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Improvement Estimation Accuracy of Futures for Small Business Effective Functional Development

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Abstract. Small businesses effectiveness depends mainly on prediction accuracy of the proposed transactions results. Operations with futures, which let you not only make a profit hedge transactions, are one of the stock market developing areas. The purpose of this study is clarifying of the model for derivative financial instruments value estimating as in the case of futures. Statistical information from PAO Moscow exchange website was used as an empirical base of the study, reference data of quotations has been taken from financial information resources. The models used to calculate the cost of derivative financial products contain assumptions concerning the equality of rates for risk-free capital investment, repurchase agreement and cash loan rates. Nevertheless, in reality they can be significantly different. We used economic and mathematical methods for clearing up the influence of these rates on the possibility of conducting arbitrage operations. This study let us determine the levels which represent price in its "normal" state, and beyond which it tends to return to the usual range of values. We determined the statistical dependence between these levels and the actual contract price. Consequently, we propose a model for determining the value of a futures contract. In that model we take into account the difference in interest rates achieve greater accuracy in price determination. It provides smaller average deviation between real and calculated prices lower standard deviation values, and a higher degree of correlation between real and model prices, that means we can get more reliable predictions. This model will help to expand the use of futures, including small businesses, by reducing risks.

Key words: big data, derivative financial instruments, cost modelling.

1. Introduction

Security market is one of the sources of capital raising. In developed countries it includes wide range of financial instruments used for different purposes. Various risks, that put at threat the invested capital safety, appear with the evolution of security market. Derivative financial instruments are often used to manage them. These instruments are contracts for the actual or conditional delivery of the underlying asset at a certain time in the future. They let you hedge various risks, protecting capital from possible negative market conditions, and help organizations to

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plan for the future value of their goods, resources, and money flows. These issues are also relevant for small businesses, which constantly need to increase the financial resources. At the same time, there is an active expansion of such operations in security market, what cause necessity of price prediction accuracy improvement for risks reduction. Hypothesis of the study is possibility of model quality improvement for derivative financial instruments value determination, taking into account the difference in the rates of borrowing, lending and REPO operations.

2. Models for derivative financial instruments value determination

There are several models for pricing derivative financial instruments. In the XX century the futures pricing model, given in the first study, was popular [1]. There are discrete and continuous calculation methods. The discrete calculation is based on the concept of the futures contract price, contained underlying asset delivery cost. They include purchasing, storing, insuring, and product delivery expenses. Financial expenses consist of funds that have been used or borrowed in money market. Expenses of storage, insurance, and products delivery are determined by the storage requirements for a particular type of product, the specifics of its insurance and delivery. In general terms, formula is based on no transaction costs assumption:

$$FP_{t,T} = CP_t + CP_t * R_{t,T} * \frac{(T-t)}{365} + G_{t,T} \quad (1),$$

Formula 1. $FP_{t,T}$ - futures prices at time t for a futures contract with a delivery date at time T; CP_t – cash market price at time t; $R_{t,T}$ – annual interest rates at which you can obtain money on credit in period t for period $(T-t)$; $G_{t,T}$ – storing cash products cost per unit for period from the moment of products purchase (t) to delivery in period T.

Formula of futures contract cost while being calculated derivative financial instruments price using continuously accrued interest:

$$FP_{t,T} = CP_t * e^{(R+G)(T-t)/365} \quad (2).$$

Some types of assets produce a profit in dividend or coupon form. If you get this income during the contract period, you should subtract the amount of income from the contract value, as basis asset current owner gets this profit (not future owner). Modified formula:

$$FP_{t,T} = \left(CP_t - \sum_{k=1}^{m} \frac{D_k}{(1+R_{t,T})^{\frac{(T-t_k)}{365}}} \right) * \left(1 + R_{t,T}\right)^{\frac{T-t}{365}} \quad (3),$$

Formula 3. D_k – dividend or coupon income on the basis asset at time k; t_k – moment of dividend payment, while $k = 1,m$.

You also can use this formula to calculate index futures value based on stocks with dividend income. It is an advantage of this formula. You can use these formulas to accurately calculate futures contracts value. Nevertheless, we continue our research, as there is no variant, which let us accurately determine futures cost change in future. I recent years researchers have been studied specifics of pricing derivatives for cryptocurrency [3, 4], oil [5, 6, 7], crops [8, 9, 10], wine [11], certified emission reduction [12], financial instruments [13, 14, 15]. At the same time there are reviews showing new pricing predicting methodologies: the ARIMA model for predicting asset returns [16], the generalized realized volatility model proposed by Christoffersen et al [17], price reconstruction based on the probability distribution of basis asset prices [18], model, based on econometrics and technical analysis [19], three-factor model of Fama and French [20]. Models include new factors affecting price changes in the futures and spot markets [21, 21, 23], and considers various arbitrage strategies [24, 25, 26].

The search for more accurate models for calculating of derivative financial instruments value continues, as there is no possibility in accurately determination of derivatives future value yet.

3. Development of derivative financial instruments value determination model

3.1. Derivative financial instruments value determination model validation

Rates for raising funds and rates for investing money are the same. That is an important assumption of the formulas described above. This fact let us simplify formulas and calculations but the difference in rates can be very significant and influence on the decision in making a deal. This especially applies to arbitrage transactions, as deviation of real price from its theoretical value is a reason for arbitration and profit making without price risks. Arbitrage proposes opportunities in the market, letting you make a profit without capital investing, using borrowed funds.

Risk-free interest rate is another criteria used in arbitrage. It nullifies credit risk while capital investment. Rate can be nominal or real. Nominal rates can be used in countries with low inflation. If there is a significant inflation level, we recommend using the real risk-free rate.

For assets without any income, calculation is based on the formula (1). There are two arbitrage variants while deviation of future cost of prices calculated with this formula:

- if $FP_r > FP$, FP_r – real futures contract price, the strategy consists in selling futures contracts and simultaneously buying products on the cash market with borrowing at the r_b rate;

- if $FP_r < FP$, if futures contract real price is lower than estimated price, futures contracts purchase and borrowed cash sale will start.

Cash flow in the first case:

$$FR_+ = C_b - C_b + CP + FP - CP - C_b - C_b\left(r_b * \frac{t}{T}\right) \ (4),$$

Formula 4. FR_+ - financial result from arbitrage, if $FP_r > FP$; C_b – borrowed capital; CP – current spot price for basis asset; FP – futures contract price (delivery price); r_b – rate; t – time until the contract expires; T - number of days in a year (365).

Cash flow is a loan of funds, which will be spent on asset purchase at the CP price and futures contract establishment. This operation does not display in cash flow, as delivery price is set without movement of assets and cash. Futures contract is sold at

FP price, basis asset is delivered and borrowed funds are returned with interest. Then we can calculate financial result using this formula:

$$FR_{+} = FP - CP\left(1 + r_b * \frac{t}{T}\right) \text{ (5).}$$

We can calculate initial arbitrage price for the operation using the formula:

$$FP_{+} = CP\left(1 + r_b * \frac{t}{T}\right), \text{ (6).}$$

Similarly, for the second situation, when derivative instrument price changed down from calculated one, an arbitrage opportunity appears which is expressed by the following cash flow [25].

$$FR_{-} = CP - CP + CP\left(1 + r * \frac{t}{T}\right) - FP - CP\left(r_s * \frac{t}{T}\right) \text{ (7),}$$

Formula 7. $FR\_$ - financial result from the arbitrage, if $FP_r < FP$; r – risk-free rate; r_s – rate for short selling.

In this case, there is a short selling, and funds are invested at a risk-free interest rate until the contract is executed. Then delivery is accepted under futures contract at stipulated price, and interest for basis asset use is returned back. Modified formula:

$$FR_{-} = CP\left(1 + (r - r_s)\frac{t}{T}\right) - F \text{ (7).}$$

In this case, you can calculate the "lower" arbitrage price using the formula:

$$FP_{-} = CP\left(1 + (r - r_s)\frac{t}{T}\right) \text{ (8).}$$

Formula for futures value calculating involves basis asset current value increase at a risk-free interest rate. The reason is capital diversion in this operation, risks of asset storing, in other words, opportunity costs associated with futures contract purchase. Consequently, the difference accumulated at risk-free rate will be the financial result of transaction with the derivative. According to the logic of arbitrage financial result calculated using formulas (5) and (7) must be higher than the result, which can be obtained by holding the asset and selling it at accounting price.

You can see an imbalance in financial results when the price deviates from its calculated value, but arbitrage opportunities do not arise immediately. The difference in interest rates, which are considered equivalent in classical methods of determining derivative financial instruments value, affect on this process. Futures contract real price should be in range between calculated arbitrage prices, taking into account the difference in rates. Consequently, futures contract price, taking into account the difference in rates (FP_m), will be equal to the average of the lower and upper arbitrage prices. The model for estimating futures contract value is shown in figure 1 (Fig. 1).

Futures contract value determination model

↓

Risk-free rate determination

↓

Short-term sales and borrowing rates determination

↓ ↓

$FP_{-} = CP\left(1 + (r - r_s)\frac{t}{T}\right)$ $FP_{+} = CP\left(1 + r_b * \frac{t}{T}\right)$

↓

$$FP_m = \frac{FP_{-} + FP_{+}}{2}$$

Fig. 1. Futures contract value calculating model

The model has following assumptions:

- there are no information or transaction expenses associated with purchase or sale of both futures contracts and real products;
- there is an unlimited opportunity of getting a loan;
- there is no credit risk, associated with purchase or sale of either a futures contract or a spot commodity (what means, that no margin is required on the futures contract);
- products can be stored eternally without changing their characteristics (quality);
- there are no taxes.

Futures contract price is "fair" price, if it is reasonable to buy or sell the contract. If $FP_r < FP_-$, arbitrage opportunities will arise, what will help price return to the range of "normal" values. If $FP_r > FP_+$, arbitrage will also be possible, and it will reduce the price. If $FP_- < FPr < FP+$, current futures price will correspond to "fair contract price".

3.2. Methodology of model validation

The model was tested on futures contracts for such companies as Sberbank, Magnit, Tatneft and Transneft. Corporates securities had different liquidity criteria in stock and futures markets, traded value, and number of open positions. The model was also used to calculate prices for commodity futures for gold and silver, and for currency futures, for the dollar/ruble and euro/ruble pairs.

Quotation data is freely available on the Moscow exchange website, as well as on other sites which provide various services related to the securities market.

Process of instruments selection for testing the model was based on several parameters. As analysis period covers three calendar years futures contracts had to correspond to the same period and have data on contract trades that cover the specified time period. Instruments are also divided into groups by trading value and number of open positions. Consequently, we selected instruments from different categories. It was necessary to choose both high-performance and low-performance contracts. There are following instruments in Table 1.

Table 1. Trading value and number of futures contracts open positions (15.03.2018)

Company	**Number of futures contracts**	**Trading value**		**Number open positions**	
		ruble	**contract**	**ruble**	**contract**
Sberbank	32 036	5 009 645 529	192 026	5 834 016 776	228 776
Magnit	18 170	497 431 484	99 598	1 086 013 440	212 112
Tatneft	640	82 975 633	1 376	162 260 000	2 660
Transneft	143	37 179 121	210	110 518 580	628

Another parameter that should be determined for derivative pricing model use is the risk-free interest rate. The question at issue is in several points of view on rate determination.

In foreign practice risk-free rate is interest rate on securities guaranteed by the US government, or the current income rate on treasury and bonds. In Russia, interest on government bonds can be accepted as a risk-free rate [29]. You can also use the deposit rate in Sberbank or a similar rate in the Central Bank of Russia. You can also use zero-coupon yield rate on federal loan bonds. It is a completely relevant and affordable variant. Zero coupon yield curve is a generally accepted method for describing interest rates time structure for similar financial instruments, instruments (debt securities) with the same quality characteristics, including similar credit quality. It is one of the main indicators of money market conditions, and it is a significant criterion for other bonds and financial instruments. Data on Zero coupon yield curve is published by the Central Bank of Russia on website [30]. The primary source of information is the Moscow Exchange. The construction of the G-curve is based on the parametric Nelson-Siegel model with terms that provide additional degrees of freedom and, as a result, a more accurate comparison of the curve and trading data [31]. Quarterly rate is chosen for calculations, as there are the most active operations for a period of up to six months.

Then you should determine borrowing money rates and short sales rates. You can borrow money with products purchase on cash market and hold them until delivery on the sold futures as one of variants of arbitrage operations. As price is being in normal values range most of time, arbitrage opportunities include quick funds borrowing for operations. The most approximate value is leverage rate provided by a broker who is a participant in securities market. Despite some money investment from required amount, transfer rate of a long position is a sufficient indicator in rate determination.

Information about short sales rates is published on brokers' websites, but they can vary significantly even within a single broker’s website, depending on chosen tariff or the volume of operations. The study examined six brokerage companies in top 10 in Russia with openly published rates. Testing brokers' rates for long and short operations, including those offered at different rates by the same broker, revealed that the model works better at the most affordable (maximum) rates.

Consequently, we recommend using average of maximum rates for the most famous brokers as the rates used in the model.

3.3. Results of derivatives prices modeling

Through the analysis most of the time real price is in range between two calculated prices, which are calculated using the formulas presented in the model. There are cases when prices exceed this range, but occurrence of arbitrage opportunities returns them to the range of "normal" values. In the model we propose to calculate futures contract price as the arithmetic mean of two arbitrage prices.

Table 2 shows number of cases when the arbitrage opportunities were higher, less, or equal to zero. *FR-* is cash flow from arbitrage, which becomes possible when real price becomes lower than the estimated one, and which is the purchase of futures with a short sale of basis asset on cash market and investment of proceeds at a risk-free interest rate until the option is exercised. *FR+* is cash flow when the spot price exceeds settlement price. Then there is an opportunity to sell futures by purchasing basis asset with borrowed funds and hold it until it expires. Consequently, when the price is in normal range, both financial results are less than zero, and when it crosses one of the prices, the result becomes positive. In this case, the model can be used for arbitrage trading or determining levels of contract undervaluation or overvaluation.

Table 2. Financial results from operations with stocks, %

Criteria	Sberbank		Magnit		Tatneft		Transneft		Arithmetic mean	
	FR-	FR+	FR-	FR+	FR-	FR+	FR-	FR+	FR-	FR+
>0	5,4	8,6	5,4	4,46	15,4	8,54	11,1	8,24	9,31	7,46
<0	95	91	95	96	85	91	89	92	90,66	92,50
0	0,01	0,01	0,02	0,02	0,01	0,01	0,09	0,09	0,03	0,03

Most of the time the price is in range between two arbitrage prices, so according to the model, the price can be determined as the arithmetic mean between these prices. In this case, we calculate a price close to a real one. This conclusion is based on analysis of results of applying the model and comparing it with results of classical approach to determining the futures contract value. Table 3 shows results of analysis of price deviations calculated using the model (*FPm*) and prices calculated using the classical formula (*FPc*).

Maximum deviation exceeding actual price is greater for prices calculated using the model than for the classic calculation method. We can get such results both in particular calculations and in arithmetic mean. There is reverse situation with deviations of calculated prices, which are lower than the real ones. Prices of our model deviate less modulo in the negative direction than classical calculated ones. Nevertheless, if you look at the structure, there are more model prices with a positive deviation, and more negative classic prices.

Table 3. Estimated price deviation for the proposed and classical models.

	Sberbank		Magnit		Tatneft		Transneft		Arithmetic mean	
	FPm	FPc	FPm	FPc	FPm	FPc	FPm	FPc	FPm	FPc
Max, %	5	3	4	3	5	4	3	3	4,18	3,21
Min, %	-4	-6	-4	-5	-7	-8	-5	-6	-5,06	-6,19
Arithmetic mean, %	0,06	-0,78	-0,23	-0,75	-0,60	-1,07	-0,42	-0,82	-0,30	-0,85
Standard deviation, %	0,92	1,07	0,90	1,07	1,52	1,63	0,91	1,04	1,06	1,20
>5%	0	0	0	0	0	0	0	0	0	0
3-5%	0	0	0	0	0	0	0	0	0	0
1-3%	15	1	2	1	3	1	3	1	6	1
0-1	49	42	50	27	49	25	37	25	46	30
From -1 to 0, %	18	22	31	40	27	47	37	41	28	38
From -3 to -1, %	16	27	14	25	9	11	18	26	14	22
From -5 to -3, %	1	7	2	5	7	9	4	6	4	7
<-5, 5%	0	1	0	1	5	7	0	0	1,24	2,32
Total	100	100	100	100	100	100	100	100	100	100
From 1 to -1, %	68	64	81	68	76	72	74	66	74,61	67,34
Correlation	99,3	99,0	98,7	98,1	94	93	98,0	97,4	0,98	0,97

Classical calculated prices are usually higher than the prices calculated using the model, what we can see on the example of Tatneft (figure 2).

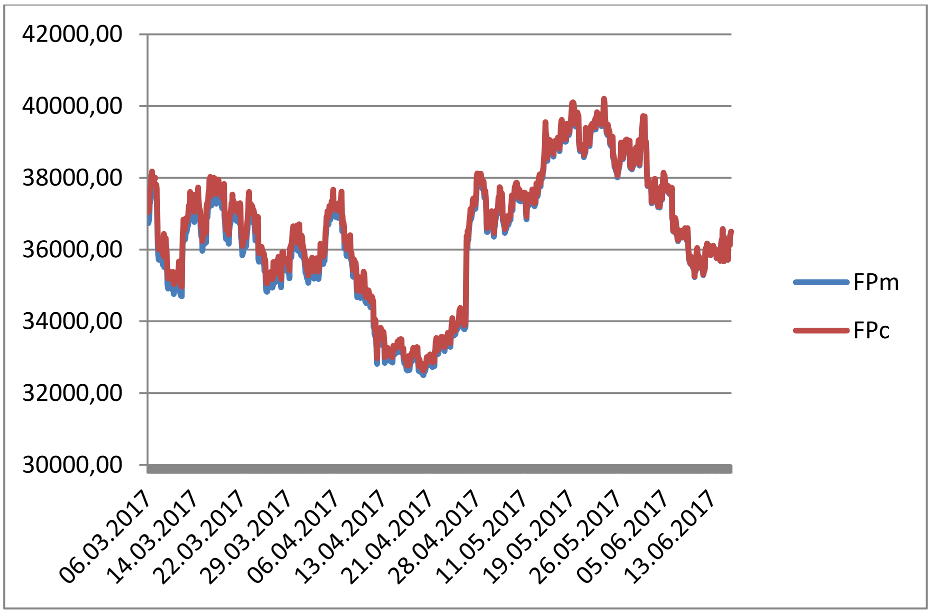

Fig. 2. Estimated prices offset on the example of Tatneft

Average price deviation from the real one is less for prices calculated by the model than using the formula. Advantage of this criterion is that it reflects average result that can be expected from using a particular model, but this result can be formed by compensating for significant multidirectional deviations and is not relevant. As prices calculated using the model have a lower standard deviation, they are generally closer to average value than prices calculated using classical method. Consequently, model prices have a smaller range and are more reliable. We do not use median, as data is characterized by a set of fractional values that are often not repeated. So we divided deviations into categories. We found quantity of numbers corresponding to these categories and investigated generated structure.

Quantity of prices with a deviation from -1 to 1% was key criterion. Advantage of this method is that there is no compensation for multidirectional deviations of the final values, but we have more details. Consequently, the model determines prices with the number of deviations from -1 to 1%, and they will occur 7.27% more often than in the standard model. That fact confirms the earlier conclusions based on average values and standard deviation. Real prices correlation degree is greater for model values than for classical calculated prices and is at least 0.94.

You can use the same model for contracts in commodity market. Table 4 shows results of estimated price deviation calculation for our and classical models for commodity futures contracts for gold and silver.

Table 4. Estimated price deviation analysis for our and classical models for commodity futures contracts for gold and silver

Criterion	Silver		Gold		Average	
	FPm	FPc	FPm	FPc	FPm	FPc
Max, %	0,9	0,7	0,9	0,6	0,9	0,7
Min, %	-3,2	-4,5	-4,2	-5,8	-3,7	-5,2
Arithmetic mean, %	-0,64	-1,11	-1,08	-1,64	-0,9	-1,4
Standard deviation,%	0,54	0,83	0,70	1,06	0,6	0,9
>5, %	0	0	0	0	0,0	0,0
3-5, %	0	0	0	0	0,0	0,0
1-3, %	0	0	0	0	0,0	0,0
0-1, %	15	10	2	1	8,5	5,6
From -1 to 0, %	59	43	48	35	53,8	39,2
From -3 to -1, %	26	43	49	50	37,0	46,2
From -5 to -3, %	0	4	1	13	0,6	8,7
<-5, %	0	0	0	0	0,0	0,3
From 1 to -1, %	74	53	50	37	62,3	44,8
Correlation	0,99	0,98	0,98	0,94	0,98	0,96

Our model is also applicable for calculating currency futures. Firstly, you should calculate interest rates to usethem in the model. Modified formulas for arbitrage prices calculation:

$$FP_{+} = CP\left(1 + (r_{b1} - r_{rf2})\frac{t}{T}\right) \quad (9)$$

$$FP_{-} = CP\left(1 + \left(r_{rf1} - r_{b2}\right)\frac{t}{T}\right) \quad (10)$$

Formulas 9-10. r_{b1} - loan rate for national currency; r_{rf1} - risk-free rate for national currency; r_{b2} – loan rate for foreign currency; r_{rf2} – risk-free rate for foreign currency.

You should find the cash loan rate in a foreign currency, and similar risk-free return rate instead of short sale rate. Major financial groups and banks are the main bidders [32]. This leads to the use of an independent indicative rate for obtaining loans in rubles MosPrime Rate for the national currency. The indicator is formed on the basis of the leading participants of the Russian money market and is determined for different periods of borrowing [33]. Yield rates are determined based on government bonds zero coupon yield curve. Return rate for us dollar on US Treasury bills and cash loan rate are published on Federal reserve's website (for euro - European Central Bank website) [34, 35]. The yield is determined based on government bonds yield. Borrowing rate is Euribor (interbank lending rate in euros).

Table 5 shows cumulative results of the model.

Table 5. Results of futures currency contract value determination by the model on example of EUR_RUB and USD_RUB

Criterion	EUR_RUB		USD_RUB		Average	
	FPm	FPc	FPm	FPc	FPm	FPc
Max, %	3,00	4,22	4,53	4,79	3,76	4,51
Min, %	-3,93	-2,93	-18,78	-18,59	-11,36	-10,76
Arithmetic mean, %	-0,05	0,36	0,11	0,06	0,03	0,21
Standard deviation, %	0,61	0,68	0,95	0,99	0,78	0,84
>5%	0,07	0,20	0,14	0,12	0,11	0,16
3-5%	0,19	0,51	0,33	0,39	0,26	0,45
1-3%	1,22	9,06	2,75	4,19	1,99	6,62
0-1%	61,31	74,70	68,48	57,59	64,89	66,15
From -1 to 0, %	31,99	13,34	25,34	33,35	28,67	23,35
From -3 to -1, %	4,03	1,70	2,75	4,07	3,39	2,88
From -5 to -3, %	0,97	0,39	0,10	0,16	0,53	0,28
<-5, %	0,21	0,09	0,11	0,12	0,16	0,11
From 1 to -1, %	93,31	88,04	93,82	90,94	93,56	89,49
Correlation	0,996	0,994	0,997	0,997	0,997	0,996

For Euro/Ruble pair, the maximum deviation is lower for model price and higher for the classic one. There is an opposite situation for minimum deviation values. Average values are multidirectional for maximum deviations, but modulo average deviation of the calculated model price is lower. Standard deviation value indicates that model price is characterized by a smaller spread of values relative to average than for classical price. Regarding deviation values structure variation, there is positive deviation for classical model. There are a significant number of values in range from 1 to 3%, and we can see indicators up to 1% more often. Nevertheless, model prices have more price values with a deviation from -1 to 0%, and aggregate values from -1% to 1% is higher than in classic model. Correlation value is higher than in classical model, what confirms a more accurate determination of prices using our model.

There is a different situation for Dollar/Ruble currency pair. Minimum and maximum price deviations show the same situation as for the Euro / Ruble pair, but the difference in modulus is minimal. The average value was lower for classical price, but standard deviation indicates that values of model price are in smaller range comparing with average. There is an opposite situation with values spread structure. Prices calculated using the model are more often in range from 0 to 1% than prices calculated using classical formula. Prices with a negative deviation (to 1%) were registered more often using the classical formula. Values from -1 to 1% were higher for model prices. The correlation values were almost identical.

Modal values have lower maximum and higher minimum deviations compared to classical estimated price. Average deviation values are lower for model prices, and standard deviation lower values indicate a higher accuracy level of values close to average. The value structure has a negative price deviation. Model prices have a higher number of values in range from -1 to 1% than classic ones. Correlation indicators confirm higher accuracy of our model.

4. Conclusion

According to the study results we have proved that it is necessary to use the rate of the zero coupon yield curve, which is calculated based on the yield of Federal loan bonds to account for difference in interest rates. Coupon income on government securities is calculated at an accounting interest rate, so when conducting a financial flow to general view, we also use simple interest rate for final calculations. So you can get more accurate futures contract future value prediction.

In the classical theory of derivative financial instruments pricing, contract value is determined by price deviations from the calculated value. So arbitrage operations conduction becomes possible, and this process affects basis asset and the futures contract in different directions, stabilizing the price. We have studied influence of borrowing rates, REPO operations, and funds investments without significant risk on the ratio between the availability levels of arbitrage operations and settlement prices. Ratio depends on the difference in interest rates written above. We have determined these levels, which are limiting factor for the real price of a futures contract. Reaching and overcoming them, the price returns to the range of "normal" values.

The formulas used to calculate the derivative financial instruments cost contain assumptions about the equality of rates for risk-free capital investment, REPO operations and cash loan rates. Nevertheless, in practice they can differ significantly. The study of rates influence on conducting arbitrage operations possibility let us determine the levels where the price is in its "normal" state, and, going beyond which, it tends to return to usual range of values. We have determined statistical relationship between these levels and actual contract price. So we have made a model for futures contract value determination, which made it possible to take into account the difference in interest rates and achieve higher accuracy in contract price determination. The model let us achieve higher accuracy in futures contract value determination. The accuracy can fluctuate, but it shows a steady advantage over the classical model. The model showed the highest positive difference in accuracy of the futures price determination with stocks and commodity contracts. We have achieved lower increment in estimation accuracy with currency contracts. Nevertheless, both model and classical calculations showed a higher approximation to real prices in comparison with stocks. Accuracy fluctuates, increasing with the approach to expiration time. Nevertheless, it shows consistently better results, in comparison with the classical model.

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