc.). For the reasons stated above, application of the binary representation enables the construction of more precise prediction models. On the basis of the binary-temporal representation and other appropriate models, such as the state model of binary representation (SMBR) [18], it is possible to estimate the probability of the direction and range of a future change in the exchange rate. Such models can be implemented in decision support systems or decision automation (HFT[2] systems). The potential profit from their application depends on the parameters of the model. This article presents research on the influence of the discretization unit and parameters of the model on the quality of modelling using the state model of binary-temporal representation (SMBTR) [19]. Selecting an optimal discretization unit enables more accurate modelling of the exchange rate and, therefore, higher profits.

The article is structured as follows. Chapter 2 discusses the assumptions underlying the binary-temporal representation and presents its advantages within the context of the traditional candlestick representation of the currency exchange rate. Chapter 3 presents the basic assumptions of the binary- temporal state model. Chapter 4 is devoted to the study of the influence of the discretization unit and other selected parameters on the quality of a model of a currency exchange rate. This chapter also includes an analysis of the opportunities for practically implementing a HFT system with a positive rate of return. The last chapter sums up the most important results provided by the study.

[2]HFT – high frequency trading.

2. Binary-temporal representation of the currency exchange rate

Currency exchange rates are characterized by a very large frequency of changes – a change in a currency rate can even occur several times within a second. In addition, currency exchange rates are characterized by frequent random fluctuations within a very small range [8, 9, 12]. Because of this, tick databases[3] include a large amount of insignificant information (such as random fluctuations) and, in consequence, any application of tick data to statistical analyses becomes impractical and questionable. A currency exchange rate is traditionally presented in the form of a candlestick chart, in which changes in the currency rate over a given time interval are described by the four following parameters: the opening rate, the closing rate and the maximum and minimum exchange rates recorded on the candlestick chart [3, 7, 11, 15]. Hence, the candlestick chart depends on the interval selected (time frame) (typically, this value fluctuates between one minute and one day). The candle representation is commonly implemented by broker platforms (e.g., MetaTrader or JForex). The majority of visual methods for technical analysis (e.g., wave analysis, formation analysis) make use of the candlestick representation. The values of indicators, e.g., RSI (relative strength index), MACD (moving average convergence/divergence) [20] are also based on the candlestick representation. Similarly, in the case of research and scientific publications, the dominant representation applied in analyses is also the candlestick representation. This method involves, however, the loss of a large amount of valuable information related to changes in the exchange rate within the candlestick signals. This stems primarily from the large variability of currency exchange rates in different time intervals. For example, at night the currency rate may change by just a few pips[4], but when important macroeconomic data for the country's economy, e.g., new interest rates, have just been published, the currency exchange rate may, within a handful of seconds, change by several tens of pips. The particular nature of such changes results in the loss of a large amount of valuable information about the number and direction of smaller changes, in particular during periods with a sustained high rate of changes. An alternative approach to expressing the currency exchange rate is the binary representation. This representation, in turn, makes use of the idea of rate binarization. In the past, such an approach was first proposed in the case of a method used for constructing and analysing graphs (charts) using the so-called point and figure method [5]. Regrettably, this method for representing the currency rate has been mainly superseded by the candlestick representation.

The binary representation of a currency exchange rate applied in this paper is described in [18]. This representation is based on a discretization of an exchange rate with respect to a defined unit of discretization unit. This leads to a presentation of changes

[3]Tick database – historical data with each change registered.

[4]Pips – unit of change in the exchange rate equal to a rate trajectory change of 0.0001.

in the exchange rate in the form of a binary sequence in which each value corresponds to a decrease (value 0) or increase (value 1) in the exchange rate by the required discretization unit. This binary representation does not take into consideration the duration of these changes, although relevant studies and investigations show [17] that the duration of a single change is associated with the probabilities of the types of future changes (decrease or increase). Having this in mind, we propose a binary-temporal representation that is, in fact, another modification (similar to the binary-wave representation [16]) of the binary representation. In the binary-temporal representation, each change in the currency rate by the defined unit of discretization unit is given two parameters: a binary variable corresponding to the direction of change and the other corresponding to its duration. Such a representation thus includes information on both the variability and duration of changes.

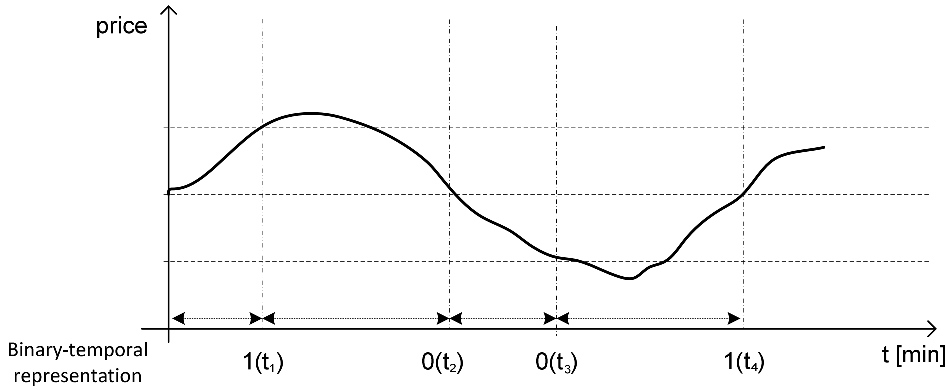

Fig. 1. An example of the binary-temporal representation

Figure 1 shows an example of the operation of the algorithm carrying out currency rate binarization algorithm. The algorithm allocates the value 0 to the binary sequence under construction when the exchange rate drops by one discretization unit, and the value 1 in the case of an increase in the exchange rate by one discretization unit, as well as the duration (or, equivalently, time) of a given change expressed in minutes. After temporal gaps in trading, the algorithm then compares the exchange rate against the first price quotation following the break in trading. In this way, application of the binary--temporal representation eliminates periods in which the exchange rate does not change (e.g., nights) from the analysis and records all of the changes within a specified range within time frames with more intense activity of investors.

The binary representation can be used to build HFT systems. Using HFT systems hundreds (or even thousands) of transactions within a small space of time, often only a few minutes, are concluded. The profit of an investor is calculated according to the statistical prevalence of profitable transactions over the number of transactions that bring losses [1]. Let us now consider an example binary representation. The assumption is that purchasing transactions are concluded in which the take profit (TP) parameter is equal to the current price plus the discretization unit, whereas the stop loss (SL) parameter is equal to the current price minus the discretization unit. The probability that a profit will be obtained is then equal to the probability of the occurrence of 1 in the binary representation. In a similar way, in the case of a selling transaction, the probability of a profit is equal to the probability of the occurrence of 0. On the basis of models that estimate the probability of future directions of change (e.g., SMBR [18], SMBTR [19], SMBWR [16]), it is possible to construct HFT systems that are characterized by a positive return rate.

Consider a HFT system that includes transactions in which the TP and SL parameters differ from the opening price by 15 pips. If we only use the candlestick representation and candlestick data, in a large number of cases it is not possible to verify whether only a single transaction was concluded and, if so, whether it involved a loss or profit (according to which of the parameters, SL or TP, was reached first). Figure 2 shows two possible scenarios for changes in the exchange rate that are represented by the same candlestick. In the first case, the investor makes a profit, while in the other the transaction involves a loss. The occurrence of such situations may lower the credibility of a backtest and empirically determined dependencies that are based on examining the candlestick representation of the exchange.

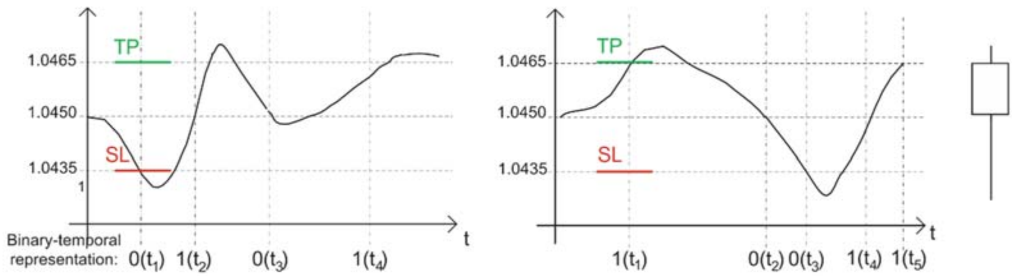

Fig. 2. Different courses of the currency rate represented by the same candle

The currency market has undergone significant changes over the past few years. While several years ago the currency market was virtually limited to professional investors, nowadays, following developments in telecommunications and automation, the number of players in the currency market has dramatically increased (due to the development of broker platforms and lower deposits required). The changes of a technological nature have made it possible to conclude transactions remotely, virtually and in real time (counted in milliseconds) by using specialised broker platforms, such as MetaTrader or Jforex. These platforms offer specialised languages to write scripts that automate trade (e.g., Mql4 for MetaTrader or Java for JForex). It is thanks to these facilitations and the concurrent significant decrease in spreads, observable recently and over the past five years in particular, that HFT systems can rapidly carry out thousands of transactions on the currency market. The investor's profit is shaped by the statistical prevalence of profitable transactions over transactions with losses. In these systems, appropriate mathematical algorithms, developed on the basis of a heuristic analysis of historical data, make decisions on investments. The widespread use of HFT systems, the change in the number of investors, lower spreads, availability of online trade, etc., have all had a strong influence on the nature of quotations. Therefore, any attempt at finding a correlation between certain patterns of investors' behaviour that were characteristic several years ago and the current behaviour of investors is now completely impractical. For the above reasons, this article uses five-year tick data for the example currency pair AUD/NZD from the period of 01.01.2012 –31.12.2016 as recorded by the Swiss brokerage forex house Ducascopy. The binary sequences constructed based on this period include, depending on the choice of the discretization unit, from several to tens of thousands of binary values. This number is large enough to perform reliable statistical analysis of the current course of the currency market.

Predictive modelling is based on the adoption of a hypothesis about the existence of a certain dependence between historical changes and the probabilities of the directions of future changes in the exchange rate. If the exchange rate satisfies the hypothesis of an effective market [6], which assume the absence of such a dependence, then the construction of predictive systems based on the analysis of historical data is groundless. By applying statistical tests developed for testing pseudo-random number generators, as recommended by NIST (the National Institute of Standards and Technology) [14], an examination of the exchange rate in its binary-temporal representation was performed. The examination of the binary changes involved the following tests: frequency test, poker test, series test and long series in block test. In the case of all of the selected discretization units, similar results were obtained. The first test confirmed the random character of these changes – this result means that there are a similar number of decreases and increases in the exchange rate quotations [4, 10, 14]. However, the last three tests indicated the existence of certain dependencies, i.e., frequent occurrence of certain sequences and series of given lengths [4, 10, 14]. The study used a significance level of 0.05. To determine whether there was a dependence between the duration and direction of changes, time distributions were verified, using the Kolmogorov–Smirnov test [2] and Anderson–Darling test [13], with respect to their memorylessness property. A detailed description of the way in which this particular test was performed is presented in [17]. As a result of these tests, it can be stated that for all discretization units under investigation, similar results were obtained, thus rejecting the hypothesis on memorylessness of the time distribution at the 0.05 significance level. The obtained results prove then that it is possible to apply the binary-temporal representation with selected values of the discretization unit to model the currency exchange rate.

3. Modelling currency exchange rates using the binary-temporal representation

A model based on the binary-temporal representation enables the probability of a given direction of a future change to be approximated based on the analysis of the times and sequence of historical changes. The concept of this model is grounded in defining states of the market that correspond to designated patterns of the behaviour of investors. A model is determined by the following parameters:

- l – number of historical changes analysed,
- l_t – number of times of historical changes analysed,
- t – time threshold, expressed in minutes.

In the SMBTR model, the state is defined to be the pattern determined by the l last changes and the binary variable w_i that determines whether the time threshold for the ith change was exceeded or not:

$$w_i = \begin{cases} 0 \text{ if } t_i > t \\ 1 \text{ if } t_i \le t \end{cases} \tag{1}$$

where the parameter t_i determines the duration of the ith change in the binary-temporal representation. For example, in a model with the parameters $l = 2$, $l_t = 1$, $t = 10$ min, the state (01, 1) denotes that the currency rate dropped during the penultimate change by a discretization unit and then increased by the same unit, while the last change was shorter than 10 minutes. Therefore, the number of states can be determined by the following formula:

$$P = 2^{(l+l_t)} \tag{2}$$

On the basis of these states, it is possible to construct a diagram for the process of the changes of currency rate that maps all the possible changes of states. Figure 3 shows an example state diagram for this kind of model with parameters $l = 2$, $l_t = 1$, t (the structure of the state diagram is independent of the t value). The probabilities of transitions between states are based on estimators of probabilities of an increase or decrease, defined by the frequencies of increases/decreases obtained on the basis of the analysis of historical data. As a consequence, after recording a given state, it is possible, based on the state diagram, to determine the probability of an increase or decrease. For the model presented in Fig. 3, this probability is defined as the sum of the relevant probabilities of the transitions between given states and can be determined by the following formula:

$$P_{\text{increase}}(01,1) = P[(01,1) \to (11,0)] + P[(01,1) \to (11,1)] \tag{3}$$

In a similar way, the probability of the next change being a decrease when in state (01, 1) can be determined by:

$$P_{\text{decrease}}(01,1) = P[(01,1) \to (10,0)] + P[(01,1) \to (10,1)] \tag{4}$$

The probabilities

$$P[(01,1) \to (00,0)],\ P[(01,1) \to (00,1)],\ P[(01,1) \to (01,0)]$$
$$P[(01,1) \to (01,0)],\ \text{and}\ P[(01,1) \to (01,1)]$$

in Eqs. (3) and (4) determine the probabilities of the next state after leaving state (01, 1). Since the sum of all the probabilities of ways of leaving a given state is equal to one, then:

$$P_{\text{increase}}(01,1) + P_{\text{decrease}}(01,1) = 1 \tag{5}$$

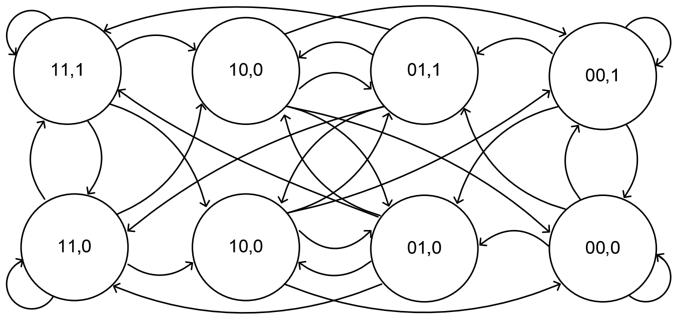

Fig. 3. State diagram for SMBTR ($l = 2$, $l_t = 1$, $t = 5$)

As appropriate statistical examination has shown, this model is characterized by high accuracy in estimating the probabilities of various changes. A detailed description of the model and its properties is to be found in [19].

4. The influence of the discretization unit and the parameters of the model on the effectiveness of modelling

The results of modelling are influenced by the parameters of the SMBTR model and the value of the discretization unit adopted to construct the relevant binary-temporal representation. Let us consider a model with parameters $l = 2$, $l_t = 1$, i.e., a model that analyses the direction of the last two changes and duration of the last change. A model with these parameters enables quite precise assessment of the probabilities of particular changes, but also requires a fairly small number of states – an increase in the number (l) of changes analysed in the model leads to an increase in the number of states, which, in consequence, prevents reliable statistical analysis. The most favourable (optimal) choice of the time threshold and discretization unit for such a model can thus be estimated based on an empirical study with the application of historical data. The optimal choice of such a set of parameters is understood as the set that leads to the most accurate estimation of the probability of the direction of a future change. In this paper, the estimator of the probability of an increase was analysed. The greater this estimator, the better the prediction of an increase in the exchange rate. However, if this estimator is below 0.5 (which indicates that a decrease is more probable), maximization of the estimator of the probability of a decrease should be performed.

Let us now consider the range of possible discretization units. The aim of applying the binary-temporal representation is to filter the size of changes in the exchange rate to eliminate random fluctuations, among other things. In the case of setting the value of the discretization unit to be very small, e.g., 4 pips, the influence of noise will also be visible in the binary-temporal representation. In the case of building HFT systems based on binary representations, the influence of spreads has to be taken into consideration. In the case of small discretization units, the spread itself can be a very significant proportion of the value of a transaction. By taking into consideration the influence of noise in the study and for practical reasons, it was assumed that the smallest possible discretization unit took the value of 10 pips. On the other hand, applying a large discretization unit leads to a loss in the informative value of the model regarding the course of the exchange rate, since we also lose a large amount of potential information on the nature of less important changes. In the same way, an increase in the size of the discretization unit leads to a decrease in the number of recorded changes (and, in consequence, of the number of potential signals). After taking into account the above reasoning, it was decided that the maximum value of the discretization unit should be set to 30 pips.

Now consider the range of the time threshold. The minimum value adopted for the time threshold was five minutes. In the case of very low thresholds, the number of states whose duration is shorter (states of the form *XX*, 1) is very low. Since the number of occurrences of a given state is equal to the number of potential signals, considering lower values is thus of no value at all. Another argument that excludes low time thresholds from the analysis is the characteristic behaviour of exchange rates on the currency market, i.e., very dynamic changes occurring at moments of intensified activity amongst investors, for example, just after the publication of some important macro-economic data. At these moments, spreads become extended to the upper part of their ranges. In addition, price slippages may occur and eventually lead to a given transaction not being completed. In the study, 120 minutes was assumed to be the maximum possible value of the time threshold, since for all discretization units the duration of most of the changes is much shorter.

To examine the influence of the discretization unit and time threshold on the effectiveness of models, software written in C++ and Mql4 was developed. The study was carried out based on tick data for the currency pair AUD/NZD recorded by the Swiss brokerage forex house Ducascopy over a period of five years. An association between the time threshold and the estimator of the probability of an increase can be observed to varying degrees, depending on the state. The greatest influence (at similar levels) was observed for the states (01, 1) and (10, 1). Figure 4 shows the dependence between the estimator of the probability of an increase starting in the state (10, 1). This state is defined according to SMBTR as an increase and then decrease in the currency rate by a discretization unit, such that the duration of the previous state did not exceed the adopted time threshold.

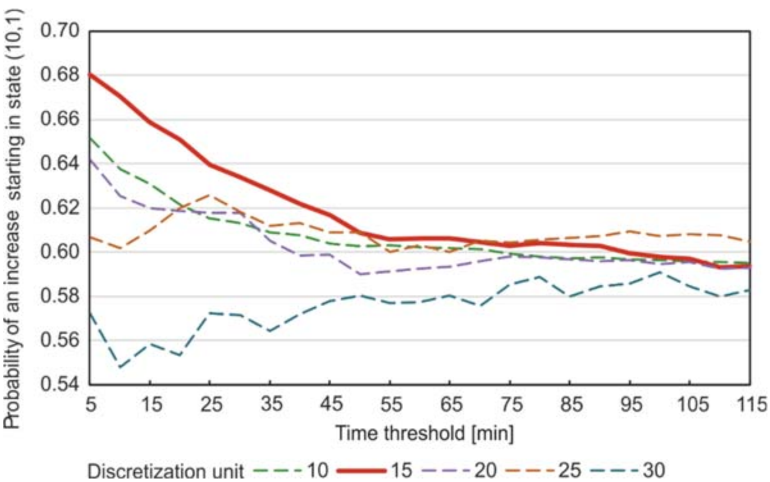

Fig. 4. Probability of an increase starting in state (10, 1)
depending on the adopted time threshold used in SMBTR

The largest estimates of the probability of an increase were observed for a 15-pip discretization unit with the time threshold equal to 5 minutes. For time thresholds below one hour, larger estimates of the probability of increase were obtained with a discretization unit of 15 pips than with any other discretization unit. When the time threshold was greater than one hour (60 min), the effectiveness of prediction tends to be similar for all discretization units. When the discretization unit is equal to 10, 15 or 20 pips, the estimate of the probability of an increase falls as the time threshold increases. On the other hand, in the case of applying larger discretization units, i.e. equal to 25 and 30 pips, the results of the study indicate a lack of a distinct dependence between the size of a time threshold and the quality of modelling. The results obtained clearly point to the absence of a linear dependence between the size of a discretization unit and the maximal estimate of an increase. For the smallest discretization unit, equal to 10 pips, worse results are obtained than in the case of applying a 15-pip threshold. The results obtained with a discretization unit of 10 pips can be explained by the noticeable influence of random fluctuations that worsened the quality of prediction. Similarly, for larger discretization units (greater than 15 pips) considerably worse results are obtained. This fact can be explained by the decrease in the informative value of the binary-temporal representation as the value of the discretization unit increases. It is worth noting that when the time threshold tends to infinity, the SMBTR model converges to the SMBR model.

When estimating the dependence between the discretization unit applied and the probability of a future change direction, the number of the recorded occurrences of each state should also be taken into account. This number also influences both the accuracy of estimation (the greater the number of changes under investigation, the more reliable the results) and the possibility of using the SMBTR model to construct HFT systems in everyday practice – the greater the number of transactions, the more possible it is to apply more advanced money management algorithms, which, in consequence, leads to higher profits.

Table 1. The number of occurrences of the state (10, 1) depending on the adopted discretization unit and time threshold using the SMBTR (2, 1, *t*) model

JD [pips]/*t* [m]	10	15	20	25	30
5	3911	1010	397	196	110
10	5325	1330	494	241	135
15	6387	1563	571	264	145
20	7241	1761	645	292	159
25	7931	1993	709	318	173
30	8525	2150	764	343	175
35	9027	2317	828	361	186
40	9400	2471	892	388	194
45	9753	2640	935	412	206
50	10 054	2779	993	440	217
55	10 295	2898	1038	453	227
60	10 551	3016	1092	489	239
65	10 742	3134	1136	515	248
70	10 957	3231	1173	537	264
75	11 135	3323	1222	561	275
80	11 297	3413	1268	586	282
85	11 433	3493	1307	610	293
90	11 549	3559	1349	634	301
95	11 668	3640	1385	653	309
100	11 767	3714	1421	675	313
105	11 868	3778	1461	689	325
110	11 955	3844	1485	706	343
115	12 035	3912	1521	724	350

Table 1 shows the number of recorded occurrences of the state (10, 1) using the SMBTR model, depending on the time threshold and discretization unit. In the case of the optimal (the most favourable) set of parameters in terms of probability estimation, 1010 occurrences of the state (10, 1) were recorded. For the values of the discretization unit greater than 15 pips (i.e., 20, 25 or 30), the number of signals is decreasing in the discretization unit for all the time thresholds. Although we get the highest number of occurrences of this state as a result of applying a 10-pip discretization unit and a 5 minute threshold, the maximal estimate of the probability of a future change is lower by 4%. It seems that, for these reasons, application of a 15-pip discretization unit and a 5-minute time threshold to construct a HFT system would be the best solution for the currency pair under investigation.

When considering the practical application of the model, it is important to determine the influence of the spreads offered by a broker on the rate of return using the HFT system. As a result of the operation of the SMBTR model, appropriate signals for a transaction to be concluded are obtained in which the TP and SL parameters differ from the opening price by the discretization unit. To determine the nominal value of a potential profit or loss, the HFT system should take into consideration the value of the spread. The potential profit and loss of an investor can be determined on the basis of the following formulas:

$$\text{Profit} = (JD - \text{spread}) \times Lot \tag{6}$$

$$\text{Loss} = (JD + \text{spread}) \times Lot \tag{7}$$

where the variable *Lot* defines the volume of a transaction (based on 100 000 units of the base currency). Assuming that the volume is constant, this parameter only scales the value of a transaction and is of no significance as far as the assumptions presented in this article are concerned. The *JD* parameter is the value of the discretization unit. On the basis of Eqs. (6) and (7) and the following elementary transformations, the boundary value of the estimate of the probability estimation of the change of P_g above which the HFT system – based on the model considered – will generate a expected profit, can be determined as:

$$P_g = \frac{(JD + \text{spread})}{2JD} \tag{8}$$

It is then possible to determine, with the help of Eq. (8), knowledge of the offered spread, selected discretization unit and the value of the probability of the direction of future change, whether the HFT system will generate profits in the long run and for a longer period. An increase in the difference between the profitability threshold (Eq. (8)) and the value of the probability of the direction of future change will lead to higher profit generated by the HFT system. Assuming the average level of spread at the level of 1.4 pips (broker IC Markets), the profitability threshold is 0.54, which means that an application of each of the considered discretization units and each of the considered time thresholds will allow profits to be achieved.

5. Summary

The exchange rate can be presented in the form of a binary-temporal representation that includes information on both price movements (with the volume determined by the discretization unit adopted), as well as their duration. Such a format is an alternative solution to the less accurate candlestick representation. As a result, the binary-temporal representation of an exchange rate can be used to construct effective HFT systems. Using these systems, the probability that a subsequent change in the exchange rate occurs is interpreted as the probability that a profit or loss follow. This parameter can be estimated on the basis of the SMBTR model.

In the article, the dependences between the quality of modelling, the discretization unit adopted and other parameters of the state model have been examined in detail. The results of this study indicate that for the currency pair AUD/NZD we can estimate, by applying the binary-temporal model, that the probability of the direction of future change at the level of about 68%. Such a result is good enough to enable the construction of effective HFT systems that are characterized by a positive rate of return. The analysis presented is of a universal nature and can be used to support the choice of appropriate discretization units for any other currency pairs.

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