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MONETARY POLICY AND EXPECTATION HYPOTHESIS AT THE RUSSIAN TREASURY BILLS MARKET

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Introduction

In contradistinction to similar studies of developed financial markets an analysis of the term structure of the Russian government short term bond (*Russ. abbr.* GKO) yields meets certain difficulties and takes into account a number of assumptions, which are to be specifically noted.

First, the time period of observation is less than four years. So, we mainly review the data with week (or month) frequency in order to ensure a sufficient number of degrees of freedom in econometric models. At the same time, the majority of studies of term structure of interest rates on Western markets are based on quarterly data. The higher frequency of observations may cause stronger influence of random noises and fluctuations on the market related rather to short term variations of market liquidity, actions of individual large actors than to macroeconomic factors. In this case, the results of analysis of yield dynamics across individual GKO tranches, in particular of testing the hypotheses on the term structure may shift toward rejection of certain hypotheses (expectations, preference of liquidity) in behalf of other (time-varying term premium, market segmentation, 'preferred habitat').

Second, the longest maturity of discount bonds on the Russian market was less than one year. The proposed classification of GKOs as short, medium, and long-term securities is rather conventional since similar instruments on developed markets would be classified as shortest-term (up to three months), or short term (up to one year) bills. However, the specifics of the domestic market were that investors considered GKO tranches with maturity over three months as long-term securities the risk premium of which includes a unique term component (as compared with short term GKOs). It is possible that over a considerable part of the period under observation (probably excluding 1997) short and long-term GKOs were in demand of different groups operating on the market. So, it is assumed that GKOs may be divided into short (up to three months) and long-term (from nine to twelve months) government securities.

Third, since over years the maximum duration of GKOs varied from three to twelve months, it does not permit to analyze the dynamics of long-term (in our terms) bonds over the whole period under observation. From our point of view, the most acceptable solution of this problem is to evaluate ratios between GKOs with different maturity terms over each time intervals.

Forth, more frequent observations leads to a greater number of gaps in actually observed data. Except of certain short periods in 1997 and 1998 there were not a week when bills maturing at all terms from 1 to 52 weeks (or from one to twelve months) were simultaneously present on the market. In order to create continuous time series of yields across GKOs of different maturity we approximated weekly and monthly yield curves. Such an approximation somewhat distorts the term structure of interest rates smoothing the yield curve; however it does not change its form.

Fifth, a majority of theoretical models of the term structure (including stochastic models) is either based on the analysis of real interest rates, or does not specify the division into nominal and real interest rates. At the same time, empirical studies of the term structure of yields on developed and emerging markets deal with nominal rates. This is chiefly related to the fact that in developed countries inflation is low over short (monthly, quarterly) periods, and the transition to real *ex post* rates affects the general market patterns insignificantly, while the economic interpretation of real *ex post* rates is ambiguous. Furthermore, in case the hypothesis that the real rate is constant (over short periods) is applied, the variation of inflationary expectations and risk premium randomize the dynamics of nominal interest rates thus making possible to model them as a stochastic process. Information on expected price growth rates may be important for finding out term premium values. Therefore, this study also deals with the analysis of the term structure of nominal GKOs yields (except of specifically mentioned cases).

§1. Data

The source data for the study of the term structure of interest rates on the GKO/OFZ market were taken from the database of Finmarket information agency. Notwithstanding the fact that since 1995 coupon bonds (mainly with varying coupon yields) have been present on the Russian government securities market, we are working with discount securities (GKOs) only[1].

In order to achieve the comparability of rates for bills of different maturity we computed continuously compounded GKO yields over all tranches for each trading day, i.e.

$$I_d = \frac{-\ln P_t}{T/365},$$

where P_t is the bond price in portions per one.

The term structure of GKO yields to maturity is shown in Fig. 1.1.

The yield in real terms is determined basing on the ratio between the nominal yield to maturity and the consumer price index as computed by RF Goskomstat in accordance with the following formula:

[1] This limitation does not significantly affect the results of analysis of dynamics of interest rates and term structure of government securities yields.

$$R_t = \frac{I_t - p_t}{1 + p_t}.$$

GKO forward rates are calculated according to a formula similar to the yield to maturity expression:

$$f_t(n, m) = \frac{(m - n) r_t(m) - n r_t(n)}{m - n},$$

where *m* is the term before the maturity of a long-term bill (months), *n* is the term before the maturity of a short term bill (months). The designation of forward rates is assumed to be $f_t(n, m)$. For instance, $f(1,2)$ means the forward rate of a one-month bill computed on the basis of yield to maturity for bonds due in one and two months.

Other macroeconomic indicators are as cited in official documents of the RF Central Bank and RF Goskomstat.

§2. Analyzing the properties of GKO rates time series

An analysis of statistical characteristics of GKO rate time series (yields to maturity, forward rates) permits to compare the behavior of variables under observation, to demonstrate ratios between average rates, volatility (dispersion), and inertia (serial autocorrelation) across series of different rates. The analysis is made on the basis of comparing sample statistical moments, which characterize the distribution of rates.

Analyzing the term structure of GKO yields

Statistical characteristics of yields across maturity terms. For key statistical characteristics of time series of GKOs with different terms before maturity (the number of observations, mean value, standard deviation, values of first three autocorrelation coefficients) see Table 2.1. These indicators (except autocorrelation coefficients) were computed basing on actual observations without taking into account the values deduced by applying the interpolation method.

In order to analyze the fluctuation of statistical indicators of GKO yield term structure over the whole time interval (1993 through 1998) we divided it into three sub-periods, in which different dynamics of the average GKO yield level were observed[2]:

- September of 1994 till July of 1996 was a period of market turbulence resulting from higher inflationary and political risks and the emergence of the GKO/OFZ market;
- August of 1996 till November of 1997 was a period of low average level of yields characterized by lowering risks and high liquidity;

- December of 1997 till August of 1998 was a period of emerging financial crisis, eroding confidence of market operators in government securities, and the most intensive support of bond prices by the Central Bank.

In order to get a clearer picture of the relation between yields and volatility of GKOs of different maturity Figures 2.1 and 2.2 demonstrate mean yield curves and mean standard deviation of GKO yields for the whole observation period and each sub-period.

As these results demonstrate, over the whole period the GKO yield term structure is complex-shaped: at the short end (up to three months) the slope of the yield curve is positive; it is followed by a horizontal segment from three to six months; the tranches yields decrease at the long end. A more detailed investigation of each sub-period allows for a conclusion that the shape of the yield curve was rather affected by fluctuations of the average yield level and by the number of observations at different time intervals[3].

During the first sub-period (1994 through 1996) the yield curve had an apparent positive slope. However, at that time short and medium term bills dominated the market thus facilitating the rise of the short and medium segment of the term structure over the whole period, since they represented longer and therefore more risky securities. Bills with maturity exceeding six months had begun to be traded on the market only since 1997, when the average yield level fell dramatically. In late 1997 and early 1998 the crisis developments exploded over a short interval within this sub-period. Average GKO yields over this period, although outpacing values of 1996 through 1997, remained at rather low levels. So, although the GKO yield term structure had primary positive slope, in real terms it may be noted that the yield curve was stable for terms up to six months.

An analysis of the volatility of GKO yields across different maturity terms estimated as a standard deviation of rates demonstrates that the general pattern of the Russian market agrees with general economic principles[4]. Practically over all observed periods the volatility

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[2] The period from May 1993 till August 1994 was excluded in order to ensure the continuity of actual yield values for shortest GKO tranches.

[3] For similar results of an analysis of the level and volatility of GKO yields at different periods see: Barinov V., Pervozvanski A., Pervozvanskaya T. The Policy of the Government Debt Floatation and the Behavior of the Government Securities Market. *EERC Scientific Report*, EERC, 1999.

[4] See, for instance, Shiller, R., J. Campbell, K. Schoenholtz (1983) 'Forward rates and future policy: Interpreting the term structure of interest rates', *Brookings Papers on Economic Activity*, 1, pp. 173 – 217; Mankiw, N. G., L. Summers (1984) 'Do long-term interest rates overreact to short-term interest rates?', *Brookings Papers on Economic Activity*, 1, pp. 223 – 247; Mankiw, N. G. (1986) 'The term structure of interest rates revisited', *Brookings Papers on Economic Activity*, 1, pp. 223 – 242; Mankiw, N. G., J. Miron (1986) 'The changing behavior of the term structure of interest rates', *Quarterly Journal of Economics*, 101, pp. 211 – 228; Salyer, K. (1990) 'The term structure and time series properties of nominal interest rates: Implications from theory', *Journal of Money, Credit, and Banking*, 22, pp. 478 – 490; Duffee, G. (1996) 'Idiosyncretic variation of Treasury bill yields', *Journal of Finance*, 51, pp. 527 – 551.

of short term rates was higher than that of yields of longer tranches. However, it is necessary to note that the lesser volatility of GKO maturing after six months is mostly related to a small number of observations (less than a half of all business weeks), their relatively low liquidity, and the Russian Central bank actions toward supporting the required yield level. An obvious example of this were the estimates of the sub-period from 1996 through 1997, when CRB and primary dealers had to "clamp" the ends of the yield curve[5]: as Fig. 2.2 demonstrates the lowest volatility in this period was observed at the yield curve ends, while its medium segment experienced rather strong fluctuations.

The first three coefficients of autocorrelation of GKO yields time series as shown in Table 2.1 also confirm the conclusion that longer termed bonds are less volatile. The values of autocorrelation rises practically up to one as the maturity becomes longer. At the same time the values of all coefficients, coefficients of third order including, are high. The yields to maturity of the shortest termed GKOs (one to two weeks, one month) are considerably less autocorrelated, while the spot rate of week-termed GKOs was not correlated over the period from 1996 through 1997. In 1998 a gradually evolving crisis caused a sharp decrease in "memory" of yields' time series: over this sub-period coefficients of autocorrelation had lower values for the majority of terms than averages of this period on the whole and over other sub-periods; besides, values of autocorrelation coefficients of second and third order drop considerably.

Stationarity of time series. The problem of analysis of stationarity of tiem series of bills' yields is outside of the usual testing of the hypothesis about the presence of a unit root in the time series.

First, time series of interest rates of bills with different maturity terms are not independent, the random deviations of interest rates for different terms are correlated with each other[6]. While evaluating the unit root tests statistics, the number of lags may be chosen taking into account the correction for autocorrelation in the residuals in accordance with the Newey-West method[7].

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[5] I.e. to support certain yield levels at the ends of the yield curve.

[6] Salyer, K. (1990) 'The term structure and time series properties of nominal interest rates: Implications from theory', *Journal of Money, Credit, and Banking*, 22, pp. 478 – 490.

[7] Newey, W., K. West (1987) 'A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix', *Econometrica*, 55, pp. 703 – 708. The number of lags is approximately $\sqrt[3]{n}$, where *n* is the number of observations.

Second, as Enders and Granger demonstrated[8], the property of asymmetry in the rate dynamics is typical for time series of the term structure of bill rates. In this case usual Dickey-Fuller and Phillips-Perron tests are not effective enough. The transformation of the Dickey-Fuller test proposed by Enders and Granger allows for an increase in its effectiveness and for testing the hypothesis about asymmetry in the stochastic process of bill rates.

Third, theoretical studies of random processes modeled similarly to relationships between time series of the term structure of interest rates have not given a definitive answer about the number of unit roots in the term structure of interest rates[9]. Empirical studies of the term structure of bill yields in different countries confirm that actual time series of rates are of different order of integration. Fama[10] noted that the hypothesis about random walk of time series of financial assets appears to be true for an analysis of stock prices requires an obvious economic justification while studying yields across Treasury bills with different maturity[11].

The results of unit root Dickey-Fuller, Phillips-Perron, and Enders-Granger tests (for unit root and the asymmetry of the process[12]) for week time series of the GKO yield term structure are shown in Table 2.2. These time series include both actual values, and those interpolated in order to bridge the gaps. For each series continuous time intervals of actual and calculated values and the number of observation over these intervals were given.

On the whole the results do not contradict to most frequent cases of properties of the term structure of government bond yields. Tests reject the hypothesis about a presence of unit root for the series of the shortest termed bills (one and two week GKOs), the hypothesis about asymmetry has been confirmed over practically all terms (except of one and two months), the Dickey-Fuller test tends often not to reject the unit root hypothesis as compared with two other tests. The influence of asymmetry exert on the evaluation of a series order of integration

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[8] Enders, W., C. Granger (1998) 'Unit-root tests and asymmetric adjustment with an example using the term structure of interest rates', *Journal of Business and Economic Statistics*, 16, pp. 304 – 311.

[9] See, for instance: Bradley, M., S. Lumpkin (1992) 'The treasury yield curve as a cointegrated system', *Journal of Financial and Quantitative Analysis*, 27, pp. 449 – 463; Zhang, H. (1993) 'Treasury yield curves and cointegration', *Applied Economics*, 25. pp. 361 – 367; Johnson, P. (1994) 'On the number of common unit roots in the term structure of interest rates', *Applied Economics*, 26, pp. 815 – 820; Engsted, T., C. Tanggaard (1994) 'Cointegration and the US term structure', *Journal of Banking and Finance*, 18, pp. 167 – 181; Engsted, T., C. Tanggaard (1994) 'A cointegration analysis of Danish zero-coupon bond yields', *Applied Financial Economics*, 4, pp. 265 – 278; Cuthbertson, K., S. Hayes, D. Nitzsche (1998) 'Interest rates in Germany and the UK: Cointegration and error correction models', *Manchester School of Economic and Social Studies*, 66, pp. 27 – 43.

[10] Fama, E. (1970) 'Efficient capital markets: A review of theory and empirical work', *Journal of Finance*, 25, pp. 383 – 417.

[11] Nominal rates contain inflationary expectations, and inflation time series has (as a rule) a unit root. Thus, in case expectations are not biased and assuming the constancy of real interest rate, the time series of nominal bill yield will also be non-stationary.

[12] The asymmetry of the process presupposes that interest rates usually deviate from mean values non-uniformly (for instance, increase more than decrease), what may be considered as the non-stationarity of the process during usual tests for unit root.

is most noticeable for longer term tranches: both symmetric tests (Dickey-Fuller and Phillips-Perron) do not reject the presence of unit root, while the Enders-Granger test rejects the hypothesis at 5 per cent significance level. Thus, the time series under observation are rather related to an autoregressive process than are a random walk.

Similar evaluations were obtained while analyzing month series of the term structure of GKO yields. Since these series mostly represent aggregated values in order to find out if they were stationary we applied the Phillips-Perron test (see Table 2.3).

Thus, the assumption that the time series of differently termed GKO yields are non-stationary can not be rejected, at least while analyzing a system including several time series, or while analyzing them with inclusion of other variables of the first order of integration.

An analysis of the term structure of GKO forward rates

We have computed the values of implicit GKO forward rates across all terms from one to twelve months, totaling to 66 time series of forward rates. These series are not continuous, since only actual observations of GKO yields were used in order to ensure the correctness of the computation. Besides, negative values of forward rates were excluded (23 cases, i.e. 0.29 per cent of the sample). For statistical characteristics of the term structure of GKO forward rates see Table 2.4.

Since forward rates are determined basing on the comparison of yields to maturity of two different bills and are indicators of future GKO yields to maturity, the parameters of their distribution must correspond with the parameters of distribution of GKO yields to maturity. However, the results of tests for the equality of the first two moments of distribution shown in Table 2.5 do not confirm this assumption.

The hypothesis about the equality of mean values of forward rates and yields was not rejected only for longest termed GKO tranches, the yields of which were most tightly controlled by the Central Bank of Russia. The distribution of both GKO rate values seriously differs from the normal one as the results of the Bartlett test for the equality of distribution variance demonstrate. This test is highly sensitive to the deviation of the sample distribution from normal. Less sensitive to the normal distribution requirement Levene and Brown-Forsythe tests often do not reject the null hypothesis about the equality of mean values. In particular, a more powerful Brown-Forsythe test demonstrate the identical volatility of GKO yields and forward rates over the first (from May of 1993 till July of 1996, and the last (from December of 1996 till August of 1998) sub-periods. The obtained results, from our point of view, reflect the fact that in periods of intensifying general instability fluctuations of the forward and spot rates are symmetrical. Over the second sub-period (from August of 1996 till

November of 1997) the current GKO yields fell steadily that causing more intense volatility of yields to maturity over the whole sub-period as compared with forward rate fluctuations.

§3. Monetary policy shocks and the term structure of GKO yield

While analyzing the effects of monetary policies on the government bond yield term structure two lines of research depending on different targets of monetary policy could be singled out. First, it is the study of the ratio between targeted interest rates (for instance, federal reserve rates of short term instruments of the US money market) set by the monetary authorities and yields of bonds with different maturity. This approach developed as a number of countries started to monitor interest rates as monetary policy targets[13].

The second line of research is related to the study of direct effects of money supply shocks on the term structure of interest rates. The theoretical principles of such an analysis include not only standard macroeconomic models, but also special macroeconomic approaches to the study of the term structure of interest rates[14]. Since the RF Central Bank had the dymanics of various monetary aggregates as the target of its monetary policy, the second approach seems to be more adequate for the study of the Russian government bond market.

While analyzing the effect of monetary shocks on the yields of differently termed government bonds it is important to choose suitable monetary aggregates. Chari, Christiano, and Eichenbaum[15] noted the difference in signs of coefficients of correlation between time series of short term rates and various monetary aggregates: nominal short term rates positively correlate with the money base and monetary aggregates Ì$_0$ and Ì$_1$ while a negative correlation with the amount of non-borrowed reserves is simultaneously observed. The positive dependency was explained by endogenic change in both variables: at higher interest rates the FRS intensifies its activity on the open market increasing narrow monetary aggregates. On the other hand, growth of non-borrowed reserves is connected with the

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[13] For studies in the framework of this approach see: Svensson, L. (1994) 'Estimating and interpreting forward interest rates: Sweden 1992 – 1994', *IIES Seminar paper*, 579; McCallum, B. (1994) 'Monetary policy and the term structure of interest rates', *NBER Working paper*, 4938; Campbell, J. (1995) 'Some lessons from the yield curve', *NBER Working papers*, 5031; Balduzzi, P., G. Bertola, S. Foresi (1997) 'A model of target changes and the term structure of interest rates', *Journal of Monetary Economics*, 39, pp. 223 – 249; Dillen, H. (1997) 'A model of the term structure of interest rates in an open economy with regime shifts', *Journal of International Money and Finance*, 16, pp. 795 – 819 è äð.

[14] See, for instance: Blanchard, O. (1981) 'Output, the stock market, and interest rates', *American Economic Review*, 71, pp. 132 – 143; Turnovsky, S. (1989) 'The term structure of interest rates and the effects of macroeconomic policy', *Journal of Money, Credit and Banking*, 21, pp. 321 – 347.

[15] Chari, V., L. Christiano, M. Eichenbaum (1995) ‘Inside money, outside money and short term interest rates’, *NBER Working paper*, 5269.

sluggish decision-making on the enhancement of active operations of commercial banks after positive money supply shocks resulting in lower interest rates.

So, the effect of monetary policy shocks may be studied first taking into account of emerging inflationary expectations, and second changes in liquidity on the market. At the same time these effects may be divided by the financial instrument types (in our case it is GKO term of maturity) and depending on the monetary aggregate under observation.

In order to analyze the interrelation between the monetary aggregate dynamics and differently termed interest rates on the Russian financial market we have chosen yields of GKOs maturing in one week, one, three, six, and nine months. Week term GKOs were defined as shortest term bonds, month term GKOs as short term bonds, three and six month GKOs as long term bonds. Four monetary aggregates were analyzed:

- Narrow money base (cash plus required reserves, Ì Â);
- Money supply Ì$_0$ (cash outside the banking system, M0);
- Money supply Ì$_2$ (cash outside the banking system plus Ruble denominated deposits, M2);
- Broad money (Ì$_2$ plus all forex denominated deposits, BM).

Table 3.1 demonstrates coefficients of correlation between changes in GKO yields to maturity and rates of changes in monetary aggregates.

The obtained results correspond to the aforementioned specifics of the correlation between differently termed interest rates and the dynamics of monetary aggregates. The Russian money market demonstrated in this case a behavior similar to that of such a developed market as that of U.S. Changes in yields of shortest and short term GKOs positively correlated with money base and cash Ì$_0$ gr owth rates while correlating negatively with broader monetary aggregates, M_2, and broad money (the case of one month term GKO and broad money is an exception). Changes in yields of longer GKO tranches (over three months) demonstrate negative values of the coefficients of correlation with growth of all monetary aggregates. The highest absolute values of correlation coefficients for medium and long term rates were observed for the series of M_2 increments, for shortest and short term rates they were observed as the money base grew[16].

[16] Similar findings, although without qualitative interpretation, were presented by Mishkin for the US T-bill market (See: Mishkin, F. (1993) *Money, Interest Rates and Inflation*. Edward Elgar).

From our point of view, the interpretation of these results may be similar to that offered by Chari, Christiano, and Eichenbaum[17]. Substantial rises (reductions) of the shortest term rates chiefly reflected the liquidity inside the banking system prior to primary GKO auctions. In case the amount of liquid funds diminished, many banks started sales of shortest term GKO tranches. Since the Central Bank has been taking the responsibility for supporting liquidity on the GKO/OFZ market through open market operations and crediting dealers on REPO terms over a considerable part of the period under observation, at the instances liquidity deteriorated money base grew. It is probable that a portion of funds obtained by commercial banks due to increasing money base were converted in cash thus facilitating increases in M_0. Taking into account the frequency period we have chosen (one month) such fluctuations of the money base and M_0 coincide with the moment of respective change in yield.

Signs of coefficients of correlation between medium and long term rates and all monetary aggregates, and between short term rates and broad monetary aggregates reflect the effects of growing liquidity, i.e. decreasing interest rates at the background of money expansion. Besides, as average yield levels were falling at the result of growing volume of transactions on the market (and correspondingly accelerating rates of growth of broad monetary aggregates) the volatility of GKO yields abated in the second half of 1996 through 1998. So, over the whole period under observation the estimation of correlation coefficients were primarily affected by the general trend toward abating amplitude of fluctuations of yields across all GKO tranches at accelerating pace of broad monetary aggregates.

In order to estimate the dynamic consequences of monetary policy shocks were used vector autoregression models (VAR) for growth rate of four monetary aggregates and first differences of nominal yields of GKOs maturing at terms we have chosen. Such approaches are often used while analyzing the effects of monetary policy on the dynamics of the term structure of interest rates[18].

The approach we have taking is particularly close to that presented in the work by Evans and Marshall[19]. The CPI growth rates were included as the endogenous variable in vector

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[17] A theoretical background for these conclusions based on the model of money supply influencing interest rates with endogeneously segmented markets was presented in: (Alvarez, F., A. Atkeson, P. Kehoe (1999) 'Money and interest rates with endogeneously segmented markets', *NBER Working paper*, 7060).

[18] See, for instance: Sims, C. (1986) 'Are forecasting models usable for policy analysis?', *Federal Reserve Bank of Minneapolis Quarterly Review*, 10, pp. 2 – 16; McCallum, B. (1994) 'Monetary policy and the term structure of interest rates', *NBER Working paper*, 4938; Roubini, N., V. Grilli (1995) 'Liquidity models in open economies: Theory and empirical evidence', *NBER Working paper*, 5513, è äð.)

[19] Evans, C., D. Marshall (1998) 'Monetary policy and the term structure of nominal interest rates: Evidence and theory', *Carnegie-Rochester Conference Series on Public Policy*, 49, pp. 53 - 111.

autoregression models. At the same time, taking into account cointegrating equations between inflation rates and nominal GKO yield levels we estimate vector error correction (VEC) models what permits to evaluate the reaction of interest rates to growing money supply taking into account simultaneous changes in inflation rates.

Figure 3.1 demonstrates the impulse response functions of the first differences of nominal yields of differently termed GKOs at positive shocks of monetary policies, i.e. at accelerating growth rates of respective monetary aggregates *d*, equal to one standard deviation.

As the graphs demonstrate, the rates react to shocks somewhat differently depending on the monetary aggregate under observation. Increases in money supply (accelerating growth rates of money base and Ì$_0$) causes growing yields across all GKO tranches (except of the longest nine month term GKOs) with a lag of about four to five months. This fact is related to evolving inflationary expectations, which intensify in cases monetary policy becomes softer over several months in a row. Later, for a period up to a year rates of one, three, and six month GKO remain high reflecting the growth of nominal GKO yields at accelerating inflation rates. It worth noting that the reaction of shortest rates ceases (indistinguishable from zero in statistical terms) in six months, since they least take into account inflation outside the current moment in time and stabilize at a higher new level[20].

A similar reaction of shortest (week) rates to accelerating growth rates of broad monetary aggregates reflects rather the absence of the direct influence of the latter and may be explained by the simultaneous processes of increase of interest rates and of money expansion in the economy caused by the dynamics of narrow monetary aggregates.

Accelerating Ì$_2$ and broad money growth rates indicating an increasing amount of money in the economy and of liquid funds on the market results in lower GKO yields reflected in negative changes in short and medium term GKO tranches. At the same time, yields of longer term bills (six and nine month) practically do not react to changes in broad monetary aggregates (while nine month term GKOs do not react even to money supply). The

[20] At the same time, the duration of shock effects and lagging reaction of rates may be related to fluctuations of the inflation level and mean growth rates of monetary aggregates. Kim, Limpaphayom and Goodfriend (Kim, K., P. Limpaphayom (1997) 'The effect of economic regimes on the relation between term structure and real activity in Japan', *Journal of Economics and Business*, 49, pp. 379 - 392; Goodfriend, M. (1998) 'Using the term structure of interest rates for monetary policy', *Economic Quarterly (Federal Reserve Bank of Richmond)*, 84, pp. 13 - 30) have demonstrated that fluctuations of the term structure of the interest rates are extremely sensitive to changes in inflation regime and the regime of monetary policy. In particular, while transiting from high to low inflation the reaction of interest rates of different terms to tougher monetary policy becomes less distinguished by regression methods. Unfortunately, small number of observations does not allow us to analyze the impulse response functions for each sub-period with different inflationary regimes.

transition to a new yield level occurs with a lag of about six to ten months that coinciding with the lag between the start of money issuance and the accelerating of price growth rate thus reflecting the inflationary effect. This conclusion corresponds to an assumption that longer rates are less volatile.

Since real interest rates reflect the liquidity effect more than nominal rates, in order to distinguish between the effect of inflationary expectations and that of liquidity we reviewed simple vector autoregression models including monetary aggregate growth rates and real *ex post* GKO interest rates. Since inside the pairs of narrow and broad monetary aggregates the influence is similar we analyzed only models including money base and M_2 growth rates. For impulse response functions for these models see Figure 3.2.

The dynamics of real rates in response to monetary policy shocks are not so transparent as while analyzing GKO nominal yields. It seems that the behavior of longer term GKO are most explainable: real yields of nine month term GKOs practically do not react to fluctuations in monetary aggregate growth rates, while real yields of six month term GKOs fall over first four months and start to rise somewhat only after the reaction of respective nominal rates becomes perceptible (see Fig. 3.1).

The reaction of shorter real rates is more contradictory. Nevertheless, the impulse response function of real yields of three month term GKOs is close to the graph typical for other medium term bills (six month); however, the initial decrease and consequent growth are not so statistically significant chiefly due to shorter time these fluctuations exist (this period is limited to the securities' time of circulation). The reaction of shortest and short term real rates is rather absent than not.

In order to study changes in the pattern of the term structure of nominal GKO yields to maturity we have reviewed the relationship between monetary aggregate dynamics (money base and Ì_2) and the time series of the term structure characteristics basing on the impulse response functions of vector autoregression models. In order to describe the movements in the term structure we have used the quadratic approximation of yield curves for each month basing on the three-factor models of the term structure by Dai, Singleton,[21]. In order to do so we have estimated regression equation of the following type:

$$i_m(t) = C(t) + A(t)m + B(t)m^2 + e_t ,$$

where i_m is the yield of GKO with maturity m at the moment t . Since an individual yield curve for each observation is considered, regression coefficients are functions of time.

Coefficients of quadratic approximation $A(t)$, $B(t)$ è $C(t)$ are reviewed as three parameters describing the yield curve at any given time and are, respectively, *intercept*, *slope*, and *curvature*. In order to analyze the effects of monetary shocks we estimated vector regression models, including monetary aggregates growth rates and time series of these three indicators[22]. For the impulse response functions see Figure 3.3[23].

As the graphs demonstrate monetary shocks rise intercept, steepen the slope, and increase the degree of curvature of the yield curve, since the negative response of curvature means an increase in the concavity of yield curve (the mean yield curve for the period is concave, i.e. the curvature value is negative)[24]. The positive response of intercept is similar to the response of short term GKO rates (see Fig. 3.1). As in case of nominal yields the parameters of the yield curve react to monetary policy shocks with a lag of about four to five months that reflecting the prevalence of the inflationary effect as compared with the liquidity effect. In this case responses of intercept, slope, and curvature demonstrate the trend to damping starting after six to seven months. This fact is especially apparent in case of M_2.

The results we obtained are compatible with the term structure models basing on macroeconomic approaches worked out by Blanchard, McCafferty, and Turnovsky[25]. The impulse response functions of nominal and real GKO yields across maturity terms correspond to theoretically determined changes in interest rates (nominal and real) for a case of expected increase in money supply.

§4. Testing hypotheses about the term structure of GKO rates

The testing of the expectations hypothesis is most interesting from the viewpoint of monetary policy goals. The hypothesis assumes (in terms of rational expectations[26]) that the

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[21] Dai, Q., K. Singleton (1997) 'Specification analysis of affine term structure models', *NBER Working paper*, 6128.

[22] The Dickey-Fuller test reject the hypothesis that there is a unit root for all three time series at 5 per cent significance level.

[23] It was found out that a similar character of impulse response functions existed for interest spreads between three month, six month, and week term GKO tranches.

[24] Evans and Marshall have obtained similar results basing on monthly data on US Treasury bill market. The only difference was in the lag of term structure response to monetary shocks (one to two months). From our point of view, the latter fact reflects the difference of market development and government capacity to control the situation. Lynch and Ewing (Lynch, G., B. Ewing (1998) 'Money growth variability and the yield spread in Japan', *American Business Review*, 16, pp. 61 - 67) while analyzing the Japan case also noted that greater money growth variability resulting from shocks of monetary policy leads to more inclined slope of the yield curve.

[25] Blanchard, O. (1981) 'Output, the stock market, and interest rates', *American Economic Review*, 71, pp. 132 – 143; McCafferty, S. (1986) 'Aggregate demand and interest rates: a macroeconomic approach to the term structure', *Economic Inquiry*, 24, pp. 521 – 533; Turnovsky, S. (1989) 'The term structure of interest rates and the effects of macroeconomic policy', *Journal of Money, Credit and Banking*, 21, pp. 321 – 347.

[26] Sargent, T. (1972) 'Rational expectations and the term structure of interest rates', *Journal of Money, Credit and Banking*, 4, pp. 74 – 97; Modigliani, F., R. Shiller (1973) 'Inflation, rational expectations and the term structure of interest rates', *Economica*, 40, pp. 12 – 23.

term structure of bond yields contains information on future interest rates if market operators use all available information (including measures of monetary policy being undertaken). The other hypotheses about the term structure (liquidity preference, time-varying term premium, market segmentation, "preferred habitat") are considered either as an explanation of negative results of the expectations hypothesis testing, or as an additional aspect influencing the bond yield curves behavior.

A study of how interest rates reacted to monetary policy shocks revealed that the formation of yields of GKOs across maturity terms corresponded to GKO market operators having rational expectations. Therefore, we *a priori* assume that market operators' expectations are rational and that confirmation or rejection of the expectations hypothesis shall not be an evaluation of the rationality of their behavior.

Expectations hypothesis

In this study two methods of testing the expectations hypothesis are reviewed:

1) the cointegration analysis of time series of the term structure of bill yields;

2) the estimation of regression equations in the specification for the expectations hypothesis.

Cointegration analysis. In case interest rate dynamics agree with the expectations hypothesis the term structure must either have one common stochastic (in case of non-stationary separate time series), or a deterministic trend[27]. So, the existence of one cointegrating equation determining a long term trend to the convergence of differently termed rates may be interpreted as a confirmation of the expectations hypothesis.

In order to evaluate the number of cointegrating equations for the GKO yield term structure we studied a system consisting of six time series of yield to maturity of GKOs maturing in one to six months. Yields of longer term tranches were excluded from the system since the number of observation available for them is considerably (by two to three times) less than the number of observations for shorter term tranches. Besides, as was demonstrated earlier, the reaction of long term rates to economic policy shocks was ambiguous. These circumstances make more difficult to interpret the results of their evaluation. The results of the Johansen test for cointegration are shown in Table 4.1[28]. The number of included observations is 130, the number of lags is 6.

[27] Hall, A., H. Anderson, C. Granger (1992) 'A cointegration analysis of Treasury bill yields', *Review of Economics and Statistics*, 74, pp. 117 – 126; Johnson, P. (1994) 'On the number of common unit roots in the term structure of interest rates', *Applied Economics*, 26, pp. 815 – 820.

[28] Similar methods of testing for cointegration permitting to determine the number of cointegration relations were used in: (Zhang, H. (1993) 'Treasury yield curves and cointegration', *Applied Economics*, 25. pp. 361 –

According to the results the term structure of GKO yields has three common stochastic trends. A similar result was obtained by Zhang[29] for the U.S. Treasury bills market, and three cointegrating equations were interpreted as the intercept, slope, and curvature of the term structure. However, Johnson[30] proved that Zhang's conclusions resulted from the evaluation of a mixed system, which included both discount and coupon bonds. In our case only discount bills are reviewed. Therefore, the existence of three cointegrating equations does not permit to reject the hypothesis about a long term trend toward the convergence of GKOs yields, at the same time the expectations hypothesis is challenged.

Estimation of linear regression equations. The most common (and the first in terms of history) method of testing the expectations hypothesis is the estimation of linear regression equations specified in compliance with the rational expectations hypothesis of the term structure of interest rates. In this study we choose the following specification of regression equations:

$$i_{t+t}(m) - i_t(m) = a + b[f_t(t+n,m) - i_t(m)] + ge_{t-1} + e_t \qquad (1)$$

where ãäå $i_t(m)$ is the current monthly rate of GKO maturing in *m*, $i_{t+t}(m)$ is the monthly rate of GKO maturing in *m*, observed after *t* weeks, $f_t(t+n,m)$ is the current forward rate of GKO for the period $[t+n,m], n < m$. In case the rational expectations hypothesis is true $a = 0, b = 1, \mathrm{E}(e_t) = 0$. The choice of equations specification is based on the following presumptions.

First, forward rates as explanatory variables shall be preferred to interest spreads for monetary policy analysis[31]. Forward rates express future interest rates *ex ante* anticipated of

367; Engsted, T., C. Tanggaard (1994) 'Cointegration and the US term structure', *Journal of Banking and Finance*, 18, pp. 167 – 181; Engsted, T., C. Tanggaard (1994) 'A cointegration analysis of Danish zero-coupon bond yields', *Applied Financial Economics*, 4, pp. 265 – 278; Cuthbertson, K., S. Hayes, D. Nitzsche (1998) 'Interest rates in Germany and the UK: Cointegration and error correction models', *Manchester School of Economic and Social Studies*, 66, pp. 27 – 43). For testing the hypothesis about cointegration between individual time series of differently termed rates Bradley and Lumpkin (Bradley, M., S. Lumpkin (1992) 'The treasury yield curve as a cointegrated system', *Journal of Financial and Quantitative Analysis*, 27, pp. 449 – 463), Katbertson and Nitzsche applied the Phillips – Hansen test (Phillips, P., L. Hansen (1990) 'Statistical inference in instrumental variables regression with I(0) processes', *Review of Economic Studies*, 57, pp. 99 – 125), while Hassler and Nautz (Hassler, U., D. Nautz (1998) 'Der Zusammenhang zwischen kurz- und langfristigen Zinssaetzen in Deutschland', *Jahrbucher fuer Nationaloeconomie und Statistik*, 217/2, s. 214 – 226) used the Engle – Granger test.

[29] Zhang, H. (1993) 'Treasury yield curves and cointegration', *Applied Economics*, 25. pp. 361 – 367.

[30] Johnson, P. (1994) 'On the number of common unit roots in the term structure of interest rates', *Applied Economics*, 26, pp. 815 – 820.

[31] See: Shiller, R., J. Campbell, K. Schoenholtz (1983) 'Forward rates and future policy: Interpreting the term structure of interest rates', *Brookings Papers on Economic Activity*, 1, pp. 173 – 217; Svensson, L. (1994) 'Estimating and interpreting forward interest rates: Sweden 1992 – 1994', *IIES Seminar paper*, 579; Dahlquist, M., L. Svensson (1996) 'Estimating the term structure of interest rates for monetary policy analysis', *Scandinavian Journal of Economics*, 98, pp. 163 – 183.

the observed yield curve. Equations with interest spread in the right part serve to test the expectation hypothesis *ex post*[32].

Second, forward rates may be interpreted as expectations of future interest rates. This formulation makes possible to use this specification for testing the expectations hypothesis taking into account rational expectations instead of pure expectations hypothesis[33].

Third, the additional term (the MA(1) term) was included in the equation in order to correct for autocorrelation in residuals originating as a result of the linear approximation of the rational expectations model and errors of expectations measurement on the basis of forward rates[34].

The number of equation for $m = 1 \ldots 6$ months is 15. To allow for a greater number of observations we reviewed the weekly time series, therefore in order to ensure the compatibility with the periodization of maturity terms ($n = 1 \ldots 5$) values of $t = 4, 9, 13, 18, 22$ weeks.

The computation of forward rates is based on the comparison of GKO yields across maturity terms, so the same bill transits from one category of securities to another as its maturity approaches. In this case, residuals of regression equations will be autocorrelated and estimates obtained by the OLS will be ineffective. In order to ensure the effectiveness of estimates we applied the seemingly unrelated equations technique (SUR)[35]. Estimates of seemingly unrelated equations (1) are shown in Table 4.2. The period of observation is from July 26, 1993, through July 26, 1998.

On the whole, the obtained results contradict the expectations hypothesis. With an exception of one or two cases (for yields to maturity of three and five month bills and forward rates from one to four and six months respectively) the null hypothesis corresponding to the expectations hypothesis is rejected with a very low error probability.

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[32] See: Mankiw, N. G. (1986) 'The term structure of interest rates revisited', *Brookings Papers on Economic Activity*, 1, pp. 223 – 242; Mankiw, N. G., J. Miron (1986) 'The changing behavior of the term structure of interest rates', *Quarterly Journal of Economics*, 101, pp. 211 – 228; Anderson, N., F. Breedon, M. Deacon, A. Derry, G. Murphy (1996) *Estimating and Interpreting the Yield Curve*. John Wiley & Sons Ltd, è äð.

[33] See: Shiller, R. (1981) 'Alternative tests of rational expectations models: The case of the term structure', *Journal of Econometrics*, 16, pp. 71 – 87.

[34] See: Mankiw, N. G. (1986) 'The term structure of interest rates revisited', *Brookings Papers on Economic Activity*, 1, pp. 223 – 242; Anderson, N., F. Breedon, M. Deacon, A. Derry, G. Murphy (1996) *Estimating and Interpreting the Yield Curve*. John Wiley & Sons Ltd.

[35] The presence of the first order moving average is a sufficient condition for eliminating the autocorrelation in residuals of individual equations (Zellner, A., F. Palm (1974) 'Time series analysis and simultaneous equation econometric models', *Journal of Econometrics*, 2, pp. 17 – 54; Tiao, G., G. Box (1981) 'Modeling multiple time series with applications', *Journal of the American Statistical Association*, 76, pp. 802 – 816). An alternative method to estimate systems of this type is to apply convergent-parameter regression models (Rosenfeld, B. (1973) 'Random coefficients models. The analysis of a cross section of time series by stochastically convergent parameter regression', *Annals of Economic and Social Measurement*, 2, pp. 399 – 428).

At the same time, the constant term in practically all equations does not differ statistically significant from zero that corresponding to a zero term premium. Estimates of coefficient *b*, although being different from one (at 5 per cent significance level) have expected signs (positive). The majority of equations ensure a high percentage of explained variance of changes in GKO yields ($R^2 > 0{,}5$)[36].

Thus, in spite of aforementioned inconsistencies with the expectations hypothesis the evaluations permit to note that forward rates contain some information of future spot rates. However, the accuracy of such forecasts is low and forward rates, although not biased ($a \approx 0$), are ineffective estimates of future spot rates[37] (forward rates vary more than spot rates, see Tables 2.1 and 2.4).

Liquidity preference and time-varying term premium hypotheses

A possible explanation of the fact that the expectations hypothesis for the GKO market was rejected is the varying term premium (or liquidity premium). As Campbell and Longstaff[38] demonstrated that time-varying term premiums are a most frequent cause of the rejection of the expectations hypothesis in empirical studies. Engsted[39] reviewed a case of the expectations hypothesis rejection in behalf of the liquidity preference hypothesis, i.e. term premium depending on the bond maturity term[40].

In order to test the liquidity preference and time varying term premium hypotheses we analyzed the dynamics of time series of different premiums (in assumption of unbiased rational expectations of market participants):

1) Liquidity premium (interest spread):

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[36] High values of R-squared may be also explained by the influence of strong serial autocorrelation in residuals and a correlation between residuals across equations.

[37] Similar results obtained while testing the expectations hypothesis (basing on similar specifications of equations) on the GKO market were presented in: (*The Russian Financial Market Development and New Investment-Attracting Instruments, Moscow*, IET, 1998). However, that study analyzed equations individually (not as a system of simultaneous equations) over a shorter observation period (January of 1994 through January of 1998). The authors’ estimates of relevant coefficients were within the margin of our evaluations, the null expectations hypothesis was rejected at a 5 per cent significance level.

[38] Campbell, J. (1986) 'A defense of traditional hypothesis about the term structure of interest rates', *Journal of Finance*, 41, pp. 183 – 193; Longstaff, F. (1990) 'Time-varying term premia and traditional hypothesis about the term structure', *Journal of Finance*, 45, pp. 1307 – 1314.

[39] Engsted, T. (1993) 'The term structure of interest rates in Denmark 1982 – 1989: Testing the rational expectations / constant liquidity premium theory', *Bulletin of Economic Research*, 45, pp. 19 – 37.

[40] We do not review other term structure hypotheses in this study. Although the compliance with the conditions of the market segmentation hypothesis may lead to the negation of the expectations hypothesis (see: Taylor, M. (1992) 'Modelling the yield curve', *Economic Journal*, 102, pp. 524 – 532; Baldini, N., U. Cherubini (1998) 'Yield curve movements and market segmentation: A LISREL analysis of the Italian case', *Economic Notes by Banca Monte dei Paschi di Siena SpA*, 27, pp. 35 - 54), this explanation is of little use for the monetary policy analysis of the term structure. On the other hand, Mishkin (Mishkin, F. (1980) 'Is the preferred habitat model of the term structure inconsistent with financial market efficiency?', *Journal of Political Economy*, 88, pp. 406 –

$$s_t(n,m) = i_t(m) - i_t(n)$$

2) Term premium:

$$\Phi_t(n,m) = f_t(t+n,m) - i_{t+n}(m)$$

3) Holding period term premium:

$$H_t(n,m) = h_t(t-n,m) - i_{t-n}(n)\ ,$$

where $i_t(m)$ – is the current yield to maturity of GKOs maturing in *m*, $f_t(t+n,m)$ is the forward rate of GKO for a period from *n* to *m* months in the future, $h_t(t-n.,m)$ is the holding period GKOs rate maturing in *m* months over *n* months.

The liquidity preference hypothesis. According to the liquidity preference hypothesis securities yields depend only on the term of maturity. The longer maturity term is, the higher bond yields are. So, interest spreads and term (holding period) premiums of bonds are constant for each maturity pairs and have strictly positive values.

Table 4.3 contains the statistic characteristics of time series of individual GKO premiums, which, from our point of view, are most representative. As this table demonstrates, time series of all premiums are stationary (except of the term premium for the period from three to six months), have positive mean value and high serial correlation (values of the first order autocorrelation coefficients are within the range from 0,5 to 0,9).

Nevertheless, these results do not permit to state that liquidity preference of market operators explain the rejection of the expectations hypothesis for the GKO time structure. ***First***, premium values have large variation (the absolute value of standard deviation considerably exceeds the mean for all series). ***Second,*** the premium magnitudes do not always increase depending on the bill maturity. This property is well noticeable in comparison with the holding period term premium. At the same time, the results of a comparison between interest spreads and term premiums are less obvious. ***Third***, small values of autocorrelation coefficients of higher orders (above the first) in many cases have different signs that being an evidence of strong fluctuations of premiums.

Time-varying term premium hypothesis. The time-varying term premium hypothesis is an alternative of the liquidity preference hypothesis. According to the latter the sign and amount of premium may vary depending on changes in observed or implicit (non-measurable in quantitative terms) factors. The influence of implicit factors is often the main reason of the expectations hypothesis rejection, since observed factors (for instance,

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411) has demonstrated that the conditions of the “preferred habitat” hypothesis may be complied with in the framework of the expectations hypothesis in the form of rational expectations.

macroeconomic variables) may be directly considered in the specification of regression equation for testing the expectations hypothesis[41].

Since the character of premium dynamics is *a priori* unknown we reviewed two functional forms presupposing different characteristics of this process.

1) The time series of premiums is represented as an autoregressive – moving average process with autoregressive conditional heteroscedasticity of residuals[42]:

$$\begin{aligned} f_t(n,m) &= \mathrm{ARMA}(p,q) + e_t \\ s_t^{\,2} &= x\mathrm{GARCH}(1,1) \end{aligned}, \qquad (2)$$

where ãäå $f_t(n,m)$ – is any premium (liquidity, term, holding period), p and q are determined basing on an analysis of the autocorrelation and partial autocorrelation functions of time series, $x\mathrm{GARCH}(1,1)$ are different specifications of GARCH.

2) It is assumed that the degree of the time series mean reversion (the first order autoregressive term in model AR(1)) corresponds to a stochastic process being a “random walk”[43]:

$$\begin{aligned} f_t(n,m) &= c + a_t f_{t-1}(n,m) + e_t \\ a_t &= a_{t-1} + h_t \end{aligned}. \qquad (3)$$

Such a specification of the risk premium puts less constraints on the character of stochastic process than ARMA-GARCH model.

In order to test the aforementioned hypotheses concerning the type of functional form describing the dynamics of premium stochastic processes we estimated the parameters of equations (2) and (3) for three time series – the interest spread $s(1,2)$, the term premium $\Phi(2,3)$, and the holding period term premium $H(1,1)$. Table 4.4 contains the results of estimation of best (in terms of information criteria) specifications of models (2) for each of selected time series. Estimations of models (3), made using Kalman filter are shown in Table 4.5.

The obtained results confirm the aforementioned hypothesis about strong fluctuations of premiums and reflect features of each premium pattern. As Tables 4.4 and 4.5 demonstrate the mean values of interest spread and the term premium is close to zero, while deviations

[41] Cuthbertson, K. (1996) *Quantitative Financial Economics*. John Wiley & Sons Ltd.
[42] Similarly in: Engle, R., V. Ng (1993) 'Time-varying volatility and the dynamic behavior of the term structure', *Journal of Money, Credit, and Banking,* 25, pp. 336 – 349.
[43] Similarly in: Bhar, R. (1996) 'Modelling Australian bank bill rates: A Kalman filter approach', *Accounting and Finance,* 36, pp. 1 – 14.

from the mean are proportional to the conditional variance[44] (both series are better described by equations of ARCH-M type). The variances of these series are stationary (the sum of coefficients of the conditional variance equation are close to one). Asymmetric response of the term premium (the specification of conditional variance as TARCH) to negative and positive values of residuals may be caused by non identical changes in the expectations of market participants concerning future rates in cases of inflow of “good” and “bad” news. Estimates of random coefficients in the autoregressive term obtained by means of the Kalman filter is less than zero. So, both series have the property of the mean reversion[45]. However, the stochastic character of the premiums results from different causes: while in the case of the term premium it is caused by random fluctuations of the autoregressive term, in the case of the interest spread the respective coefficient is stable, while fluctuations are caused by random additive errors (according to the significance of variances of the observation equation and the state equation)[46].

The characteristics of the holding period term premium considerably differ from the characteristics of the interest spread and the term premium. First, the term premium has stable positive value (the mean is above zero and is statistically significant). Second, the mean of this premium is relatively constant (the estimates of the coefficients of the autoregressive term in model (4.3), or of the coefficients of conditional variance in the observation equation do not differ statistically significant from zero). Third, the variance of H11 time series is not stationary (the sum of coefficients in the equation of conditional variance is more than one). Besides, the variance of this time series is formed as the sum of the premium random deviation variances and fluctuations of a_t coefficient.

These differences may be explained from the viewpoint of formation of reviewed premiums. The interest spread reflects current evaluations of bill risks depending on the maturity and the market liquidity, while the term premium expresses conditional expectations of future rates. So, the interest spread dynamics reflects the fluctuations of ratios between the riskiness of bills of different maturity and changes in market liquidity (via short term rates).

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44 A similar property of the time-varying term premium on the US Treasury bill market was noted in (Engle, R., D. Lilien, R. Robins (1987) ‘Estimating time-varying risk premia in the term structure: The ARCH-M model’, *Econometrica*, 55, pp. 391 – 407).

45 The property of mean reversion of term premium series of US Treasury bills was noted in (Park, T., L. Switzer (1996) 'Mean reversion of interest-rate term premiums and profits from trading strategies with treasury futures spreads', *Journal of Futures Markets*, 16, pp. 331 – 352).

46 A similar result for series of interest spreads between one, two, and six month GKOs over a shorter observation period was obtained (see: Paltseva H. *Modelling Inflationary Expectations: the Russian Case*, Moscow, NES, 1998) while evaluating a somewhat different specification of the observation equation and the

At the same time, the term premium may take into account systematic bias of market participants' forecasts the value of which changes depending on the mean yield, changes in the economic environment, etc. The holding period term premium expresses the actual extra revenues derived at the moment of sale as compared with the short term rate prevalent on the market at the time of investment.

So, since the character of dynamics varies considerably across premiums, the choice of a concrete hypothesis explaining their behavior is difficult to make, and it is sensitive to the premium type. Both hypotheses (liquidity preference and time-varying term premium) may explain negative results obtained while testing the expectations hypothesis as applied to the GKO market. Thus, in case the dynamics of the holding period term premium is analyzed, the liquidity preference hypothesis may be preferred. The character of the term premium stochastic process is more consistent with the conditions of the time-varying term premium, while the results of the study of interest spreads were ambiguous.

Conclusions

An analysis of the statistical characteristics of GKO rates across periods reveals that the character of GKO yield curve over the whole period under observation has changed considerably depending on the degree of the institutional development of the GKO/OFZ market. Over the first sub-period (1993 through 1996) the shape of the yield curve was unstable. The ratio between yields of short, medium, and long term bills was determined by fluctuations of outstanding volumes of differently termed bills, the appearance of new GKO types, political risks. The second sub-period (1996 through 1997) was characterized by primary smooth yield curves with positive slope. Over the third period (1998), which coincided with the evolving financial crisis in Russia, the average mean yield curve has high short and long ends, while the medium segment is horizontal. It was characteristic of the term structure of GKO yields to maturity that short term bill rates were more volatile than rates of long term bills. Tests for unit root reveal different integration orders (zero or first) of time series of differently termed rates.

Expectations of market operators were unstable over the whole period under observation; at the same time the possibility of arbitrage between GKOs maturing at different times was used not enough. This conclusion is confirmed by the fact that term structures of GKO forward and holding period rates have statistical characteristics differing from the term structure of GKO yields to maturity. In particular, the hypothesis about the equality of the

state equation by the Kalman filter: the observation equation presupposed not the autoregressive process, but a constant with random errors.

distribution of GKO spot and forward rates is rejected at 5 per cent significance level. The forward rates and holding period rates are more volatile than the GKO yields to maturity.

The study of the GKO term structure provides important information about the effects of monetary policy shocks on the yields of government securities. The impulse response function to monetary policy shocks plotted basing on the estimation of vector autoregression models reveal that the reaction of GKO yields depend both on bill terms and the choice of a monetary aggregate. Estimates for the GKO yield term structure do not contradict to results of empirical studies of developed financial markets, and to conclusions arrived to on the basis of theoretical macroeconomic approaches to the analysis of the term structure of interest rates. Both yields of short and long term bills and the parameters of the GKO yield curve (intercept, slope, curvature) react to shocks of narrow and broad monetary aggregates supply consistently with theoretical conclusions and indicate the rationality of market participants' expectations. So, the influence of monetary policy on the bill yield curve in a transitional economy is similar to that observed on developed financial markets and is distinguishable even over a short period.

The study of the term structure of GKO rates for monetary policy goals revealed that current forward GKO rates contain some information on future spot rates, although on the whole the expectations hypothesis (in form of the rational expectations hypothesis) for the Russian government discount bond market is rejected. In order to explain this result we reviewed the liquidity preference and time-varying term premium hypotheses. Consideration Estimation of dynamics equations across different premium types (liquidity, term, holding period) does not permit to reject neither of the latter hypotheses. From our point of view the factors determining premium dynamics might be insufficient use of arbitrage between differently termed bills by market participants[47], systematic bias of the forecast of future rates in the situation of falling GKO yields, and fluctuations of the default risk premium across differently termed GKOs.

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[47] Such a conclusion may be either an evidence of market segmentation, or of the validity of the "preferred habitat" hypothesis.

Tables and figures.

Figure 1.1. The term structure of GKO yields to maturity.

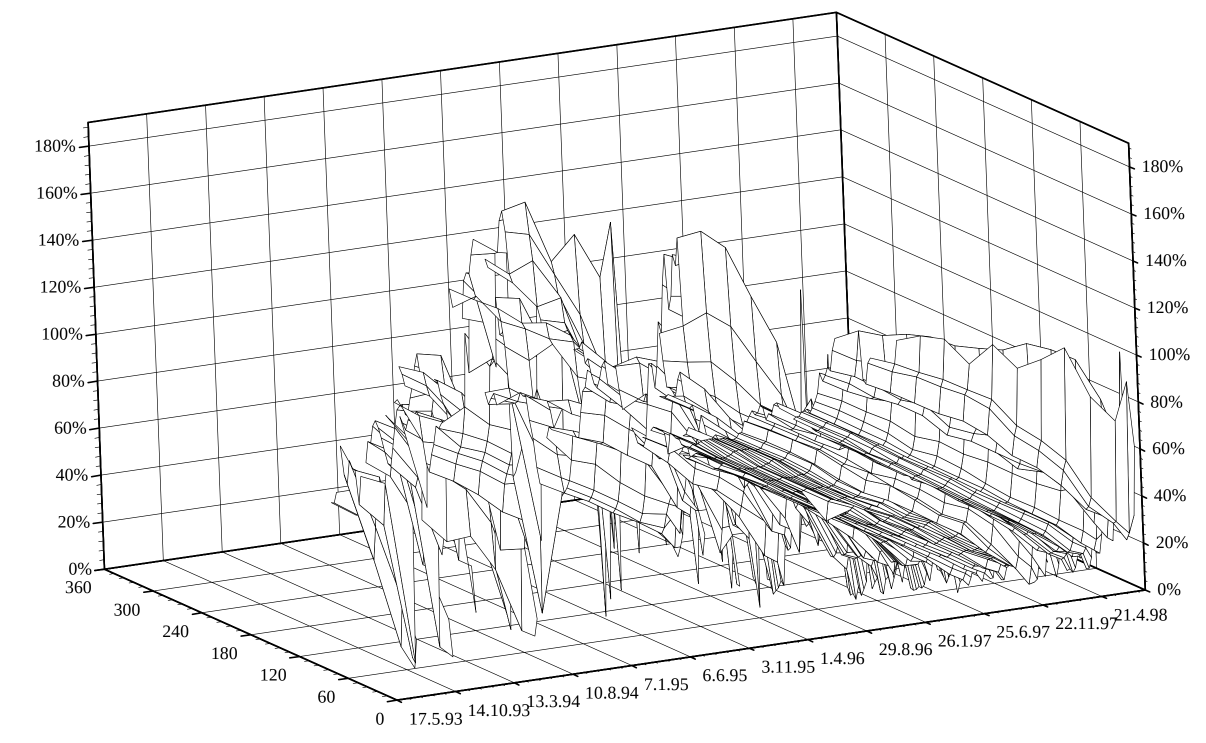

Figure 2.1.

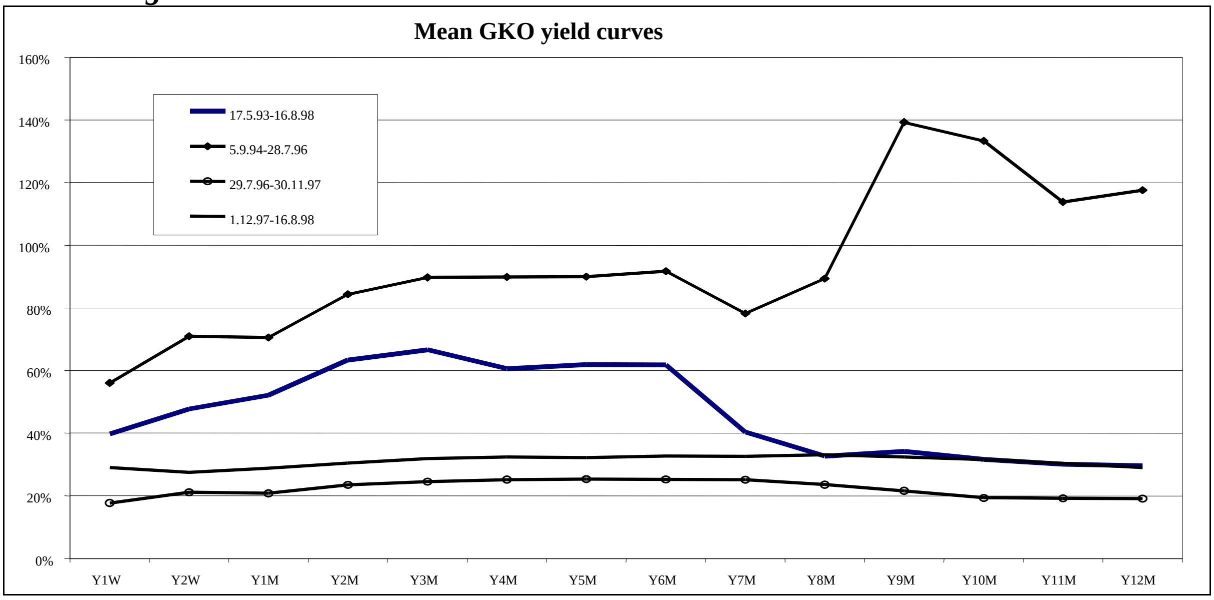

Figure 2.2.

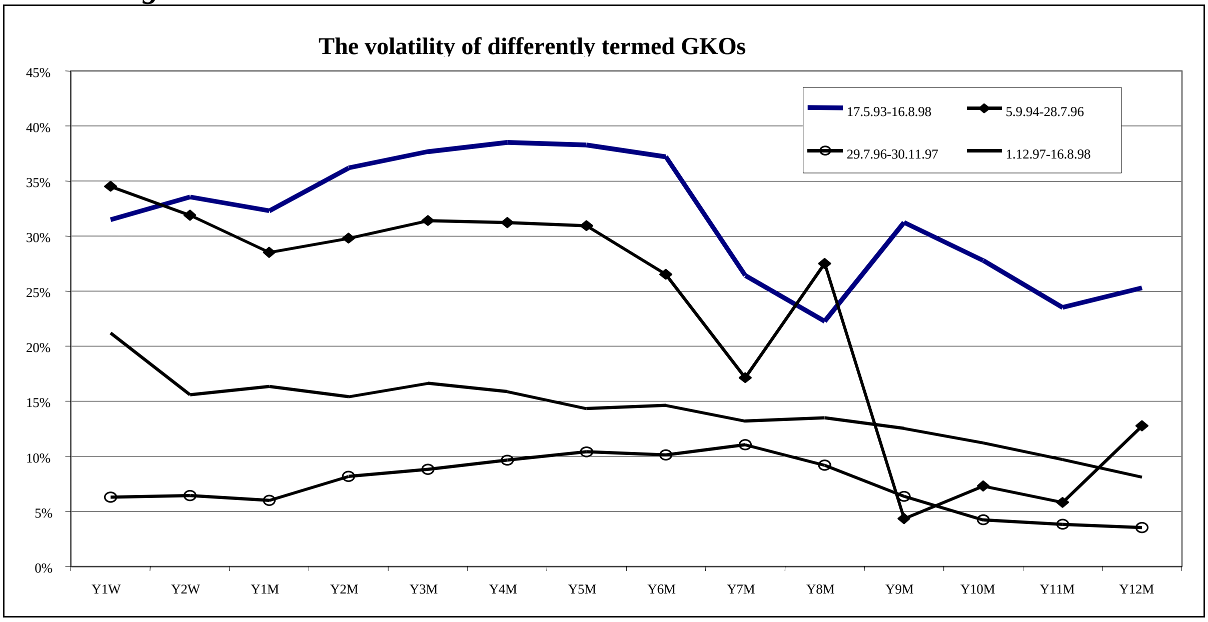

Table 2.1.

	Y1W	**Y2W**	**Y1M**	**Y2M**	**Y3M**	**Y4M**	**Y5M**	**Y6M**	**Y7M**	**Y8M**	**Y9M**	**Y10M**	**Y11M**	**Y12M**
17.5.93-16.8.98														
Number of observations	212	221	266	269	270	212	222	213	127	104	97	83	80	73
Mean value	39,75%	47,76%	52,17%	63,39%	66,70%	60,64%	61,98%	61,81%	40,42%	32,63%	34,18%	31,63%	30,09%	29,61%
Standard deviation	31,48%	33,55%	32,29%	36,20%	37,68%	38,52%	38,29%	37,21%	26,43%	22,28%	31,26%	27,80%	23,52%	25,28%
AR(1)	0,720	0,849	0,851	0,943	0,945	0,960	0,956	0,980	0,977	0,969	0,990	0,988	0,986	0,989
AR(2)	0,691	0,809	0,760	0,898	0,891	0,923	0,918	0,952	0,924	0,926	0,978	0,972	0,969	0,975
AR(3)	0,585	0,769	0,739	0,869	0,856	0,895	0,881	0,929	0,906	0,883	0,967	0,958	0,960	0,963
5.9.94-28.7.96														
Number of observations	99	100	108	108	108	96	99	92	26	9	7	5	5	5
Mean value	56,07%	70,92%	70,56%	84,35%	89,76%	89,83%	89,93%	91,69%	78,23%	89,33%	139,3%	133,3%	113,8%	117,5%
Standard deviation	34,53%	31,90%	28,52%	29,82%	31,42%	31,22%	30,95%	26,53%	17,13%	27,51%	4,33%	7,30%	5,79%	12,77%
AR(1)	0,605	0,707	0,767	0,893	0,856	0,916	0,887	0,940	0,936	0,986	0,783	0,929	0,768	0,706
AR(2)	0,592	0,645	0,658	0,780	0,705	0,807	0,776	0,845	0,625	0,965	0,832	0,778	1,000	0,659
AR(3)	0,424	0,592	0,618	0,707	0,595	0,698	0,665	0,744	0,629	0,950	0,360	1,000	1,000	1,000
29.7.96-30.11.97														
Number of observations	61	61	61	61	61	61	61	61	60	58	53	41	39	40
Mean value	17,71%	21,17%	20,76%	23,52%	24,50%	25,14%	25,34%	25,25%	25,08%	23,57%	21,55%	19,32%	19,16%	19,07%
Standard deviation	6,27%	6,42%	5,99%	8,17%	8,81%	9,65%	10,40%	10,12%	11,04%	9,18%	6,36%	4,22%	3,82%	3,51%
AR(1)	0,257	0,759	0,783	0,955	0,967	0,977	0,981	0,932	0,980	0,984	0,969	0,959	0,948	0,769
AR(2)	-0,107	0,692	0,656	0,924	0,939	0,952	0,950	0,922	0,947	0,957	0,926	0,899	0,862	0,676
AR(3)	0,014	0,647	0,572	0,897	0,913	0,932	0,924	0,919	0,928	0,933	0,876	0,778	0,724	0,547
1.12.97-16.8.98														
Number of observations	36	37	37	37	37	37	37	37	37	37	37	37	36	28
Mean value	29,04%	27,48%	28,77%	30,45%	31,85%	32,40%	32,13%	32,66%	32,56%	33,04%	32,39%	31,54%	30,30%	28,96%
Standard deviation	21,20%	15,58%	16,33%	15,41%	16,62%	15,86%	14,34%	14,61%	13,20%	13,49%	12,51%	11,23%	9,72%	8,13%
AR(1)	0,627	0,485	0,630	0,495	0,558	0,668	0,765	0,806	0,835	0,820	0,856	0,861	0,850	0,926
AR(2)	0,362	0,152	0,291	0,198	0,338	0,457	0,575	0,644	0,687	0,669	0,734	0,741	0,736	0,865
AR(3)	0,233	0,105	0,194	0,182	0,325	0,461	0,544	0,601	0,642	0,649	0,681	0,716	0,757	0,841

Table 2.2.

	Interval, number of observations	**Dickey-Fuller test**	**Phillips-Perron test**	**Enders-Granger test**	**Asymmetry of the process**
Y1W	12.9.94–16.8.98, 205	-4,60	-4,74	18,52	34,24
Y2W	5.7.94–16.8.98, 206	-2,26*	-3,38	15,13	20,65
Y1M	12.7.93–16.8.98, 266	-3,41*	-5,44	1,14*	1,74**
Y2M	12.7.93–16.8.98, 266	-3,25*	-3,73	2,79*	5,34
Y3M	12.7.93–16.8.98, 266	-1,84*	-2,49	8,11	24,59
Y4M	18.4.94–16.8.98, 226	-1,91*	-2,37*	2,38*	6,31
Y5M	18.4.94–16.8.98, 226	-1,96*	-2,27*	4,00	10,26
Y6M	6.2.95–16.8.98, 184	-2,24*	-2,62*	1,32*	0,91**
Y7M	17.6.96–16.8.98, 113	-0,40*	-1,60*	4,39	9,70
Y8M	11.11.96–16.8.98, 92	-0,45*	-0,81*	12,78	31,65
Y9M	25.11.96–16.8.98, 90	-0,42*	-0,32*	5,82	11,73
Y10M	3.2.97–16.8.98, 80	-0,07*	-0,69*	7,64	19,50
Y11M	24.2.97–9.8.98, 76	-1,27*	-1,71*	4,49	13,87
Y12M	24.2.97–12.7.98, 72	-0,19*	-0,24*	3,82*	9,79

* The unit root hypothesis is not rejected at 5 per cent significance level.
** The hypothesis about the asymmetry of the process is rejected at 5 per cent significance level.

Table 2.3.

	Y1W	**Y2W**	**Y1M**	**Y2M**	**Y3M**	**Y4M**	**Y5M**	**Y6M**	**Y7M**	**Y8M**	**Y9M**	**Y10M**	**Y11M**	**Y12M**
Test statistics	-3,97	-3,57	-3,17	-3,47	-2,91	-4,35	-2,02	-1,75	-1,03	-0,21	-0,67	-0,34	-0,72	-0,29
Critical values (5%)	-2,51	-3,48	-3,48	-3,48	-3,48	-3,49	-2,91	-2,91	-3,59	-3,61	-3,65	-3,69	-3,69	-0,71

Table 2.4*.

	Number of observations	**Mean value**	**Standard deviation**		**Number of observations**	**Mean value**	**Standard deviation**
f(1,2)	265	68,90%	40,49%	*f*(2,7)	127	41,20%	27,00%
f(2,3)	264	72,89%	43,69%	*f*(3,8)	104	32,94%	22,25%
f(3,4)	208	63,77%	45,77%	*f*(4,9)	97	33,33%	29,48%
f(4,5)	196	60,06%	43,88%	*f*(5,10)	83	30,70%	25,71%
f(5,6)	194	62,84%	47,32%	*f*(6,11)	80	28,45%	19,68%
f(6,7)	122	38,36%	29,58%	*f*(7,12)	67	22,40%	6,16%
f(7,8)	101	31,66%	21,72%	*f*(1,7)	127	41,05%	27,00%
f(8,9)	89	26,52%	20,11%	*f*(2,8)	104	33,14%	22,66%
f(9,10)	78	24,26%	14,03%	*f*(3,9)	97	33,97%	30,67%
f(10,11)	75	24,10%	13,62%	*f*(4,10)	80	27,20%	17,95%
f(11,12)	66	22,05%	11,95%	*f*(5,11)	78	27,33%	17,58%
f(1,3)	262	70,81%	40,75%	*f*(6,12)	71	25,35%	16,47%
f(2,4)	212	64,07%	42,37%	*f*(1,8)	104	33,04%	22,74%
f(3,5)	220	62,99%	40,32%	*f*(2,9)	97	34,39%	31,44%
f(4,6)	190	59,22%	39,60%	*f*(3,10)	83	31,02%	25,85%
f(5,7)	124	40,92%	29,76%	*f*(4,11)	78	28,01%	20,88%
f(6,8)	104	31,78%	22,20%	*f*(5,12)	70	25,42%	18,34%
f(7,9)	88	26,23%	10,57%	*f*(1,9)	97	34,44%	31,62%
f(8,10)	77	23,68%	6,72%	*f*(2,10)	83	31,53%	27,01%
f(9,11)	75	23,10%	5,90%	*f*(3,11)	80	30,38%	24,66%
f(10,12)	65	21,30%	6,35%	*f*(4,12)	73	28,78%	24,20%

	Number of observations	Mean value	Standard deviation		Number of observations	Mean value	Standard deviation
$f(1,4)$	211	62,65%	40,42%	$f(1,10)$	83	31,81%	28,06%
$f(2,5)$	221	64,47%	40,62%	$f(2,11)$	80	30,24%	23,64%
$f(3,6)$	213	63,49%	39,17%	$f(3,12)$	73	29,33%	25,19%
$f(4,7)$	124	40,46%	26,80%	$f(1,11)$	80	30,25%	23,75%
$f(5,8)$	103	31,92%	20,70%	$f(2,12)$	73	29,47%	25,12%
$f(6,9)$	94	29,78%	24,89%	$f(1,12)$	73	29,66%	25,35%
$f(7,10)$	76	25,07%	7,80%	$f(1)$	1658	54,36%	42,18%
$f(8,11)$	74	23,62%	5,84%	$f(2)$	1417	51,43%	38,55%
$f(9,12)$	67	21,93%	4,82%	$f(3)$	1183	48,37%	36,56%
$f(1,5)$	222	63,62%	39,69%	$f(4)$	982	45,51%	34,80%
$f(2,6)$	213	63,95%	39,19%	$f(5)$	771	41,11%	32,03%
$f(3,7)$	126	40,44%	26,20%	$f(6)$	557	32,43%	24,02%
$f(4,8)$	103	32,20%	21,83%	$f(7)$	432	30,81%	24,76%
$f(5,9)$	95	30,90%	24,62%	$f(8)$	333	31,50%	27,30%
$f(6,10)$	82	28,42%	21,08%	$f(9)$	236	30,51%	25,65%
$f(7,11)$	74	24,14%	7,01%	$f(10)$	153	29,88%	24,34%
$f(8,12)$	67	22,11%	5,02%	$f(11)$	73	29,66%	25,35%
$f(1,6)$	213	63,28%	38,46%				

* FN is a fîrward rate for N months calculated across all possible combinations of bill maturity terms.

Table 2.5.**

	Y1M	Y2M	Y3M	Y4M	Y5M	Y6M	Y7M	Y8M	Y9M	Y10M	Y11M
17.5.93-28.7.96											
Equality of mean values	7,53	2,53	2,20	2,19	4,25	5,52	17,33	6,30	12,28	5,36	0,43*
Equality of variances (Bartlett)	56,68	19,11	16,40	17,56	28,77	33,66	17,98	12,00	6,89*	3,18*	2,01*
Equality of variances (Levene)	2,34	2,73	2,40	2,45	3,43	4,29	2,63	3,22	3,20*	5,53	9,87
Equality of variances (Brown-Forsythe)	1,59*	1,70*	1,75*	2,01*	2,72	3,63	1,02*	1,12*	1,52*	0,91*	1,12*
29.7.96-30.11.97											
Equality of mean values	5,85	5,94	6,77	7,72	9,17	10,41	10,66	8,04	3,13	0,04*	0,01*
Equality of variances (Bartlett)	268,63	267,60	309,39	327,24	271,16	263,13	225,42	137,66	24,25	1,82*	0,17*
Equality of variances (Levene)	13,44	14,82	17,88	19,78	19,94	21,54	23,83	18,36	14,79	2,49*	0,51*
Equality of variances (Brown-Forsythe)	8,12	8,28	10,22	12,19	12,69	14,27	16,24	14,62	10,71	1,18*	0,24*
1.12.97-16.8.98											
Equality of mean values	2,69	2,79	2,24	2,07	1,46*	1,24*	1,18*	1,11*	0,87*	0,69*	0,34*
Equality of variances (Bartlett)	59,06	71,58	70,85	48,87	39,61	37,94	27,65	19,75	10,80	4,91*	1,27*
Equality of variances (Levene)	3,08	4,08	4,83	4,58	5,03	5,17	4,70	4,26	3,48	2,82*	1,97*
Equality of variances (Brown-Forsythe)	1,51*	1,89	2,23	1,92*	2,06	2,00*	1,82*	1,70*	1,32*	1,12*	0,92*

* The hypothesis about the equality is not rejected at 5 per cent significance level.

** The table contains values of statistics of tests for equality of the mean value (ANOVA F-test, see: Johnston, DiNardo, 1997) and of variance (Bartlett's test, Levene test, Brown-Forsythe test, see: ñì. Judge, Griffiths, Hill, Luetkepohl, Lee, 1985) of two and more samples. Since different tests for the equality of variance are of different power across cases, we show statistic values for all three cases.

Table 3.1.

	Ì Â	**M0**	**M2**	**BM**
D(Y1W)	0,128	0,045	-0,017	-0,012
D(Y1M)	0,051	0,011	-0,027	0,067
D(Y3M)	-0,098	-0,085	-0,300	-0,042
D(Y6M)	-0,184	-0,140	-0,432	-0,182
D(Y9M)	-0,201	-0,111	-0,479	-0,201

Figure 3.1.

Δ ÌÂ$\Rightarrow \Delta i$ $\Delta M0 \Rightarrow \Delta i$ $\Delta M2 \Rightarrow \Delta i$ $\Delta BM \Rightarrow \Delta i$

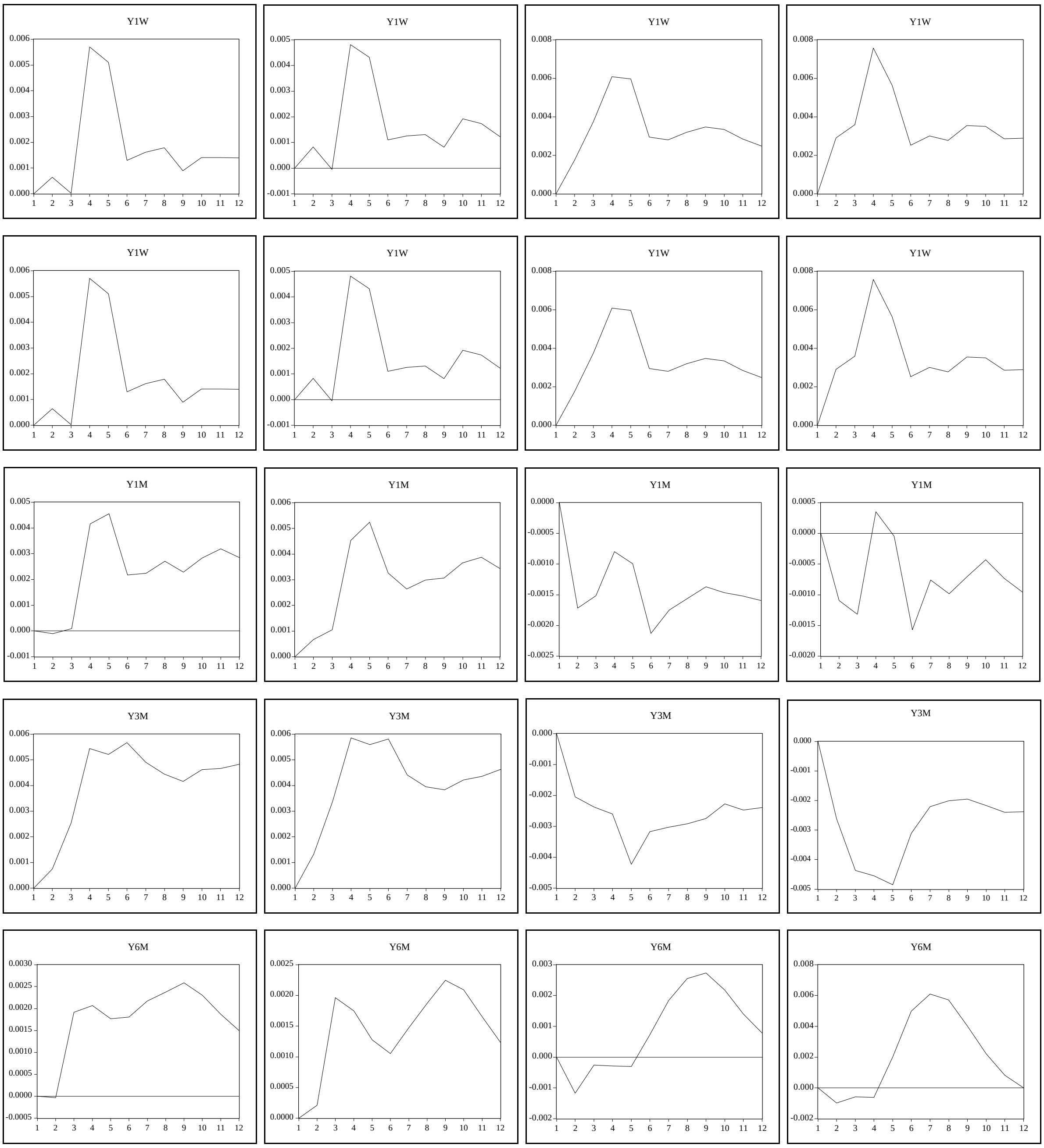

Figure 3.1 (continued).

Δ ÌÂ⇒Δ*i* ΔM0⇒Δ*i* ΔM2⇒Δ*i* ΔBM⇒Δ*i*

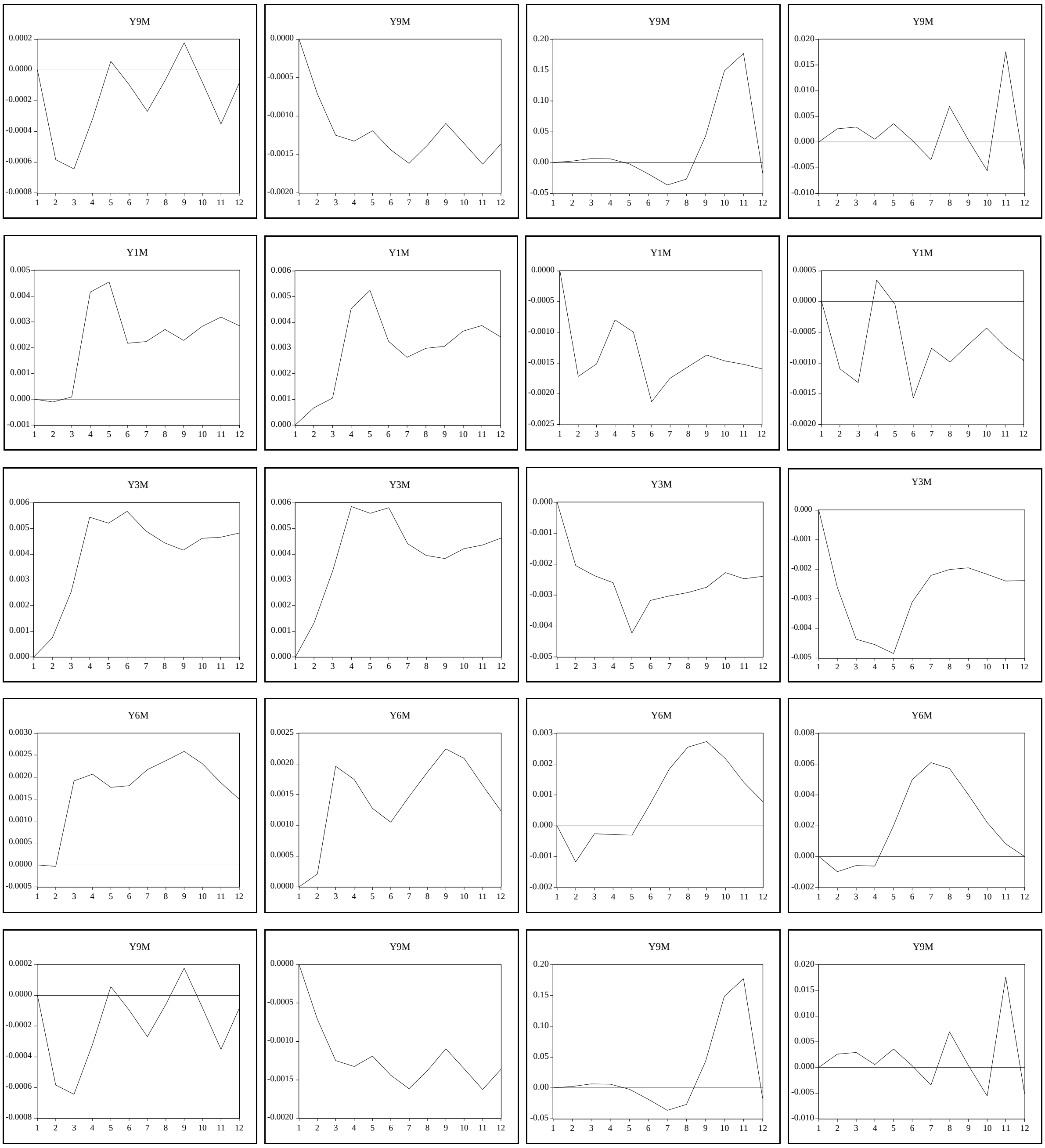

Figure 3.2.

Δ ÌÂ⇒Δ*i* ΔM2⇒Δ*i*

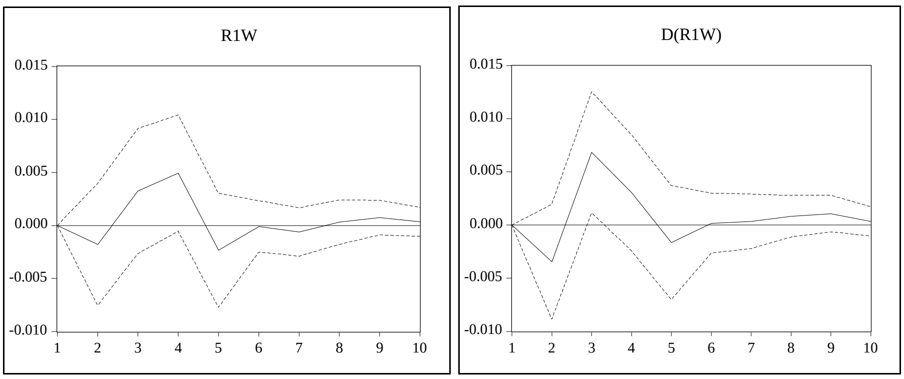

Figure 3.2.

Δ ÌÂ⇒Δ*i* ΔM2⇒Δ*i*

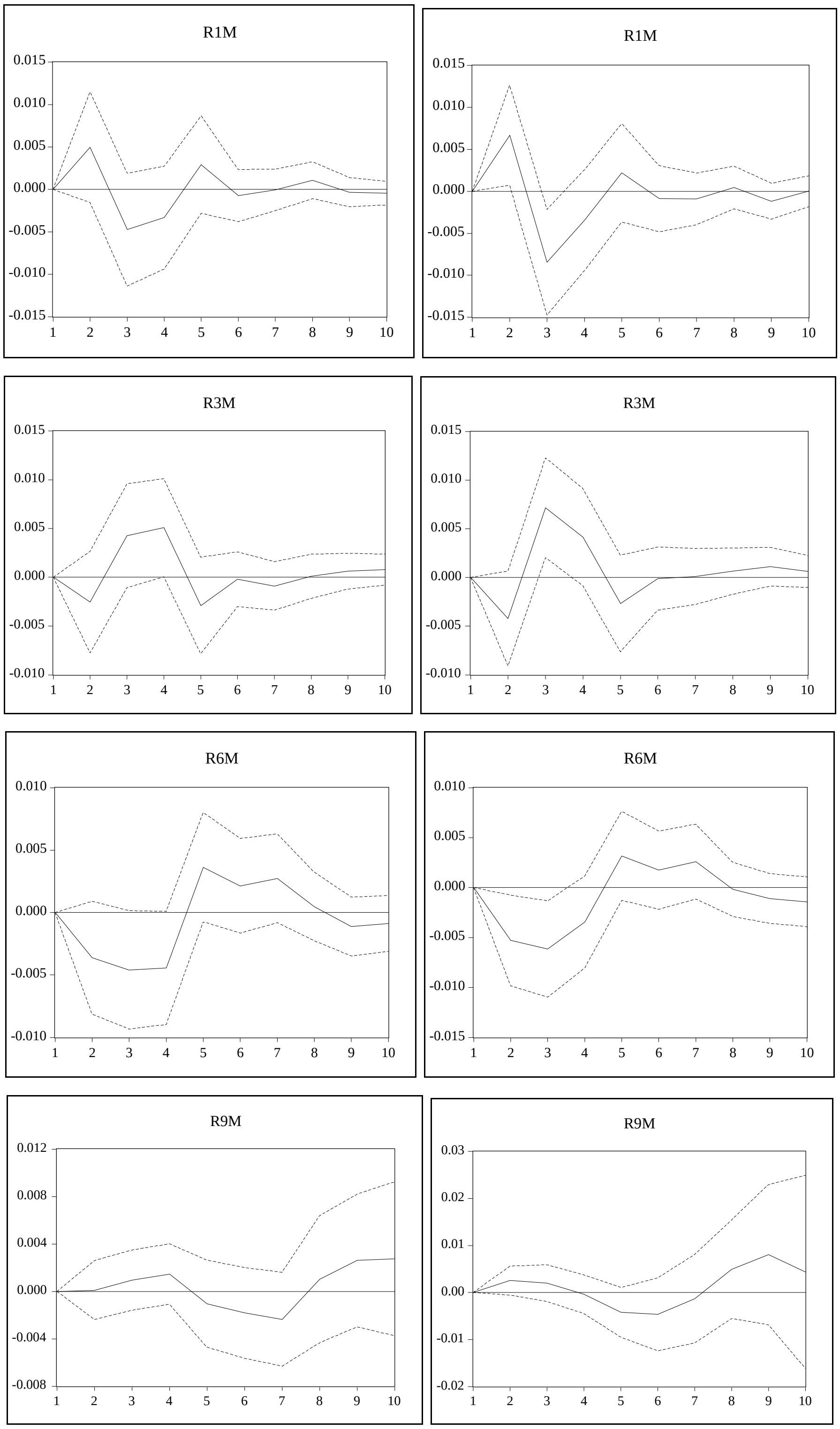

Figure 3.3.

Δ ÌÂ⇒ ΔM2⇒

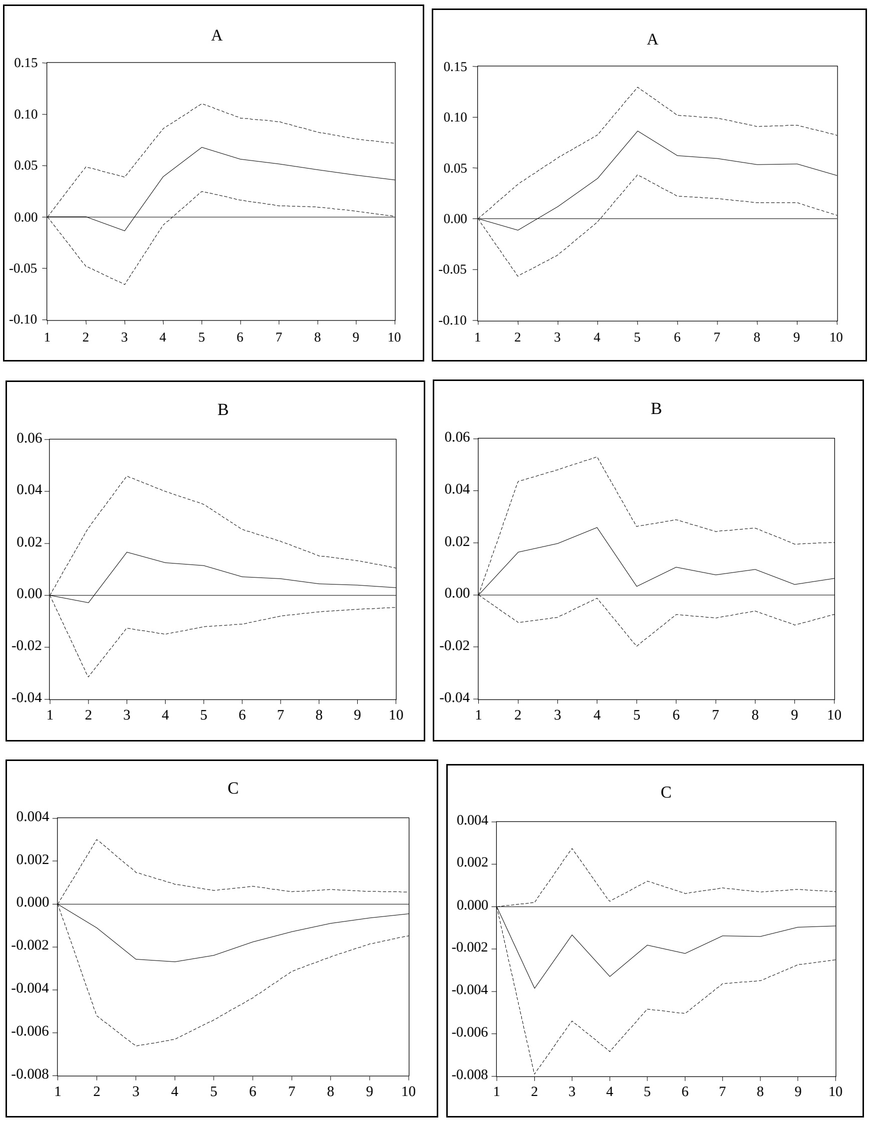

Table 4.1.

Eigenvalue	Likelihood Ratio	Critical value (5%)	Critical value (1%)	Hypothesized No. of CE(s)
0,405358	175,5429	94,15	103,18	0**
0,308326	107,9694	68,52	76,07	≤ 1**
0,245381	60,04607	47,21	54,46	≤ 2**
0,091644	23,44565	29,68	35,65	≤ 3
0,079716	10,95014	15,41	20,04	≤ 4
0,001158	0,150589	3,76	6,65	≤ 5
L.R. test indicates 3 cointegrating equations at 5% significance level.				
*(**) denotes rejection of the hypothesis at 5%(1%) significance level.				

*Table 4.2**.

Dependent variable	Explanatory variable	*a*	*b*	$H_0: a=0, b=1$	R^2
$i_{t+4}(1)-i_t(1)$	$f_t(1,2)-i_t(1)$	-0,076 (-2,63)	0,470 (8,78)	132,15**	0,335
$i_{t+9}(1)-i_{t+4}(1)$	$f_t(2,3)-i_{t+4}(1)$	-0,068 (-1,64)	0,398 (11,37)	312,28**	0,458
$i_{t+13}(1)-i_{t+9}(1)$	$f_t(3,4)-i_{t+9}(1)$	-0,076 (-2,09)	0,230 (5,71)	408,43**	0,235
$i_{t+18}(1)-i_{t+13}(1)$	$f_t(4,5)-i_{t+13}(1)$	-0,048 (-1,42)	0,275 (6,57)	320,91**	0,345
$i_{t+22}(1)-i_{t+18}(1)$	$f_t(5,6)-i_{t+18}(1)$	-0,029 (-0,97)	0,081 (2,88)	1107,89**	0,220
$i_{t+9}(2)-i_t(2)$	$f_t(1,3)-i_t(2)$	-0,038 (-0,86)	0,764 (9,45)	9,74**	0,659
$i_{t+13}(2)-i_{t+4}(2)$	$f_t(2,4)-i_{t+4}(2)$	-0,090 (-1,86)	0,664 (18,34)	92,04**	0,676
$i_{t+18}(2)-i_{t+9}(2)$	$f_t(3,5)-i_{t+9}(2)$	-0,061 (-1,40)	0,472 (12,21)	193,13**	0,650
$i_{t+22}(2)-i_{t+13}(2)$	$f_t(4,6)-i_{t+13}(2)$	-0,016 (-0,21)	0,294 (7,11)	292,15**	0,698
$i_{t+13}(3)-i_t(3)$	$f_t(1,4)-i_t(3)$	-0,048 (-0,90)	0,910 (11,55)	2,21	0,766
$i_{t+18}(3)-i_{t+4}(3)$	$f_t(2,5)-i_{t+4}(3)$	-0,024 (-0,42)	0,734 (16,35)	35,89**	0,774
$i_{t+22}(3)-i_{t+9}(3)$	$f_t(3,6)-i_{t+9}(3)$	0,014 (0,14)	0,613 (11,29)	50,79**	0,804
$i_{t+18}(4)-i_t(4)$	$f_t(1,5)-i_t(4)$	-0,044 (-0,70)	0,458 (2,76)	11,43**	0,856
$i_{t+22}(4)-i_{t+4}(4)$	$f_t(2,6)-i_{t+4}(4)$	-0,020 (-0,22)	0,813 (15,14)	12,12**	0,887
$i_{t+22}(5)-i_t(5)$	$f_t(1,6)-i_t(5)$	0,181 (1,24)	0,809 (7,61)	4,96	0,897

* *t*-statistics in parenthesis.
** The hypothesis is rejected at 5 per cent significance level.

Table 4.3.*

	Mean value	Standard deviation	ADF	PP	r_1	r_2	r_3	Q(16)
$s(1,2)$	0,112	0,150	-6,23	-10,04	0,580	0,111	0,202	379,73
$s(1,3)$	0,149	0,195	-4,35	-8,62	0,616	0,063	0,171	351,44
$s(2,4)$	0,046	0,102	-3,30	-4,49	0,799	0,171	-0,137	464,14
$s(3,6)$	0,020	0,105	-4,28	-7,51	0,520	-0,162	0,031	68,15
$s(1,6)$	0,147	0,188	-2,57**	-4,76	0,695	0,173	0,103	459,84
$\Phi(1,2)$	0,170	0,276	-4,93	-8,23	0,621	0,107	0,114	277,77
$\Phi(1,3)$	0,077	0,245	-4,71	-6,99	0,643	-0,078	-0,021	165,63
$\Phi(2,3)$	0,207	0,402	-3,28	-5,74	0,731	-0,010	0,123	377,67
$\Phi(3,4)$	0,182	0,446	-3,38	-3,88	0,710	0,120	0,151	351,65
$\Phi(3,6)$	0,062	0,345	-1,86**	-2,69**	0,813	-0,053	0,136	475,86
$H(1,1)$	0,722	0,813	-4,11	-5,30	0,858	0,143	-0,040	937,00
$H(1,3)$	1,403	3,641	-3,43	-3,87	0,819	-0,241	-0,142	233,58
$H(2,1)$	0,631	0,756	-3,80	-4,12	0,888	0,177	0,137	1042,30

	Mean value	Standard deviation	ADF	PP	r_1	r_2	r_3	Q(16)
$H(3,1)$	0,538	0,802	-3,36	-3,61	0,859	0,030	-0,049	556,63
$H(3,3)$	0,782	1,420	-2,25**	-3,43	0,793	0,142	-0,028	399,41

* ADF – the Augmented Dickey-Fuller test statistics, PP– the Phillips-Perron test statistics, r_1, r_2, r_3 – first three coefficients of the serial correlation, Q(16) - the Box-Lyung test statistics (the number of lags is 16).

** The unit root hypothesis is not rejected at 5 per cent significance level.

Table 4.4.*

	$s(1,2)$	$\Phi(2,3)$	$H(1,1)$
Form of conditional variance	GARCH-M(1,1) $s_t(1,2) = c + as_{t-1}(1,2) + l s_t + e_t$ $s(e)_t^2 = d + ae_{t-1}^2 + bs_{t-1}^2 + h_t$	TARCH-M(1,1) $\Phi_t(2,3) = c + a\Phi_{t-1}(2,3) + l s_t + e_t$ $s(e)_t^2 = d + ae_{t-1}^2 + bs_{t-1}^2 + ge_{t-1}^2 d_{t-1} + h_t$ $d_t = \begin{cases} 1, e_t < 0 \\ 0, e_t \ge 0 \end{cases}$	GARCH(1,1) $H_t(1,1) = c + aH_{t-1}(1,1) + bH_{t-2}(1,1) + e_t$ $s(e)_t^2 = d + ae_{t-1}^2 + bs_{t-1}^2 + h_t$
l	0,657 (6,05)	0,281 (2,71)	–
d	$2{,}64\cdot 10^{-5}$ (0,78)	0,000 (1,83)	0,000 (0,59)
a	0,356 (7,04)	0,192 (2,37)	0,789 (6,25)
b	0,736 (28,86)	0,716 (22,99)	0,533 (10,37)
g	–	0,368 (2,38)	–
R^2	0,441	0,564	0,742

* *t*-statistics in parenthesis.

Table 4.5.*

	$s(1,2)$	$\Phi(2,3)$	$H(1,1)$
ñ	0,423 (0,15)	0,352 (0,00)	0,131 (5,62)
a_t	-0,312 (-34,22)	-0,597 (-2,14)	0,061 (0,114)
$s^2(e)$	0,022 (5,06)	$1{,}60\cdot 10^{-27}$ ($9{,}58\cdot 10^{-50}$)	0,034 (5,09)
$s^2(h)$	$3{,}13\cdot 10^{-20}$ ($3{,}57\cdot 10^{-35}$)	0,078 (36,26)	0,281 (9,37)

* *t*-statistics in parenthesis. For coefficient a_t the statistics of its mean value is shown.