St. Petersburg University
Graduate School of Management

Master in Corporate Finance

PREDICTING RUSSIAN EXCHANGE RATES UNDER BEHAVIORAL UNCERTAINTY

Master's Thesis by the 2nd year student Nikiforova Anna

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ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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АННОТАЦИЯ

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Описание цели, задач и основных результатов	Исследовательский вопрос: «Как отклонения от рациональных ожиданий меняют предсказуемость и прогноз российского валютного рынка?» Научно-исследовательские цели: 1. Обзор существующих тенденций в области поведенческих финансов. 2. Анализ и обзор эконометрических моделей и тестов, которые используются в работе. 3. Включение поведенческих отклонений в существующие модели. 4. Измерение эффективности прогнозирования и интерпретация результатов. Главные результаты: 1.Рассмотрение предположений об иррациональности, включенных в квантильную регрессию подходит для российского валютного рынка. 2.Предположения об иррациональном поведении инвесторов могут повысить предсказуемость обменных курсов в России, но их предсказательная способная достаточно низкая. 3. Рассмотрение иррационального поведения инвесторов оказывает влияние на будущий прогноз доходности российских обменных курсов. 4. Российский валютный рынок слабоэффективен.
Ключевые слова	Курс валют, Поведенческие финансы, Гипотеза эффективного рынка, Случайное блуждание, Тест отношения дисперсий, Квантильная регрессия.

ABSTRACT

Master Student's Name	Nikiforova Anna Anatolyevna
Master Thesis Title	Predicting Russian exchange rates under behavioral uncertainty
Educational Program	Management
Main field of study	Corporate Finance
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Academic Advisor's Name	Loukianova Anna Evgenyevna
Description of the goal, tasks and main results	Research question: "How departures from rational expectations shift predictability and forecast of the Russian currency market?" Research objectives: 1. Review of existing behavioural finance biases and their systematization. 2. Analysis and review of econometric models and tests which are used in the paper. 3. Incorporating behavioural biases into existing models. 4.Forecasting performance measurement and interpretation of the results Main findings: 1.Consideration of irrationality assumptions incorporated into Quantile Regression is proven to be appropriate for the Russian Exchange market. 2.Assumptions of irrational behaviour of investors can increase predictability of the Russian exchange rates but their predictive power in many cases is relevantly low. 3.Consideration of irrational behaviour of investors have an impact on future forecast of Russian exchange rates returns. 4.Russian currency market is weakly efficient.
Keywords	Exchange rates, Behavioural finance, Efficient market Hypothesis, Random Walk, Variance Ratio test, Quantile Regression.

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Introduction

In todays global economy efficiency and accuracy in forecasting exchange rates are highly important in almost any investment decisions. Many companies in the Russian Federation have international transactions in Euro/USD that is why an accurate forecast of exchange rates gives more opportunities for the company avoiding losses associated with volatility of the exchange rates. Forecasting the foreign exchange rates are especially important for multinational companies because they make investement decisions based on forecasting information. In addition, forecasting exchange rates is essential for domestic firms to evaluate their potentials to enter international markets and determine the intensity of foreign competitors.

In traditional economy agents are always fully rational. Agents seek to maximize gains and minimize losses. However,in the reality people/agents are prone to emotions and behavioural biases and their behaviour is rather "normal" than rational [18]. Concept of behavior finance implies irrational behaviour of agents in the market. Behavioral finance argues that some financial phenomena are better explained by considering models in which some agents are not fully rational.

The concept of market efficiency was introduced by Fama in 1970: "A market in which prices always fully reflect available information is called efficient" [12]. In the econometrics literature the market efficiency is usually associated with Random Walk behaviour of the prices. Currency markets of the developed countries in many cases are proved to be efficient. However, too few researches were devoted to the testing of Efficient Market Hypothesis in the Russian currency market. Moreover, if irrationality is present in the market, accuracy and efficiency of the test conducted on Efficient Market Hypothesis and forecasting performance of the model which produces future exchange rates movements become questionable.The paper departures from the traditional econometrics models and more focuses on irrational models that possibly outperforms Random Walk model in terms of predictability and forecasting performance.

The research question: "How departures from rational expectations shift predictability and forecast of the Russian currency market?"

The research goal is to analyse the models of the Russian exchange rates market which incorporate behavioural assumptions.

Research objectives:

1) Review of existing behavioural finance biases and their systematization.

Behavioural finance is a relevantly new research field and have deviations from the traditional economics and finance. That is why it is important to clarify the main concepts of behavioural finance. Also, systematization of the behavioural biases and their origins is essential for the further modelling.

2) Analysis and review of econometric models and tests which are used in the paper.

The research paper is based on Quintile regression approach and Variance Ratio test. Both of the methods are not frequently used by the previous researches especially in the Russian currency market. However, the chosen methods are proved to be powerful in terms of detection of predictability patterns.

3) Incorporating behavioural biases into existing models.

Behavioural finance is proven to be a powerful tool in many financial disciplines. However, the behavioural biases usage is still challenging. Formulation of behavioural biases and especially incorporation of them into mathematical model is ambiguous. The paper provides insights into irrationality modelling. Particularly, modelling irrationality biases is provided by the method of weighted returns where some returns are emphasized or de-emphasized by investors in the Russian exchange rates market. The paper employs five behavioral biases that are commonly occur in the market: optimism, pessimism, availability heuristics, overconfidence and underconfidence.

4) Forecasting performance measurement and interpretation of the results.

If the irrationality assumptions incorporated into the model have some impact on predictability of the exchange rates then irrationality is present in the Russian foreign exchange rates market. However, it is important to detect in what way and to what extend each of irrationality assumptions change the forecast of the future prices. The forecasting performance evaluation is conducted on Random Walk model, rational models and irrational models with incorporated behavioural biases.

The paper contains an introduction, three chapters, a conclusion, a list of references and three appendices. Introduction reveals the relevance of the chosen topic and states the research question and research objectives. The first chapter is devoted to the analysis of concepts that explain investors behavioural biases and cognitive errors. This chapter reflects the basic concepts of behavioral finance as well as the psychological causes of irrational behavior and the classification of cognitive errors. The second chapter provides theoretical background of the Random Walk test and irrationality modelling features. This chapter reveals the method of Quantile Regression and its application to test the ability to predict Russian exchange rates prices. In addition, Chapter 2 describes the methodology for conducting a Variance Ratio statistics (Lo-McKinley and Chow and Denning tests) to test the Random Walk hypothesis. Also, this chapter represents the method of incorporation of irrationality assumptions into the classical models. The third chapter presents the results of calculations of predictability statistics on the Russian exchange rates data and interpretation of the obtained results. Chapter 3 also involves results of measurement of forecasting performance of the proposed models. Managerial implications and possible research limitations are discussed at the end of the third chapter. The conclusion summarizes the research results and provides recommendations and suggestions for analysis of the Russian exchanger rates market. A list of literature and appendices with Rcodes developed during the research are provided at the end of the paper.

The paper methodology and research on Russian currency market are based on existing literature related to modelling of the decision-making process. The paper employs Quantile AutoRegression approach which has already been used in the USA stock market. [21]. In order to model irrationality the paper inroduces a weighting methodology [3], which has already been implemented on European market. [26] Forecasting performance estimations used in the paper are also based on a research of the European exchange rates market. [26]. Main concepts of behavioural finance and classifications of cognitive errors are based on the classical Prospect theory. [9]

Chapter 1. Foreign exchange rates and behavioural finance

1.1 Modelling foreign exchange rates

The concept of the currency market includes a variety of financial instruments, institutions and regulatory bodies. Participants, who have a multidirectional impact on the dynamics of exchange rates leading to their variability is the main reason of uncertaincy in the currency market. Therefore, for all participants of the foreign exchange market forecast of possible changes (the direction of the movement - growth or fall) is highly essensial in minimizing losses and ensuring profitability of transactions.

The methods of fundamental analysis are used to forecast the exchange rates. All technical analysis methods can be divided into three groups: graphical, cycle- theory and mathematical-statistical. The latter group includes methods based on formalized models that describe the patterns of behavior of macroeconomic indicators (exchange rate) constructed with the help of existing mathematical and economic theories.

With the development of computer technology, communications and the Internet, it become possible to automate the decision-making process in the form of a mechanical trading system for the trader. This allows to formalize the rules of trade and to scientifically justify the elements of the accepted trading strategy.

Many researches already used econometric approaches to deal with financial exchange rates data. C.Engel in his paper [7] introduced a factor model which explains currency movements and allows to forecast future values of exchange rates. The three factor model was compared with Random Walk model and in some data samples the introduced factor model outperforms Random Walk. Domenico Ferraro [11] uses oil prices as a variable which helps to predict future movements of U.S. Canada nominal exchange rates. He indicates the strong relation between oil prices and exchange rates in short-term run. However, predictability was very low in quarterly and monthly data. At the end of the research the random walk model was superior to other proposed models. The main problem of the previous studies is that Random Walk always outperforms any factor or linear models. Accuracy and predictability of the proposed models from the previous studies above significantly depends on the choice of regressors, the sample size and a forecast horizon.

1.2 Behavioural economics and finance

Every economic agent is a person or a human collective, which has its own style of acting and making decisions. The psychology of perception and the psychology of behavior inevitably participate in economic life causing systematic deviations from rational behavior.

On closer examination of behavioural biases, it turned out that these deviations are not accidental, but they are systematic and quite predictable. Behavioral economics is engaged in studying such irrational behavior of economic agents, which is already shaping into a self-standing direction and is tightly intertwined in our daily life. Trying to find the boundaries of rational choice, behavioral economics studies behavior patterns. Therefore, among the behavioral economy, psychology and behaviorism very close relationship are observed. So, on the basis of a psychophysical analysis of value and probability, the entire human community is divided into large groups of people: risk-averse, risk-averse, and risk-neutral. [**?**]

In mathematical context people who are not risk-averse are people whose preferences are expressed by a convex value function (a function with a declining marginal value of capital). A group of people who are prone to risk are people whose preferences are expressed by a concave value function (a function with increasing priceless value of capital). The group of people who are neutral to risk is formed by preferences expressed a function with a constant limit value of capital, which has the form of a straight.

Investigating this question, Daniel Bernoulli [10] came to the conclusion that people are mainly prone to risk and moreover, the risk aversion decreases with increasing wealth. He believed that a person estimates the possible outcomes of the game based not on the expected monetary result, but on the basis of expected subjective value of these results as a weighted average estimated by analyzing probabilities.

The previously mentioned aversion to risk is expressed by a much greater steepness of the function in the field of losses. The theory of subjective value was further developed in the late twentieth and early twenty-first centuries in the works of Daniel Kahnmann and Amos Tversky [9].Investigating the issues of choice under the risk they found that the prevailing number of people make decisions, which exactly correspond to the hypothetical value function: concave for incomes (gains) and convex for losses (expenses). This prospect theory [8] has three main elements.

The first element is as follows: it claims that our relation to money is determined not just by the amount of money that we have, but it is determined by to what we compare this amount. This is called a point-of-reference effect, or a context effect, and this effect has a strong biological basis. Psychologists have paid attention to such an interesting fact that, if, say, we have a thousand rubles, this is not the end of the story: in fact, it is important how we got this thousand. For example, we could get it in the form of an unexpected bonus, and then we experience positive emotions. On the other hand, we could expect a bonus of two thousand, and received only a thousand and then the same amount of money already means for us completely different and we can, on the contrary, experience negative emotions.

The second element of the prospect theory of Kahneman Tversky is that we evaluate gains and losses. Scientists have estimated that the difference in perception of benefits and losses is about 2.5 times.So, we perceive losses 2.5 times more than we perceive gains. [9] Therefore, as a result of the fact that the losses we estimate more than the benefits, it becomes much more important for us to avoid losses. So, we often do not aim to maximize our benefits but we tend to avoid losses.

The third element of the prospect theory of Kahneman Tversky is that we have a reduced sensitivity to losses: the more we lose, the less we feel the extra money lost.

If we combine these three elements, we will understand why people are very often involved in a such series of losses. This is called the illusion of irrevocable losses. We begin to make a number of decisions, in the middle we understand that we have already suffered some losses and instead of minimizing and stopping them we forget about what we have already spent and trying to make a new decision as if it were a new one. Then our sensitivity to losses has already decreased, and the next dollar, which we will put on this auction, will already be less important for us.

Behaviour finance and the prospect theory is already used in some papers as an assumption to forecast future prices movement. Kamstra, Kramer and Levi [16] highlights the importance of investors sentiment in market movements predictions. The paper investigates how psychological factors influence on players in financial markets by considering the weekeds effect on market movements.

1.3 Behavioural biases background

The beginning of the investigation of influence of perception errors on decision-making is related to the theory introduced by Tversky and Kahneman [**?**]. Their research was devoted to the problem of subjective probabilities and as a consequence the errors that people are experience in the decision-making process. Tversky and Kahneman identify 3 heuristic methods: representativeness, accessibility and adjustment. Also there is a binding effect by which the probabilities, values of the quantities and errors caused by these methods are evaluated. Further, the more evidence of the use of

in making decisions and other classifications of thinking errors received, the more behavioural assumptions are applicable in the market. Abreu, M. [1] suggests the classification which is used as a theoretical basis further.

"Perception and processing errors".

Oftenly people tend to assess the probability of events with the ease which they come to mind. So, for example, when assessing the probability of a plane crashing, an individual can begin to recall the incidents of air crashes that he heard about. This is called the availability heuristic. In general, this method is useful for estimating the frequency or probability of events, since examples of more frequent events are recalled, as a rule, but this rule does not always work and leads to incorrect conclusions.

Heuristic accessibility contributes to understanding of financial phenomena, such as excessive market reaction to a series of bad or good news. In accordance with the hypothesis of market efficiency, new information should be reflected instantly and fully in the price of shares, but in practice investors tend to overreact to new information. According to the accessibility heuristic, people tend to give significantly more weight to the latest news, so fresh information can form a preconceived opinion and leads to an incorrect assessment.

In addition, 4 distortions are directly related to the limitations of perception and processing:

1. The effect of visibility (Salience bias)

This effect occurs due to the impossibility of processing all available information. The individual concentrates only on the information that stands out from the general set of series. Knowledge of this fact allows to manipulate on people's opinions. An example of this effect in finance is a purchase by individual investors of shares atrracting attention [23]. The idea is that such a kind of purchase are due to the difficulties in finding assets for investment. Errors caused by this effect are the most common mistakes in perception and processing.

2. Halo effect

This bias is manifested when the overall impression of a certain person affects the perception of his individual traits. Especially often this distortion occurs when the individual makes a judgment without having enough information about the person as a whole and he is forced to make a certain decision with some restrictions.

3. Competition of signals

The effect of competition of signals occurs when an increase in the reliability of one fact reduces the subjective evaluation of another fact even if they are jointly independent. Oftenly this effect occurs in a prediction situation, for example, when people need to predict future events based on past events by taking into account the current situation.

4. The effect of familiarity with the object (Familiarity principle)

People are inclined to give preference to what they are already familiar with. For example, investors consider investing in a company they know to be less risky and/ or more profitable.

Framing effect

Framing is defined as dependence between a person's choice and the formulation of the problem. The choice under risk depends on the perception of possible outcomes and their probabilities. Errors of choice can be associated not only with the wrong subjective assessment of probabilities, but also with the attitude to outcomes depending on how they are formulated. Rationality implies the presence of unvariance, namely, the absence of differences in the decisions made in equivalent situations, described in different ways. However, studies show that this rule is violated in practice.

Representativeness

The heuristic of representativeness is usually used by individuals in the process of assigning the probability whether an object or event belongs to a certain class as well as of evaluating cause-effect relationships between events. To assess these probabilities people answer the question "To what extent does this object look like a representative of this class?". Thus, the higher the representativeness of an object is evaluated in relation to a class, the higher a person estimates the probability that an object belongs to a given class. A similar logic is also used in the case of constructing cause-effect relationships.

Under representativeness heuristics people make the following mistakes [9]:

1. Ignoring of a priori probability

When people assess the probability to an object belonging to a certain class, their attention is focused on how much the object looks like a representative of this class, while the size of the class itself is not taken into account in most cases.

2. Ignoring sample sizes

Commonly the representativeness heuristic lead to the fact that the individual does not take into account that probability of obtaining averages deviated from the true values decreases with the increase in a sample size.

3. Misconceptions about the odds

People tend to expect that the specificity of a random process occurs even in short intervals of time, but that is not always the case.

4. Ignoring predictability

When making judgments about the prospects of an object or solution (for example, predicting the success of a company's activity or the originality of an idea for a future business), people are guided by their attitude to this object and do not take into account the reliability of evidence and statistics on similar objects in general.

Emotions

One of the main factors shaping our impressions is the emotional reaction. This is our perception of "good" or "bad" depending on the stimuli. For example, the word "treasure" provokes a positive reaction, and the word "hatred" provokes a negative reaction. In many cases, emotions correctly direct our impressions. Most of the phenomenas that cause positive emotions indeed have a positive effects. However, emotions can distort judgments. Investors should beware of such distortions.

Emotions logically complement the prospect theory according to which investors are more prone to risk in order to avoid losses, and less prone to risk when they want to make a profit. Experiments studies show that the emotional perception of the financial opportunity can aggravate the biases that arise from the prospect theory.

Conditions that qualify as emotions include the following [1]:

1. social emotions (anger, guilt, shame, pride);

2. emotions generated by thoughts of what might have happened, but did not happen yet (regret, jubilation, disappointment);

3. emotions generated by the thought of what can happen (fear, hope);

4. emotions generated by good or bad things that have happened (for example, joy and sorrow);

5. emotions caused by the thought of other people's possessions (envy, jealousy);

There are 2 types of emotions: expected and experienced [13]:

1. Expected emotions occur when the result of a decision is displayed but not at the moment of choice. Expected emotions are experienced, for example, by an investor in the purchase of shares. He can imagine his disappointment in the event of a stock price decline, the happiness of growth and regrets or relief in case when the shares were not bought and the price rose or fell, respectively.

2. Experienced emotions are emotions experienced by an individual at the moment of making a decision. Experienced emotions take place, for example, when an investor at the thought of a possible drop in the share price. He experiences a momentary fear. In addition, this kind of emotion may not be directly related to the solution. So, the decision can be influenced by the music playing at the moment in the room.

The paper considers 5 behavioural biases that are commonly occur in the market: optimism, pessimism, overconfidence, underconfidence and availability heuristic.

1. Optimism and pessimism

In financial market optimistic/pessimistic investors expect an increase/decrease in prices by internal subjective probabilities assigned to the future outcomes without any objective justifications. Wenstein N. [28] studying individual methods of risk assessment, identified and described the phenomenon of "unjustified optimism" or "overoptimism". He argues that people tend to understate the likelihood of unpleasant events and to exaggerate their ability to cope with consequences.

Optimism bias is expressed, for example, in the fact that people recognize that 50% of marriages break up, but consider the break up likelihood of their own family close to zero. In other words, people correctly estimate the statistical probability of an event, but subconsciously do not project it onto themselves.

Unjustified optimism is found both in relation to health problems and in relation to family. Illusions of invulnerability are especially susceptible to people who have not previously encountered tragic and terrible events. However, there are exceptions of this rule. For example, with regard to cancer, there is both unjustified optimism and unjustified pessimism (a person exaggerates the probability of the disease). People also tend to overestimate car crash risk assessments.

2. Availability heuristic

Availability heuristic is applicable for investors in financial markets when they are tend to put more attention to the most recent information ignoring the past historical information.

Availability heuristic can complicate financial conditions. After a shock in the market, a sharp decline in property prices is expected, and subjective probability of shock increases much more than its reliable level. At the same time, creditors sharply increase the level of interest rates, because they seek to reduce exposure to risk and increase Risk premiums in response to a sharply increased probability of shock. Power credit adjustment is likely to affect borrowers who can not offer the expected level of interest rates that would allow compensate creditors for the expected increase in the risk of non-payment.

3. Over-confidence and under-confidence.

Underconfidence/overconfident investors are investors who have/do not have doubts of the future prices movements.

The overconfidence bias is characterized by the tendency of people to overestimate their knowledge, abilities and accuracy of the information they possess, as well as their ability to assess future events and the ability to control them. The main factors that lead to overconfidence:

1. Mismatch in the subjective and objective estimates of the accuracy of the forecast.

Studies show that events that people think will happen, in fact, only about 80% of these events actually occur. Events that people consider impossible to happen in about 20% of cases occur [13]

2. "Better than average" effect

Perhaps the best illustration of this error is the result of a study conducted in 1981, which states that 93% of American drivers believe that they drive better than the average. [20]

Assumptions of the irrationality of investors is one of the two components of the theory of behavioral finance. This direction of financial theory is important because it explains why markets can be ineffective. Assumptions of classical financial theory have their analogues in the theory of behavioral finance, but the limitations imposed by them are less strict.

In the decision-making process, people use heuristics, which are simple intuitive rules that have been acquired empirically. Although these mental simplifications help to reduce cognitive burden and find satisfactory solutions (not necessarily optimal), they lead to systematic errors and behavior that do not fall within the framework of the traditional concept of the rationality of economic agents.There are three reasons for the appearance of perception errors: heuristic simplification, self-deception and loss of control under emotions.Knowing the basic mistakes that people make in the decision-making process and the basic conditions in which these errors occur helps to model people's behavior with the assumption of their irrationality. This allows them to analyze the markets, moving away from the axioms of classical financial theory.

Chapter 2. Predictability detection

2.1 Random Walk and Autoregressive model

By now it has become obvious that with empirical verification most of the theories of exchange rates lead to different types of shortcomings. At the same time, a few number of drawbacks are typical for almost all models. Firstly, models and theories in which the dynamics of nominal exchange rates are studied have a narrow set of factors and these models do no take into account the interrelations between the fundamental indicators. Secondly, R. Miz and K. Rogoff, as a result of the research [17], came to the conclusion that the exchange rate forecast obtained on the basis of the random walk model is more reliable than the forecasts obtained by applying the basic models of economic theory.

In the paper I used log returns of the exchange rates instead of real prices. Let P_t be price of an exchange rate then $r_t = ln(P_t) - ln(P_{t-1})$ is a log return at time t.

Commonly, financial data itself is non-stationary in long-term with a changing variance and a mean. Therefore, to make a data stationary financial researches take log returns of the data. This methodology seems to be more reasonable from the investors point of view. Investors are less interested in prices but more interested in returns, how much they can earn by price fluctuations.

One of the concepts of Efficient Market theory is that prices are random. Market prices behave randomly, so past trends or patterns do not allow to judge their future movement. In other words, in an efficient market the use of tools for technical and fundamental analysis is completely useless. The past information which can be useful or useless to predict future movements of a return r_t at time t can be represented as previous values of r_t, $r_{t-1}, r_{t-2}, ...r_{t-n}$, so called lagged returns. Autoregressive model helps to incorporate the previous values of r_t and contract the relation among them. Autoregressive model of order p, is defined as:

$$AR(p) = r_t = \beta_0 + \beta_1 r_{t-1} + \beta_2 r_{t-2} ... \beta_p r_{t-p} + \varepsilon_t, \tag{1}$$

where p is a number of previous values considered in the model, ε_t is an error term, $r_{t-1}...r_{t-p}$ are returns in time $t, t-1, t-2, ..., t-p$ and $\beta_1 ... \beta_p$ are the coefficients of AR(p).Choice of order p is usually defined by Partial Autocorrelation function or using economic intuition. For example, in a daily data if a certain investor is assured that information in the last three weeks may influence on future price movements, p will be equal to 21 or 3 weeks. The autoregressive model is a good example of how past movements of the price can have an impact on future values.

The Random Walk model is an opposite of autoregressive model, the future returns are completely unpredictable. If all coefficients except β_0 are zero in AR(p)(1) model then the model will be transformed into the following:

$$r_t = \beta_0 + \varepsilon_t, \tag{2}$$

where β_0 is a drift and ε_t is $WN(0, \sigma^2)$.

This model is called Random Walk or Random Walk with drift. Here the return r_t does not rely on previous values of $r_{t-1}...r_{t-p}$. Actually returns depend on error terms ε_t which are White Noise.

2.2 Random Walk hypothesis testing. Variance Ratio Test.

Random Walk is a special case of Unit Root process. The coefficient before a lagged return r_{t-1} is 1 so called a unit root. As it was explained before the exchange rate prices are transformed into returns and a unit root is revealed in the corresponding equation: $ln(P_t) = \beta_0 + 1 * ln(P_{t-1}) + \varepsilon_t; r_t = \beta_0 + \varepsilon_t$. [30]. The most common method to test presence a unit root is Augment Dickey Fuller test [2]. Let $yt = ln(P_t)$ and $\Delta y_t = y_t - y_{t-1}$. Dickey Fuller(3) tests whether the coefficient $(1 - \phi)$ before y_{t-1} is 1 [4]:

$$\Delta y_t = \alpha + (1 - \phi)y_{t-1} + \varepsilon_t. \tag{3}$$

If $(1-\phi) = 0$ then the model is Random Walk. However, many research papers argue that Augment Dickey Fuller test ignores nature of Random Walk. Lo and MacKinlay [5] introduced Variance Ratio test that proved to be superior among other Random Walk Tests. Stephen G. Cecchetti [24] in his paper highlighted the main advantages of Variance ratio test. The Variance ratio statistics [14] is contracted as the following:

$$VR(q) = 1 + \sum_{k=1}^{q-1} 2(1 - \frac{k}{q})p(k), \tag{4}$$

where $p(k)$ is an autocorrelation coefficient at lag k. VR statistics is calculated for each q across different autocorrelation coefficients $p(1)...p(k)$. k varies from 1 to the order of considered autoregressive model and q varies from 2 to to the order of considered autoregressive model minus 1. If Variance Ratios at all q are equal to 1 then the Random Walk is rejected. In order to identify statistically to what degree Variance Ratios are closed to 1 the standardized test statistics is given by:

$$\psi(q) = \frac{\sqrt{T}(VR(q) - 1)}{\sqrt{\theta}} \backsim N(0, 1), \tag{5}$$

where $\theta(q) = \sum_{k=1}^{q-1}(2(1-\frac{k}{q}))^2\sigma(k)$ and

$$\sigma(k) = \frac{T\sum_{j=k+1}^{T}(r_j-\overline{r})^2(r_{j-k}-\overline{r})^2}{(\sum_{j=1}^{T}(r_j-\overline{r})^2)^2}. \tag{6}$$

Test statistics ψ for each period q is compared with the standard normal critical value at a specific level of significance. If the statistics value at a certain q is greater than the standard normal critical value then RW hypothesis is rejected.

The Variance Ratio test introduced by Lo and MacKinlay requires estimation analysis of variance ratios at all periods q. To summarize the previous statistics Chow and Denning [27] proposed a join test for all period so called Joint-Variance Ratio test. In fact the Joint-Variance ratio test implies calculations of $\psi(q)$s obtained in equation (5) and their maximization across different periods q:

$$\psi^*(q_i) = \max_{1<=i<m} |\psi(q_i)|. \tag{7}$$

In equation (7) $\psi^*(q_i)$ follows SMM distribution(Student Maximum Modulus distribution) with m and T degrees of freedom. The null RW hypothesis is rejected at α level of significance if $\psi^*(q_i)$ is higher than the $[1-(\alpha^*/2)]$th percentile of the standard normal distribution and $\alpha^* = 1-(1-\alpha)^{1/m}$.

For example, let consider the Individual and Joint Variance Ratio tests for q periods from 2..4. The calculations of ψ are given below in Table 1:

Table 1: Individual and Joint Variance Ratio Test. Example.Source: author's calculations

Period	Variance Ratio	$\psi(q)$	Test result
2	0,796	-3.92	Reject RW
3	0,68	-3,897	Reject RW
4	0,678	-3,07	Reject RW
Joint $\psi^*(q_i)$	-	3,92	Reject RW

The first column in Table 1 is chosen periods q, the second column is Variance Ratios calculated by (4) and the third column is corresponding $\psi(q)$s except the last row. To be more clear the Random Walk hypothesis is stated as follows:

$H_0 : RW$

$H_1 :$ not H_0;

To make a decision whether RW is rejected $\psi(q)$s are compared with the standard normal critical value. At 5% level of significance it is 1.96. Thus, Random Walk hypothesis is rejected in a certain period q at 5% level of significance if $|\psi(q)| > 1.96$.

The last row in Table 1 represents the result on Joint Variance Ratio test by maximizing an absolute value of $\psi(q)$s at all periods q. As it was stated before $\psi^*(q_i)$ follows

SMM distribution. To make a decision by Joint Variance Ratio test whether RW is rejected, $\psi^*(q_i)$ value is compared with a critical value at 5% calculated as $[1-(\alpha^*/2)]$th percentile of the standard normal distribution and $\alpha^* = 1-(1-\alpha)^{1/m}$. For example, at 5% level of significance the critical value is 2.92. If $|\psi(q)| > 2.92$ then RW is rejected at 5% level of significance.

2.3 Quantile regression approach

Quantile regression is a procedure for estimating the parameters of a linear relationship between explanatory variables and a given level of quantile of the explained variable. Unlike the usual least-squares method, quantile regression is a nonparametric method. This allows to get more information: regression parameters for any quantiles of the distribution of the dependent variable. In addition, such a model is much less sensitive to emissions in data and to violations of assumptions about the nature of the distributions. Let Y be a random variable with a probability distribution function $F(y) = Prob(Y \leq y)$. Then a quantile of level τ where $0 < \tau < 1$ will be the minimum value of Y satisfying the condition $F(y) > \tau$:

$$Q(\tau) = inf(y : F(y) \geq \tau). \tag{8}$$

Let the conditional quantiles of the given values of the variable Y depend linearly on the vector of explanatory variables X:

$$Q_\tau(y_i) = \beta_0(\tau) + \beta_1(\tau)x_{i1} + ... + \beta_p(\tau)x_{ip}, i = 1, .., n. \tag{9}$$

In equation (9) $\beta_j(\tau)$ are estimated by solving minimizing the corresponding function.

For example, let Y be a market price for a flat in the city and X is a number of the square meters. Then equation (10) describes the quatile regression as follows:

$$y_i = \alpha_\tau + \beta_1(\tau)x_i + \varepsilon_i, \text{ where } \tau \in (0,1). \tag{10}$$

The main difference from the standard regression approach is a presence of the parameter τ. This parameter allows to contrast different regressions on different parts of return distribution. Obviously, high-cost flats and low-cost flats have different relations with a number of square meters of the flat. In case of prices for flats $\tau = 0.1$ is stated for low-cost flats and $\tau = 0.9$ is stated for high-cost flats. For each τ different regression can be constructed describing relation between high-cost flats or low-cost flats and number of square meters separately.

The quantile regression can be easely transformed from (1) to a quantile autoregression or QAR of order p. The quantile autoregression helps to estimate different equations on the distribution of the dependent variable. Also, the quantitative regression shows how the predictability of future values varies with the use of past information in different parts of the distribution. Let F_{t-1} be information available at time $t-1$ and $\psi - 1$ is the standard normal cumulative distribution, the τ quantile will be incorporated in the model (1) as [21]:

$$Q_\tau(r_t|F_{t-1}) = \alpha + p(1)r_{t-1} + \sigma\phi^{-1}(\tau) = \alpha_\tau + p(1)r_{i,t-1}, \tag{11}$$

where $\tau \in (0,1)$

However, $p(1)$ is not necessarily constant across quantiles. This implies the presence of heteroscedasticity, when the slope coefficients varies across quantiles. It happens when the variables used to predict future values are subject to simultaneous influence of both the conditional mean and the conditional variance. Zhu [19] introduced the model which meets the conditions represented above :

$$r_t = \alpha + p(1)r_{t-1} + \sigma_t\epsilon_t. \tag{12}$$

$$\sigma_t = \gamma_0 + \gamma_1 r(t-1). \tag{13}$$

Here γ_1 estimates an effect of r_{t-1} on conditional volatility σ_t. According to Zhu [19] if r_{t-1} negatively correlates with the volatility then the slope $\gamma_1 < 0$ decreases with a slowing up τ from 0 to 1. In contrast if there is a positive correlation, $\gamma_1 > 0$ increases and the slope goes up across quantiles. Therefore, the predictive model is transformed into the following [21]:

$$Q_\tau(r_{t+1}|F_t) = \alpha_\tau + p_\tau(1)r_t + \varepsilon_{t+1} \text{ where } \tau \in (0,1). \tag{14}$$

The model (14) is called Quantile AutoRegression of order 1 (QAR(1)). Koenker and Xiao [22] provides the solution by minimizing a loss function and produces quantile coefficients $p_\tau(1)$ in the following form:

$$L(\alpha_\tau, p_\tau(1)) = T^{-1}\sum_{t=1}^{T} P(r_{t+1} - Q_\tau(r_{t+1}|F_t, \alpha_\tau, p_\tau(1)) \text{ where } \tau \in (0,1). \tag{15}$$

and

$$P(\varepsilon) = \begin{cases} (1-\tau)|\varepsilon| & \text{if} \varepsilon < 0 \\ \tau|\varepsilon| & \text{if} \varepsilon > 0 \end{cases} \tag{16}$$

The function (16) minimizes the sum of absolute values of the deviations.

Comming back to the Random Walk hypothesis testing the quantile autoregression slightly changes the estimation provided for the simple regression. The Variance Ratios and Variance Ratio statistics are calculated for each quantile τ. So, the Variance ratios and corresponding tests(Individual and Joint) are transformed into the following [21]:

$$VR_\tau(q) = 1 + \sum_{k=1}^{q-1} 2(1 - \frac{k}{q})p_\tau(k). \tag{17}$$

Lo and MacKinlay Individual Variance Ratio statistics [21]:

$$\psi_\tau(q) = \frac{\sqrt{T}(VR_\tau(q) - 1)}{\sqrt{\theta}} \backsim N(0,1). \tag{18}$$

Chow and Denning Joint Variance Ratio test [21]:

$$\psi^*_\tau(q_i) = \max_{1<=i<m} |\psi(q_i)|. \tag{19}$$

The equations (17),(18) and (19) are employed into the paper research in order to test RW hypothesis on the Russian exchange rates market.

2.4 Modelling irrationality

Irrationality assumptions imply that some of the returns have more impact on future returns movements. In other words, some parts of the returns distribution are emphasized or de-emphasized by a certain investor.The most common method to emphasizised or de-emphasized returns [26] in their distribution is a weighting approach. Here emphasized or de-emphasized returns affect on the whole returns distribution. One of the common weighing method is Exponentially Weighted Moving Average(EWMA) [15]. EWMA is mostly used to forecast future volatility of the prices with a decay factor $0 < \lambda < 1$. The most distinctive feature of EWMA which differs it from a simple Moving Average is that different weights are assign to each return. EWMA approach assumes that recent returns have more impact on future volatility than more older returns.

In order to somehow influence on returns distributions Alexander [3] offered the methodology of exponentially weighting of return distributions. So, instead of multiplying returns by a certain weight, weights are assign to the propability of each returns in its distribution. [3]. Thus, the propability of occuring for each return is not the same and the exponential weighting shifts the distribution according to assumptions defined before.

This research paper employs the weighting method introduced by Alexander [3]. To each return an exponential weight W_i is assigned:

$$W_i = (1 - \lambda)\lambda^{i-1} \text{ and } \lambda \in (0, 1), \tag{20}$$

where i is from 1 to T and T is a number of observations. The weighting function is considered with a fixed λ. The choice of λ depends on to what extend investors emphasizise or de-emphasizise exchange rates returns. In the paper I consider a rational assumption and five behavioural biases: optimism, pessimism, availability heuristic, over-confidence and under confidence. The weights are assigned according to behavioural assumptions provided above. Details of behavioural assumptions modelling and their the weights' assignments are described below.

1) Rationality. The traditional economy states the economic agents are rational. They act and make decisions by minimizing loses and increasing gains. The agents weight returns equally without emphasizing or de-emphasizing them. The probabilities which assing to exchange rate returns in their distribution are equal to 1. So, the weighting function is equal to one $W_i = 1$

2) Optimism

Investor are viewed as optimists when they expect that the exchange rates returns will go up. The highest returns are emphasized and the lowers are de-emphasized by a certain investors. So, the highest exchange returns receive more weight and the lowest less weight. The weighting function (20) states that weight W_i is increasing as λ moves from (0,1). For example, let a be a vector of returns $a = c(0.03, 0.02, 0.25, 0.4, 0.15)$. To construct optimism I put returns in descending order $(0.4, 0.3, 0.25, 0.2, 0.15)$ and assign weights $(1-\lambda)\lambda^0, (1-\lambda)\lambda^1, (1-\lambda)\lambda^2, (1-\lambda)\lambda^3, (1-\lambda)\lambda^4$, respectively. [26]

3) Pessimism

Pessimism is an opposite of optimism. Investors expect that the exchange rates will fall in the near future. So, the lowest exchange returns receive more weight and the highest receive less weight. This assumption reflects in the weighting function when λ moves from 1 to 0. For example, let a be a vector of returns $a = c(0.03, 0.02, 0.25, 0.4, 0.15)$. To construct optimism I put returns in ascending order $(0.15, 0.2, 0.25, 0.3, 0.4)$ and assign weights $(1-\lambda)\lambda^0, (1-\lambda)\lambda^1, (1-\lambda)\lambda^2, (1-\lambda)\lambda^3, (1-\lambda)\lambda^4$, respectively. [26]

4) Availability heuristic

Here investors believe that the recent exchange rates have more impact on future returns movements. By this assumptions investors emphasizise the most recent exchange rate returns and de-emphasize the oldest ones. For example, again let $a = c(0.03, 0.02, 0.25, 0.4, 0.15)$. Then the returns are ordered by date from the recent ones to oldest and the weights $(1-\lambda)\lambda^0, (1-\lambda)\lambda^1, (1-\lambda)\lambda^2, (1-\lambda)\lambda^3, (1-\lambda)\lambda^4$ are assigned respectively. [26]

5) Under-confidence(Over-confidence)

When agents possess some doubts(under-confidence) or have no doubts(over-confidence) about future returns movements. Instead of using observed returns the absolute distance from the observation to a historical mean is taken. These scenarious are sorted in descending(under-confidence) or acscending(over-confidence) order. In the over-confidence case the higher propability is assigned to the closest values from the historical mean and in the opposite the under-confidence implies assignment of the higher probabilities to the farthest values from the historical mean. [21]

Then these weighing functions are added to the corresponding quantile regression (**??**) and the loss function of solutions (15) is transformed into the following form [21]:

$$L(\alpha_\tau, p_\tau(1)) = T^{-1}\sum_{t=1}^{T} W_{t+1}P(r_{t+1} - Q_\tau(r_{t+1}|F_t, \alpha_\tau, p_\tau(1))). \tag{21}$$

Also, the variance of coefficients (6) with a weighting function is transformed as [21]:

$$\sigma(k) = \frac{T\sum_{j=k+1}^{T} W_j(r_j - \overline{r})^2 W_j(r_{j-k} - \overline{r})^2}{(\sum_{j=1}^{T} W_j(r_j - \overline{r})^2)^2}. \tag{22}$$

The weights in formulas (21) and (22) are constructed by exponentially weighted returns defined in (20).

2.5 Forecasting performance

Detected predictability in the previous section can be used to forecast future exchange rate returns. There are two main methods that are commonly used in prediction of future returns values: Rolling and Extended(Recuirsive) [25] methods. Rolling method implies a fixed estimation period whereas Recuirsive method expands the estimation period. Let T is a number of observations in the sample and T_1,which is less than T, is a number of observations to be included in the estimated model. So, $h = T - T_1$ is a forecasting period or horizon for in-sample forecast. One predicted value represents one iteration. In the rolling method each iteration adds a new observation to the end of the estimated sample (T_1), deletes the oldest value(the first observation) and re-estimates the model getting a new forecasted value. Recuirsive method adds a new observation to the end of the sample but does not delete the first observation and then re-estimate the model getting a new value. Generally, after each iteration T_1 become large by one obsevation whereby produces "extended window".

To estimate the forecast statistical estimates are commonly used. The simplest indicator is the deviation from the forecast in quantitative terms. In practice, a prediction error and an average prediction error for each individual position are calculated.

The paper involves two main models: Random Walk and Autoregression model of order p. The future forecast is taken from conditional expectation. For example, conditional expectation from the Random Walk is presented in (23) and (24).

$$r_{t+1} = \beta_0 + u_{t+1}, t = 1...T. \tag{23}$$

$$\text{Prediction of}(r_{t+1}) = \hat{\beta}_0. \tag{24}$$

Let consider an Autoregressive model of order 2 then the equation (25) and (26) show the conditional expectation:

$$r_{t+1} = \beta_0 + \beta_1 r_t + \beta_2 r_{t-1}, \text{where} t = 1...T. \tag{25}$$

$$\text{Prediction of}(r_{t+1}) = \hat{\beta}_0 + \hat{\beta}_1 r_t + \hat{\beta}_2 r_{t-1}. \tag{26}$$

Depending on the output of the Variance Ratio test, the Random Walk model or the Autoregressive model is used to forecast the future return values. As it was mentioned before the forecast is conducted within the sample. By that the forecasting results can be compared with the actual values in the sample. It actually reflects the forecasting performance. The most common method to estimate forecasting performance is Mean Square Error(MSE) which implies calculation of the square distance between estimated(forecasted) returns and actual returns from the data:

$$MSE = \frac{1}{N}\sum_{t=1}^{N}(r_t - \hat{r_t}). \tag{27}$$

Equation (27) shows calculations of MSE. Here N is a number of forecasted returns,r_t is an actual return taken from the initial sample and $\hat{r_t}$ is a forecasted(estimated) return. The lower the MSE value the less distance between forecasted and actual values. The small distance between forecasted and actual values reflects a high forecasting performance of the model itself. Since MSE is a relative estimation in order to compare several models in terms of forecasting performance it is better to use summurized statistics. Theils'U statistics allows to compare two models in terms of forecasting performance [26]:

$$\text{Theil's U stat} = \sqrt{\frac{\text{MSE(Model 1)}}{\text{MSE(Model 2)}}}. \tag{28}$$

The equation (28) incorporates MSE of two different models: Model 1 and Model 2. The reference point of the conclusion related to forecasting performance is $Ustatistics = 1$. When $Ustatistics = 1$ Model 1 and Model 2 are equally good in terms of forecasting performance. If $U < 1$ the Model 1 ouperforms the Model 2. If $U > 1$, the Model 2 outperforms the Model 1. [26]

Theils U statistics with incorporated Mean square error is a good indicator of how the model fitts the chosen data. Also, it allows to compare models and chose the best model in terms of forecasting performance. As the paper invloves behavioural finance assumptions such as rationality, optimism, pessimism, over-confidence and under-confidence Theils U statistics is a crutial tool to compare the models with different behavioural assumptions. Overall, the Variance Ratio test defined in the previous section allows to detect predictability in returns patterns whereas the Theils U statistics shows how the proposed models actually fit the chosen data.

Chapter 3. Empirical data analisys and results

3.1.Data and descriptive statistics

The data sample that I consider in the paper is a daily data on U.S. Dollar exchange rate with the currency of the Russian Federation, Russian Ruble. The whole sample is from 03.01.2005 to 01.02.2018, 4778 observations. The data is available online: https://www.investing.com/. The whole sample was logically divided into several parts according to economic justifications. For instance, periods of crisis, introduction of a new economic policy, political conflicts and so on. The graphical representation of the data is shown below (Figure 1), where the horizontal axis is the chosen period of time from 2005 to 2018 and the vertical axis is a ratio of 1 USD to Russian Ruble:

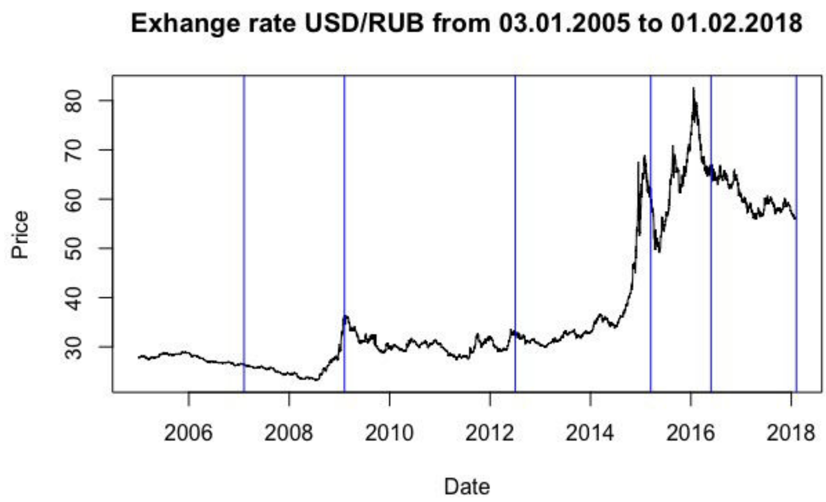


Figure 1: Russian Exchange Rates USD/RUB 2004-2018. Source: Rstudio output

Blue lines in Figure 1 identify divisions of observed periods. Further these periods are called as: Period 1, Period 2, Period 3, Period 4, Period 5, Period 6. Table 2 contains descriptive statistics for the whole sample 2005-2008:

Table 2: Descriptive statistics for the whole period 03.01.2005 - 01.02.2018. Source: author's calculations

Number of observations	4778
Mean	37.47
Median	30.88
Max	82.68
Min	37.47

Table 3 shows decriptive statistics for the divisions by periods that are used in the paper.

Table 3: Descriptive statistics by the periods. Source: author's calculations

Period	1. 03.01.05 - 01.10.07	2. 24.10.07 - 17.01.09	3. 08.02.09 - 01.05.12	4. 23.05.12 - 27.02.15	5. 21.03.15 - 01.04.16	6.23.04.16 - 11.01.18
N of observations	1004	454	1178	1012	377	629
Mean	27.22	25.06	30.38	36.15	63.99	60.66
Median	27.06	24.48	30.32	32.92	64.92	59.53
Max	29.00	33.24	36.33	68.86	82.68	67.10
Min	24.86	23.16	27.34	29.86	49.07	55.84

From the descriptive statistics represented in Table 3 it can be seen that the samples sizes are quite different and relates to different behavioural of prices movements. The most interesting periods in terms of research are periods of crisis in 2007-2009 and 2015-2016 which correspond to Period 2, Period 4 and Period 5.

3.2 Statement of the model

In this paper I use the Quantile regression approach to test the Random Walk hypothesis. I explained some theoretical details in the previous sections but to make it more clear in this section I provide the general algorithm used in the research. As it was stated before I estimate rational and irrational case and then interpret the results. Rationality and irrationality are observed independently but with the same number of lags in the corresponding Quantile AutoRegression. The choice of 7 lags is supported by the assumption that information in the previous 7 days(or one week) may have some impact on future exchange rates returns. Below I provide steps which were done in the research independently for the rational and irrational assumption.

1. MODELING RATIONALITY:

When investors are rational approaches to test the Random Walk hypothesis are not different from the traditional methods provided in the theorical section. This paper employs Variance Ratio test introduced by Lo and MacKinlay [5] and Chow and Denning [27].

STEP 1. Quantile Autoregression Estimation.

I estimate a quantile autoregression with 7 lags using internal functions of Rstudio(quantreg package). The main output is coefficients:$p(1)_\tau, p(2)_\tau, p(3)_\tau, p(4)_\tau, p(5)_\tau, p(6)_\tau, p(7)_\tau$ for each τ from the following regression:

$$Q_\tau(r_t|F_t) = \alpha_\tau + p_\tau(1)r_{t-1} + p_\tau(2)r_{t-2} + ... + p_\tau(6)r_{t-6} + p_\tau(7)r_{t-7}\varepsilon_t. \qquad (29)$$

STEP 2. Obtaining the test statistics.

Then I test the Random Walk hypothesis using Variance ratio test for

$\tau = (0.01, 0.05, 0.1, 0.25, 0.5, 0.75, 0.90, 0.95, 0.99)$

The Rcode in Appendix 1 provides the table with test statistics for Individual Variance

Ratio test for different τ. For example, the program output for the Period 1(03.01.2005-01.10.2007) :

Table 4: Variance Ratio test statistics for the period from 03.01.2005-01.10.2007. Source: author's calculations

q\tau	tau_001	tau_005	tau_01	tau_025	tau_05	tau_075	tau_090	tau_095	tau_099
2	-2,27	-2,39	-2,92	-3,83	-6,67	-5,89	-3,26	-4,30	-6,75
3	-3,44	-2,85	-3,37	-4,00	-6,56	-6,12	-3,82	-3,62	-4,66
4	-2,43	-2,01	-2,28	-2,87	-5,06	-5,31	-3,61	-3,02	-3,00
5	-1,44	-1,56	-1,48	-2,06	-3,96	-4,76	-3,65	-2,56	-1,83
6	-0,06	-1,32	-0,80	-1,30	-3,10	-4,22	-3,48	-2,20	-1,22
7	0,80	-1,07	-0,31	-0,79	-2,52	-3,77	-3,44	-1,93	-0,84
8	1,78	-1,01	-0,19	-0,64	-2,20	-3,40	-3,46	-1,71	-0,66

The left column in Table 4 represents periods q of the Variance Ratio test. The test statistics represent $\psi_\tau(q)$ from the equation (18) and incorporates autocorrelation coefficients $p(1)_\tau, p(2)_\tau, p(3)_\tau, p(4)_\tau, p(5)_\tau, p(6)_\tau, p(7)_\tau$ from the STEP 1.

STEP 3. Individual and Joint Variance Ratio test.

According to Lo and MacKinlay [5] Individual Variance Ratio test the Random Walk hypothesis is rejected if the absolute value of the test statistics at all q is greater than a critical value of the normal distribution(1.95 at 5% level of significance). The Table (4) provides the necessary data to calculate more general Variance Ratio Test(Joint Variance Ratio test by Chow and Denning [27]). The maximum values of $\psi_\tau(q)$ are obtained for each τ from the equation (19).Then the absolute value of obtained $\psi^*_\tau(q_i)$ is compared with a critical value of SMM distribution(2.92 at 5% level of significance).

These steps are repeated for each period of the data. To avoid loosing of some data and mistakes supported by human reliability all of the formulas in STEP 2 and STEP 3 are computed by programming in R without using internal econometric function.(the code is provided in Appendix 1). The program fits any data that a user enters and applicable for each period. Also, the further modelling of irrationality is not supported by Rstudio and requires some manipulations without using internal econometric functions and packages.

2. MODELLING IRRATIONALITY ASSUMPTION

In order to model irrationality I use exponentially weighted returns introduced by Alexander [3] with the weighting function: $W_i = (1-\lambda)\lambda^i$. I consider five behavioural biases: optimism, pessimism, availability heuristic, over-confidence and under-confidence. Under each of the behavioural assumptions I test the Random Walk hypothesis using Variance Ratio test.

STEP 1. Consider weighted returns instead of original data.

At this step I model irrationality assumptions such as optimism, pessimism, availability heuristic, over-confidence, under-confidence. The choice of λ depends to what degree the returns should be emphasized or de-emphasized. Each of behavioural assumption supported by a special algorithm. The algorithm is provided in the Chapter 2. Again, in case of optimistic(pessimistic) investors the exchange rate returns are arranged in descending(ascending) order with a corresponding weight:$(1-\lambda)\lambda^0$,...,$(1-\lambda)\lambda^n$. In availability heuristic the most recent returns receive more weight. In over-confidence(under-confidence) the distances from the mean of the exchange rates returns are taken instead of the real returns. Then the distances are sorted in ascending(descending) order and receive corresponding weights $(1-\lambda)\lambda^0$,...,$(1-\lambda)\lambda^n$. The Rstudio code in Appendix 3 automatically rearranges the data according to considered behavioural biases, assigns the weights and returns the initial positions of the data. The code provided in Appendix 3 results into a table with returns and assigned weights. Table 5 shows an example of the Rcode output.

Table 5: Weights assignment.Source: author's calculations

r_1	r_2	...	r_n
w_1	w_2	...	w_n

In the Table 5 r_t is a exchange rate return at time t and w_i its corresponding weight with $\lambda = 0.98$.

STEP 2. Estimation of the quantile autoregression with weighted returns.

The capability of Rstudio allows to include a vector of weighted returns into QAR and uses the weighted loss function from the equation(21). The vector of weights w_i is derived from the previous STEP 1.

STEP 3. Estimation of Variance ratios and testing RW hypothesis with weighted returns.

This step is identical to the STEP 3 in the rationality assumption but previously variances in formula (6) are transformed to the formula (22) with weighted returns.

STEP 4. Individual and Joint Variance Ratio test with weighted returns.

The weighted variances calculations from the previous step are used to calculate Variance Ratio by Lo and MacKinlay and Chow and Denning.

Table 6: Periods definition. Source: author's calculations

Period 1	03.01.05 - 01.10.07
Period 2	24.10.07 - 17.01.09
Period 3	08.02.09 - 01.05.12
Period 4	23.05.12 - 27.02.15
Period 5	21.03.15 - 01.04.16
Period 6	23.04.16 - 11.01.18

Again, I consider six period extracted from the whole sample. Table 6 defines them. Steps described above for the rational and irrational assumption were repeated for each period defined in Table 6.

3.3 Results of VR test

The Individual Variance Ratio test by Lo and MacKinlay and Joint Variance Ratio test by Chow and Denning were conducted for each Period 1..6(Table 6). The summarized results of Random Walk testing for each period are presented in Tables 7, 8, 9, 10, 12, 11.

1) Variance Ratio test. Rationality assumption.

The table 7 shows the summary results of the Joint Variance Ratio test by Chow and Denning. The periods are taken from the table (6). As it was mentioned before I estimate coefficients from the quantile autoregression (29) and employ them into the Variance Ratio test. The Variance Ratio test is conducted for each $\tau = (0.01, 0.05, 0.1, 0.25, 0.5, 0.75, 0.90, 0.95, 0.99)$. In the table 7 I construct the quantile autoregression under the rationality assumption. In traditional finance the Variance Ratio test is conducted by the assumption that investors are rational in their decisions. So, all outcomes are equally weighted by the investors and the weighting function 20 is equal to one.

In the Table 7 0 stands for the situation when the Random Walk hypothesis is not rejected and 1 is stated when the Random Walk hypothesis is rejected. Thus, ones in the table identify the case when the exchange rates are predictable and do not follow Random Walk. Overall, the Variance Ratio outputs shows that the Russian exchange rates mainly are predictable across different quantiles τ. I want to highlight the obtained results in the Period 2 and 6.

Period 2 in Table 7 shows that the exchange rates returns are predictable at low and high τ and totally unpredictable around the median $\tau = 0.5$. Thus, the exchange rates in the second period are more predictable at the tails of the distribution. These results supports the choice of the quantile regression instead of a traditional one. The quantile regression by its nature is used in connection with extreme events involving the intentional introduction of biases into the result. The Period 2 includes the financial crisis of 2007-2008 that results in extreme fluctuations of the returns up and down. That is why a high predictability at the left (the lowest prices) and at the right(high prices) is not arbitragy. So, the quintile autoregression is efficient to capture predictability of these extreme events. The Period 6 rejects the Random Walk hypothesis across all quantiles τ. The Period 6 shows a downwarding pattern of the exchange rates after the financial crisis of 2014-2015. In 2015 the Russian Central Bank gradually introduced the measures to stabilize the economic situation. That forced the prices go down. So, the Period 6 related to the situation just after the crisis that is a period of the gradual stabilization and the exchange rates returns are predictable by usage of the past information.

Table 7: Variance Ratio test. Rationality assumption. 1 - RW is rejected. 0 - do not reject RW. Source: author's calculations

$\tau =$	0,01	0,05	0,10	0,25	0,5	0,75	0,9	0,95	0,99
Period 1	1	0	1	1	1	1	1	1	1
Period 2	1	1	1	0	0	0	1	1	1
Period 3	1	1	0	0	1	0	1	1	1
Period 4	0	1	1	1	1	0	0	1	0
Period 5	1	0	1	1	1	0	1	1	1
Period 6	1	1	1	1	1	1	1	1	1

2) Variance Ratio Test. Optimism assumption.

Table 8 shows results of the Variance Ratio test assuming that investors are prone to be optimistic. By the definition under the optimism investors put more weight on the highest returns. Results show that the Russian exchange rates returns are more predictable at the right tails(presence of ones in the right columns) and totally unpredictable at left tails(absence of ones in the left columns). So, as quintiles τ move from 0 to 1 the predictability of the exchange rates returns increase. This fact explains the idea that when the currency market is bullish, the exchange rates returns are expected to rise and a part of the distribution with the highest prices is more predictable. [21] From the results table it can be seen that presence of irrationality such as optimism in the currency market is strongly proven for Period 2 and 4. Some patterns of the optimism is observed in Period 6 and Period 3. However, Period 1 and Period 5 do not reflect the presence of optimism at all. Comparing with the rational assumption predictability under the optimistic assumption is much lower for Period 1 and 5.

Table 8: Variance Ratio test. Optimism assumption. 1 - RW is rejected. 0 - do not reject RW. Source: author's calculations

$\tau =$	0,01	0,05	0,10	0,25	0,5	0,75	0,9	0,95	0,99
Period 1	0	0	0	0	0	0	0	0	0
Period 2	0	0	0	0	0	0	1	1	1
Period 3	0	0	0	0	0	0	1	0	0
Period 4	0	0	0	1	0	0	1	1	1
Period 5	0	0	0	0	0	0	0	0	0
Period 6	0	0	0	0	0	0	1	0	0

3) Variance Ratio Test. Pessimism assumption.

Table 9 shows results of the Variance Ratio test assuming that investors are pessimistic. By the definition under pessimism investors put more weight on the lowest returns. Results show that the Russian exchange rates returns are more predictable at the left tails(presence of ones in the left collumps) and totally unpredictable at left tails(absence of ones in the right columns). As quintiles move from 0 to 1 the predictability of the exchange rates returns decrease. This fact explains the idea that when the currency market is bearish, the exchange rates returns are expected to fall and a part of the distribution with the lowest prices is more predictable. [21] The strongest evidence is shown for Period 1,2 and 6. In the example of Period 2 the exchange rate returns are predictable if they are less that the median of the returns distribution. Period 4 does not capture predictability under pessimistic assumption. This can be explained by the upwarding nature of the whole Period 4.

Table 9: Variance Ratio test. Pessimism assumption. 1 - RW is rejected. 0 - do not reject RW.Source: author's calculations

$\tau =$	0,01	0,05	0,10	0,25	0,5	0,75	0,9	0,95	0,99
Period 1	1	1	1	0	0	0	0	0	0
Period 2	1	1	1	1	1	0	0	0	0
Period 3	0	1	0	0	0	0	0	0	0
Period 4	0	0	0	0	0	0	0	0	0
Period 5	0	0	1	0	0	0	0	0	0
Period 6	1	0	1	0	0	0	0	0	0

4) Variance Ratio Test. Availability heuristic assumption.

Table 10 shows results of the Variance Ratio test under availability heuristic assumption. Availability heuristic implies that investors more rely on the recent information. Thus, investors believe that more resent information has more impact on future price movements that the oldest one. The results is quite similar to the rational assumption. Period 2 still shows high predictability at left and right tails and Period 6 is almost fully predictable across all quantiles.

Table 10: Variance Ratio Test. Availability heuristic assumption. 1 - RW is rejected. 0 - do not reject RW.Source: author's calculations

$\tau =$	0,01	0,05	0,10	0,25	0,5	0,75	0,9	0,95	0,99
Period 1	1	1	0	0	0	1	1	0	0
Period 2	1	1	1	0	0	0	0	1	1
Period 3	0	0	0	1	1	1	1	1	1
Period 4	1	0	1	0	1	0	0	0	1
Period 5	1	1	0	1	1	0	1	0	0
Period 6	0	1	1	1	1	1	1	0	1

5) Variance Ratio Test. Under-Confidence assumption.

Table 11 shows results of the Variance Ratio test with under-confidence assumption. When investors are under-confident they possess some doubts about the currency market. In a general sense this assumption forces predictability to rise comparing to the rational case. However, Period 4 and Period 5 show less predictable picture than in the Rational case. Period 4 is predictable at left tails and Period 5 is almost not predictable at all.

Table 11: Variance Ratio Test. Under-Confidence assumption. 1 - RW is rejected. 0 - do not reject RW.Source: author's calculations

$\tau =$	0,01	0,05	0,10	0,25	0,5	0,75	0,9	0,95	0,99
Period 1	1	1	1	1	1	1	1	1	1
Period 2	1	1	1	1	1	0	1	1	1
Period 3	1	1	1	1	1	1	1	0	0
Period 4	1	1	1	1	0	0	0	0	0
Period 5	0	0	0	0	1	1	0	0	0
Period 6	1	1	1	1	1	1	1	1	1

6) Variance Ratio Test. Over-confidence assumption.

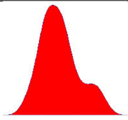
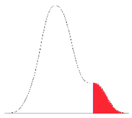
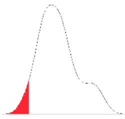
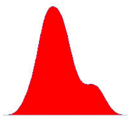
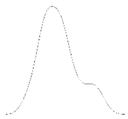
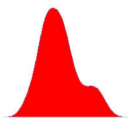
Table 12 shows results of the Variance Ratio test with over-confidence assumption. When investors are over-confident the results show that the exchange rate returns are totally unpredictable across all quintiles τ. The currency market becomes highly efficient when investors are over-confident.

Table 12: Variance Ratio Test. Over-Confidence assumption. 1 - RW is rejected. 0 - do not reject RW. Source: author's calculations

$\tau =$	0,01	0,05	0,10	0,25	0,5	0,75	0,9	0,95	0,99
Period 1	0	0	0	0	0	0	0	0	0
Period 2	0	0	0	0	0	0	0	0	0
Period 3	0	0	0	0	0	0	0	0	0
Period 4	0	0	0	0	0	0	0	0	0
Period 5	0	0	0	0	0	0	0	0	0
Period 6 t	0	0	0	0	0	0	0	0	0

The research was conducted in each of the periods individually but results of the each period presented above have the similar patters of predictability. Table 13 depicts the most frequent results on predictability of Russian exchange rates.

Table 13: Summarized results on predictability. Source: author's calculations

Behavioural assumptions	Predictability	
1. Rationality	Across quantiles	
2. Optimism	At right tails	
3. Pessimism	At left tails	
4. Availability heuristic	Across quantiles	
5. Over-confidence	Totally unpredictable	
6. Under-confidence	Across quantiles	

As it can be seen from Table 13 behavioural biases assumptions estimated in the model affect on predictability of the Russian exchange rates returns. The optimism/pessimism assumptions make the exchange rates returns more predictable at right/left tails of returns distributions. The Variance Ratio test with availability heuristic assumption shows quite similar results of predictability to the rational model. Under-confidence in majority of the cases increases predictability of the exchange rates returns while the over-confidence assumption leads to total unpredictability and makes the currency market highly efficient.

3.4 Forecasting performance

Detected predictability of the exchange rates returns under different behavioural assumptions can be used in forecasting of future exchange rates returns. In this research I use Out-of-Sample forecast for each period (Table 6).The forecast was conducted by the method of extented window(recursive). This method captures more information from estimated model and better fits ARIMA famililly models than a standard forecast approach. The forecasting horizon is $h = 21$ and as the data is daily this corresponds to 21 days or 3 weeks forecast.

In order to measure forecasting performance this paper employs Theil's U-statistics as an indicator. Theil's U-statistics involves calculations of Mean Square Errors for each model. If Theil's U-statistics 30 is lower than 1 then the proposed behavioural model(rational or irrational) outperforms Random Walk:

$$U = \sqrt{\frac{\text{MSE(Proposed model)}}{\text{MSE(RW)}}} \tag{30}$$

Calculations of Theil's U-statistics were conducted in the 21 days ahead for each period defined earlier in Table 6.

Table 14: Periods definition. Source: author's calculations

		Out-of-sample forecast
Period 1	03.01.05 - 01.10.07	02.10.07 + 21 days
Period 2	24.10.07 - 17.01.09	18.01.09 + 21 days
Period 3	08.02.09 - 01.05.12	02.05.12 + 21 days
Period 4	23.05.12 - 27.02.15	28.02.15 + 21 days
Period 5	21.03.15 - 01.04.16	02.04.16 + 21 days
Period 6	23.04.16 - 11.01.18	12.01.18 + 21 days

Table 15 shows that for the period 2.10.2007 - 22.10.2007 the rational model and irrational with underconfidence and availability heuristic assumptions outperform Random Walk in terms of forecasting performance. Pessimism assumption is totally inappropriate for the model with a high U-statistics.

Table 15: Theil's U-statistics for Out-of-sample forecast 02.10.2007 - 22.10.2007. Source: author's calculations

	Rational	Optimism	Pessimism	Availability heuristic	Over-Confidence	Under-Confidence
RW	0.91	2.54	3.51	0.93	1.86	0.85

Table 16 contains U-statistics for the period 24.10.2007 - 17.01.2009. Here the model with optimism assumption is considered as the best model which outperforms the rational and random Walk model. The model with overconfidence is as good as random walk with U-statistics approximately equals to one.

Table 16: Theil's U-statistics for Out-of-sample forecast 24.10.2007 - 17.01.2009. Source: author's calculations

	Rational	Optimism	Pessimism	Availability heuristic	Over-Confidence	Under-Confidence
RW	1.01	0.89	1.8	1.2	1.02	1.26

Table 17 is related to U-statistics for the period 08.02.2009 - 01.05.2012. The results show that the rational, optimism, over-confidence and availability heuristic models outperform the Random Walk model. Since four of them are equally efficient with approximate U-statistics of 0.5 there is no reason to use irrational models instead of models with rationality. However, availability heuristic has slightly better results and can be used instead of the rational model.

Table 17: Theil's U-statistics for Out-of-sample forecast 08.02.2009 - 01.05.2012. Source: author's calculations

	Rational	Optimism	Pessimism	Availability heuristic	Over-Confidence	Under-Confidence
RW	0.5	0.52	3.6	0.4	0.5	1.18

Theils's U statistics from 23.05.2014 to 27.02.2015 are presented in the Table 18. In this case the rational and over-confidence models have slightly better forecasting performance than the Random Walk model. Pessimism and Under-Confidence are totally inappropriate assumptions with a high U-statistics.

Table 18: Theil's U-statistics for Out-of-sample forecast 23.05.2012 - 27.02.2015. Source: author's calculations

	Rational	Optimism	Pessimism	Availability heuristic	Over-Confidence	Under-Confidence
RW	0.97	1.17	4.2	1.04	0.97	3.35

Table 19 refers to Theils's U statistics for the period 21.03.2015 - 01.04.2016. By the results the rational model and availability heuristic outperform Random Walk and other proposed model with irrationality assumption. Pessimism shows the worst results in terms of forecasting performance.

Table 19: Theil's U-statistics for Out-of-sample forecast 21.03.2015 - 01.04.2016. Source: author's calculations

	Rational	Optimism	Pessimism	Availability heuristic	Over-Confidence	Under-Confidence
RW	0.95	1.19	3.5	0.86	1.66	1.54

Theils's U statistics values for the last period forecast with an estimated model from 23.04.2016 to 11.01.2018 are presented in Table 20. In this case rational,over-confidence and availability heuristic models outperform Random Walk model. However, the models are almost equally good at forecasting performance and there is no reason to use irrational models instead of the rational.

Table 20: Theil's U-statistics for Out-of-sample forecast 23.04.2016 - 11.01.2018. Source: author's calculations

	Rational	Optimism	Pessimism	Availability heuristic	Over-Confidence	Under-Confidence
RW	0.85	1.73	5.2	0.83	0.85	5.5

Table 21: Summarized results on forecasting performance. Source: author's calculations

	Models which outperform RW	The best model in terms of FP
Period 1	Rational, Under-confidence, Availability heuristic	Under-confidence
Period 2	Optimism, Rational	Optimism
Period 3	Rational, Over-confidence Availability heuristic, Optimism.	Availability heuristic
Period 4	Rational, Over-confidence	Rational, Over-confidence
Period 5	Rational	Rational
Period 6	Rational, Over-confidence	Rational Over-confidence

The results of Theis'U statistics for the period from 2005 to 2018 shows that the Random Walk model is not the best fitting model for the Russian exchange rates returns in terms of forecasting performance.Table 21 summarized the results of conducted forecasting and its performance.

In each period there is a model which outperforms the Random Walk model. In most of the cases the rational model shows the best forecasting performance results. However, some cases considers the rational model as good as overconfidence model.

Probably, the most interesting results were obtained in Table 16 where optimist is considered as a superior model. However, that is not a big surprise. Period 2 relates to the crisis of 2007-2008 and the Russian exchange rate prices went up. So, optimistic investors who were interested in higher exchange rates expected an increase in prices.

Pessimism in most of the cases does not show good forecasting performance comparing with the Random Walk, rational model and the models with other irrationality assumptions. Even when the prices are going down like in Period 6 a pessimism assumption does not increase accuracy in forecasting. The possible explanation is related to the choice of λ in the weighting function. Again, weighted returns were used in order to model irrationality. The choice of λ depends on how or to what degree pessimistic investors emphasize low returns and de-emphasize high returns. Probably, the problem with forecasting accuracy of pessimism model can be fixed by lowering λ.

Table 18 refers to forecasting in period of the currency crisis of 2014-2015. Unlike the crisis in 2007-2009 there is no clear evidence of a superior model in terms of forecasting performance. The results are quite uncertain. The rational and over-confidence models are almost good as Random Walk. Moreover, the optimism model has U-statistics not significantly higher that 1 and can be viewed as the model which is equally performed as Random Walk.

Availability heuristic model provides interesting results. The predictability results in the Table 10 and 7 from the previous subsection show quite similar patterns with a bit higher predictability in the availability heuristic case. That actually leads to presence of irrational behaviour such as availability heuristic in the market. Participants of the Russian exchange rates market in their decision-making are prone to emphasize the most recent information and ignore historical past information.

3.5 Managerial implications

The findings of the study have important ramifications for managerial finance as they provide important insights on expected future currency returns with potential advantages in currency hedging and/or timing of international capital flows. Behavioural finance assumes irrationality in investors behaviour that definitely contradicts with a classical economy where all agents are fully rational. The applications of behavioural finance increase the predictability and accuracy of the foreign exchange rates forecast. The main business applications of the currency forecast are:

1. Foreign Exchange Market and investment decision making.

Managerial importance of forecasting exchange rates is revealed in agents who have a huge impact on exchange rates movements and closely work with them. One of the good examples of this kind of agents is hedge or investments funds.The direction of their activity is an investment in certain currencies. Also, every trader working in the Forex market is obliged to monitor all the changes that take place in the economic life of his country and the world economy. These facts help traders to make a serious profit if they manage to react on time. Thus, an accuracy in forecasting helps players in financial market make a profit.

Behavioural finance and irrationality assumptions provide an opportunity to model investment decisions taking into account the individual behavioural biases. There are three areas of application: an estimation of the average profitability of a financial asset; operations in the stock market; trade in a financial asset on time. Further development of empirical research allows to create opportunities for wider application of improved methodological approaches for describing and forecasting investment decisions that go beyond the framework of classical financial theory because it takes into account the irrational component of the attitude towards the risk and the assessment of the propability distribution.

2. Exchange Rate Risk Management.

In Russian Federation not every company faces issues of currency regulation and related operations. But in most of the cases current activities or project business practices are at least once conducted with export-import transactions. For example, a project for introducing a new technology based on equipment purchased from abroad. Import, which is also performed on a one-time basis by large amounts of payments, almost always causes currency risks that the project manager must take into account. Management and measurement of exchange rate risks is essential to reduce exposure of exchange rate changes. These changes can negatively affect comany's profit and assets value. That is why accuracy in forecasting future exchange rates is important giving an opportunity to reduce the risks. As the participants of the currency market are not always rational irrationality assumptions employed in the paper allow to incorporate an individual attitude towards the risk.Consideration of irrationality in the models improves the forecasting performance of the existing exchange rates models whereby increase the company values.

3.5 Research limitations

The paper introduce the modelling of investors behaviour in the Russian exchange rates market. Although the methods which were used in the paper are applicable not only for for the currency market, the research possess some limitations: 1. Variety of behavioural biases

The paper is based on research of behaviour biases that are commonly occur in the exchange rates market: optimism, pessimism,availability heuristic, over-confidence and under-confidence. However, behaviour finance theory is ambiguous and incorporates variety of the biases classifications. Also, the combination of two or more biases is oftenly occur in any market. So, the research is limited in the number of biases that can be incorporated into the quantitative models.

2. Variety of the models

The paper involves the Quantile regression approach ignoring other methods which can be also applicable in the research. The Quantile regression better describes periods of extreme events in the currency market but it is still questionable the usage of QR in the situations of stable economy as it only complicates the estimations.

3. Chosen data sample

The research uses Russian Exchange rates data from 2005 to 2018 and the data was divided into several periods. The results of the research strongly depends on the chosen periods. Each of the periods are unique involving economic changes, crisis and political situations and in order to accurately forecast further data the models proposed in the paper should be transformed depending on the future conditions.

Conclusion

The paper provides methods of modelling the Russian exchange rates with the assumption of investors irrationality. The research was conducted on daily data of exchange rates of Russian Ruble to US Dollar from 2005 to 2018.

In the decision-making process people use heuristic, which are simple intuitive rules that have been acquired empirically. While these mental simplifications help to reduce cognitive burden and find satisfactory solutions (not necessarily optimal), they lead to systematic errors and behavior that do not fall within the traditional framework the rationality of economic agents.

In order to analyze of the Russian Exchange rates returns on the entire distribution, instead of using standard least-squares regression model, the paper employed the quantile regression approach, which is capable to predict certain predetermined distribution intervals. To model the dependence of Russian exchange rate returns on past values, the paper introduces Quantile Autoregression Model.

Checking whether the Russian exchange rates returns follow Random Walk, and therefore whether the returns are predictable was carried out using Individual and Joint Variance Ratio test. Simulation of Russian exchange rates returns was conducted on the assumption of investor rationality, as well as in assumptions about the various mistakes that investors may make in the decision-making process. The paper considers five irrationality assumptions: pessimism, optimism, availability heuristic, overconfidence and underconfidence. To assess the impact of these biases on human behavior and predictability of Russian exchange rates returns, the paper employed a weighted quantile regression method, where the weights are based on subjective probabilities.

It was assumed that investors who are prone to pessimism assign more weight to the lowest historical values of Russian exchange rates returns, since investors tend to exaggerate the probability of losses. The behavior of optimistic investors was modeled by assigning more weight to the higher historical returns. Under the assumption of investors over-confidence in future Russian exchange rates returns, the higher subjective propability was assigned to the closest value to the historical mean of the retuns. On the contrary, the under-confidence case implies assignment of the higher probability to the returns which are far from the historical mean, Since availability heuristic assumes that people assign more weight to those events that more easily come to mind, in order to model this bias historical returns receive weights depending on the time when a particular return occured. The most recent Russian exchange rate returns receive more weight and associated probability.

After predictability assessment the paper provides results of out-of-sample forecast with rationality and irrationality assumptions. Assessment of the forecasting performance was mainly focused on comparsion between the Random Walk model and the rational/irrational model. The results of forecasting were compared by using Theil's U statistics with incorporated mean square errors.

The paper provides two main blocks of the results which are closely relate to each other: predictability and forecasting results. Both of them contribute to the formulation of the main research findings and results:

1. Consideration of irrationality assumptions incorporated into Quantile Regression is proven to be appropriate for the Russian Exchange market.

The paper results show changes in predictability patterns of the Russian exchange rates comparing with the standard Autoregression approach and the Variance Ratio test. The quantile approach is proven to be efficient for the extreme events such as crisis because it allows to observe parts of the Russian exchange rates returns distribution with extreme values instead of considering the entire distribution.

2. Assumptions of irrational behaviour of investors can increase predictability of the Russian exchange rates but their predictive power in many cases is relevantly low.

The paper investigated how irrationality assumptions of investors shift predictability of the Russian exchange rates compare to the rational models. When investors are prone to be optimistic/pessimistic the Russian exchange rates returns are more predictable in the right/left tail of the returns distribution. Over-confidence investors make the exchange rates totally unpredictable.The availability heuristic assumption of investors behaviour shows increase in the predictability of the Russian exchange rates. Only the case of availability heuristic shows increase of predictability of the Russian exchange rates. That actually implies that investors tend to emphasize the most recent information to predict the future returns movements and ignore the past historical information. Technically, this can be explained by the rejected RW hypothesis for the Russian exchange rates across almost all quantiles.Initially the Russian exchange rates are predictable and do not follow Random Walk, so irrationality assumptions may only slightly increase predictability but will never show significantly different results.

3. Consideration of irrational behaviour of investors have an impact on future forecast of Russian exchange rates returns.

Majority of behavioral assumptions models outperform the Random Walk model. However, very few irrationality assumptions are better than the rational model in terms of forecasting performance. The predictability results show improvment of predictability with a assumption that investors are availability heuristic. Moreover, implementation of availability heuristic into the model shows the best forecasting performance results in many cases. These results lead to the conclusion that investors in the Russian exchange rates market make a prediction about future retuns movements based on information that easely comes to mind or the most recent information. So, investors tend to ignore historical past information and make a decision based on the most recent events.

4. The Russian currency market is weakly efficient.

In the previous studies [26] currency markets of many Europeanen countries are proven to be efficient and the Random Walk hypothesis is not rejected. This paper investigates that the Random Walk hypothesis on the Russian exchange rates market is rejected, that actually is a sign of the market inefficiency. It can be explained by the fact that Russian economy is still developing and comparsion with Europeanen countries is inappropriate.

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Appendix 1

```
##########QAR estimation and Variance Ratio test###########
lny_1=c(NA, lndata[1:(T-1)])
lny_2=c(NA,NA, lndata[1:(T-2)])
lny_3=c(NA,NA,NA, lndata[1:(T-3)])
lny_4=c(NA,NA,NA,NA, lndata[1:(T-4)])
lny_5=c(NA,NA,NA,NA,NA, lndata[1:(T-5)])
lny_6=c(NA,NA,NA,NA,NA,NA, lndata[1:(T-6)])
lny_7=c(NA,NA,NA,NA,NA,NA,NA, lndata[1:(T-7)])
model_q <- rq(lndata~lny_1+lny_2+lny_3+lny_4+lny_5+lny_6+lny_7,
tau = c(0.01, 0.05,0.1, 0.25, 0.5, 0.75, 0.90,0.95,0.99))
d = coef(model_q)
result =cbind(tau_001,tau_005,tau_01,tau_025
,tau_05,tau_075,tau_090,tau_095,tau_099)
####################VR test$###############
for (g in (1:9)){
n_lags = 7 #number of lags
VR = NA
new_d = unname(d[2:8,g])
s = 0
for (q in 2:(n_lags+1)){
s = 0
for (k in 1:(q-1)){
s = s + 2*(1-(k/q))*new_d[k]
}
VR[q] = 1 + s
} ##VR statistic
s = 0
m = 0
sigma = NA
for (k in (1:(n_lags+1))){
s = 0
m = 0
for (j in ((k+1):T)){
s = s + w[j]*(lndata[j]-y_mean)^2*w[j]*(lndata[j-k]-y_mean)^2
```

```
}
for (j in (1:T)){
m = m + w[j]*(lndata[j]-y_mean)^2
}
sigma[k] = (s/(m^2))*T
} ###sigma
sum = 0
theta = NA
for(q in (2:(n_lags+1))){
sum = 0
for (k in (1:(q-1))){
sum = sum + (2*(1-k/q))^2*sigma[k]
}
theta[q] = sum
} #theta
###Test statistic#####
test_stat = NA
for (q in (2:(n_lags+1))){
test_stat[q] = (sqrt(T)*(VR[q]-1))/sqrt(theta[q])
} #statistic
result[1:8, g] = test_stat
}
```

Appendix 2

```
#######Extended window forecast##########
for (i in seq(0, 21, by = 7)){


lndata_f_window = fullln[4131:(4754+i)]
T1 = length(lndata_f_window)
ln_1=c(NA, lndata_f_window[1:(T1-1)])
ln_2=c(NA,NA, lndata_f_window[1:(T1-2)])
ln_3=c(NA,NA,NA, lndata_f_window[1:(T1-3)])
ln_4=c(NA,NA,NA,NA, lndata_f_window[1:(T1-4)])
ln_5=c(NA,NA,NA,NA,NA, lndata_f_window[1:(T1-5)])
ln_6=c(NA,NA,NA,NA,NA,NA,lndata_f_window[1:(T1-6)])
```

```
ln_7=c(NA,NA,NA,NA,NA,NA,NA, lndata_f_window[1:(T1-7)])
model_q_095 <- rq(lndata_f_window~ln_1+ln_2+ln_3+ln_4+ln_5+ln_6+ln_7
, tau = 0.5, weights = w[1:(624+i)])
d1 = coef(model_q_095)
r = d1[1]
d1[1:7] = d1[2:8]
d1[8] = r
ar.model = arima(lndata_f_window, order = c(7,0,0), fixed = d1)
fit = lndata_f_window - ar.model$residuals
h = 7
tf=((T1+1):(T1+h))
if (i == 0) { forst[1:7, 1] = predict(ar.model,h,xreg=tf)$pred }
else
forst[1:7,i/7]=predict(ar.model,h,xreg=tf)$pred
}
extnd_win_for = matrix(NA, nrow = 210, ncol = 0)
for (i in (1:3)){
extnd_win_for[((i*7)-6):(i*7)] = forst[1:7,i]
}
```

Appendix 3

```
######WEIGHTING ESTIMATION#######
datasort = ctt
T = length(ctt)
for  (i in 1:(T-1)){
for (j in 1:(T-i)){
if (datasort[j] < datasort[j+1]) {
k = datasort[j]
datasort[j] = datasort[j+1]
datasort[j+1] = k
}}}
newmat = matrix(0,2,T)
#matrix with weights
lamda = 0.98
for(i in (1:T)){
newmat[1,i] = datasort[i]
```

```
newmat[2,i] = (1-lamda)*lamda^(i-1)
}
newdata = matrix(0,2,T)
for(i in 1:T){
newdata[1,i] = ctt[i]
}
```