

INFLATION EXPECTATIONS MODELING: THE APPLICATION OF MARKOV SWITCHING AUTOREGRESSION

The shift of the monetary policy framework in Ukraine has led to the transformation of the power of the key transmission channels. Inflation targeting (IT) assumes the interest rates channel as the main one; besides that, since the exchange rate is floating, the influence from the key policy rate change on it is stronger and more effective. Implementation of the IT at the end of 2016 significantly affected the prices; in particular, the inflation has slowed down from almost 60 % in the corresponding month of the previous year to 2.3 % in 2020. Specifically, the interaction between the key policy rate, which is the main monetary policy instrument under the IT, consumer prices, and economic growth has changed. One of the important channels is the inflation expectations channel that became influential after IT has started. Consequently, the article is aimed to investigate how inflation expectations are dependent on the inflation dynamics, the key policy rate changes, and the index of the real wage fluctuations applying Markov switching autoregression model with two regimes, which is widely used to estimate the effects of economic crisis, break of the trend, and instability. The developed model consists of two equations, one of which defines a regime with the high volatility, and the other with the low. The obtained results show the dominance of the high volatility regime during almost all the research period because of essential inflation uncertainty and the overall unstable situation in the country caused by the crisis. Additionally, probability to stay in the first regime is much higher than in the second and is equal to 91 %. Outcomes from the modelling allow to judge about the future inflation and inflation expectations dynamics based on discovered new features. The further steps in the evaluation of effects of monetary policy regimes shift are expansion of the model to three- or four-regime switch (high, low, moderate volatility, etc.), the use of additional independent variables, experiments with the key policy rate, and inflation as dependent variables.

Keywords: inflation expectations, Markov switching model, monetary policy, inflation, monetary regimes

JEL classification: E42, E58, C34

Introduction and research problem. Price stability for most central banks of the world is a priority goal of monetary policy. It is important due to the fact that high inflation leads to a decrease in the income and savings of business, population and state on the one hand, and on the other, uncontrollable inflation causes an increase in production costs, in the cost of loans and their servicing, and in interest rates due to uncertainty about the future price level. Significant fluctuations in inflation create an unfavorable environment for attracting long-term investment in the economy, because investors focus on short-term operations. Thus, high and volatile inflation has a negative impact on economic growth. Following the success of developed countries, which have been using inflation targeting for a long time to keep the prices table and low, a large number of emerging countries have moved from a fixed exchange rate to the inflation targeting framework.

The switch of the monetary regime from the fixed exchange rate to inflation targeting leads to

change of the power of the transmission channels, in particular it is usual that inflation expectations and interest rates channels become more significant. Typically, the decision to change the monetary policy vector is triggered by crisis phenomena that make it impossible to continue to support the fixed exchange rate due to the lack of international reserves. By the way, it became the main reason for Ukraine to switch the regime, so since December 2016, the National Bank of Ukraine (NBU) has adopted the inflation targeting as new monetary policy framework with the aim to decrease high and volatile inflation mostly provoked by the rise in price of imported goods due to the significant devaluation of the exchange rate (from 8 UAH/USD to 25 UAH/USD). Under the IT policy makers manage the key policy rate based on forward-looking future inflation trends evaluation. The key rate becomes a benchmark for market players, in particular helping to understand the central bank's subsequent policy direction. The perception of the

current market situation, policy of the NBU and future prospects can be measured by the inflation expectations of economic agents, in particular banks, analysts, households etc. Due to this fact, investigation of inflation expectations is gaining special interest, namely its interaction with the key policy rate changes as an indicator of the understanding of the policymaker's steps and decisions from the one side, and from the other with the inflation, which represents the actual macroeconomic situation. Therefore, taking into consideration the importance of formulating monetary policy aimed at supporting financial stability and economic development in the short and medium term, the main research problem is to estimate the dependence of the inflation expectations from the key policy rate and inflation during the periods of high (before IT) and low volatility (after IT).

Recent publications analysis. High and volatile inflation is the source of concern of the most central banks of the world. Great variety of the models are used for inflation investigation and forecasting, one of them is traditional early warning models, which came mainly from the field of prediction of financial, banking and currency crisis (Duprey & Klaus, 2017). This type of modelling tools can be classified into three big groups: a) discrete models, which are based on transformation of variables into the probabilities of the default or crisis (Bussière & Fratzscher, 2006); b) regression trees, which are based on the numerical calculations define the most relevant variables in the form of decision-tree (Frankel & Wei, 2004); c) signaling models, where variables which deviate from its "normal" level defined as warning signals (Kaminsky et al., 1998).

The comparative advantage of the regression trees and discrete models is a possibility to estimate many variables in one model while signaling approach allows working only with one indicator at a time. More specifically, discrete models possess a flexible tool, which can be estimated using classical methods and supplementary tests to choose the most suitable explanatory variables. One of the types of discrete models is the widely used Markov models with switching modes. The Markov nonlinear models proposed by Hamilton in 1989 are taken for granted. The Markov model includes several equations to evaluate the behavior of time series under the different regimes; furthermore, it is easy to use, because it does not call for additional assumptions on timing of the crisis phenomena. The probabilities being in one (with low volatility) or the other (with high volatility) state usually can be set as a hidden Markov chain. Traditionally, Markov regressions with switching components

applied in case of modelling cyclical behaviour, for example, GNP as in Hamilton (1989), stock prices, sales, exchange rates, or the data with exact, visible trend breaking in the time-series.

Applying Bayesian methods Davig and Doh (2009) estimated a few types of the Markov-switching New Keynesian (MSNK) models on U.S data. They found out that a four-regime model with unconstrained regime changes and two shock-volatility regimes gives more sufficient results, in particular it is a better fit to the data than two regime models with the switching mechanism allowed only either for the shock volatility or monetary policy. Based on the developed MSNK model, researchers proved a significant impact of the monetary policy regime shift on inflation persistence; at the same time, switches in the volatility also have a meaningful impact on the perseverance of prices.

Similar approach has been used by Amisano and Fagan (2010) to develop a model with a money-based early warning indicator for switching inflation regimes. In this study, inflation was modelled as a process defined by the two regimes, one with high volatility, and the other with low, where the shift depends only on the lagged money growth. Estimates made on the Canada's, the Euro area's, US's, UK's, and Germany's data provide confirmation that money growth really gives warning signals of a switch of the inflation regime from low to high and vice versa (Amisano & Fagan, 2010). Besides that, five years later Nasr, Balcilar, Ajmi et al. (2015) showed a positive determinant effect between the inflation and inflation uncertainty, employing MS-VAR model, but Granger test confirmed the causality only from inflation to inflation uncertainty (Nasr et al., 2015). Therefore, inflation can be driven by its own past volatility, not exceptionally by other factors such as broad money or the key policy rate.

Over and above, Markov switching models are widely used for various types of the estimations including inflation volatility (Davig & Doh, 2009; Amisano & Fagan, 2010; Nasr et al., 2015), sustainability of the current account (Bazhenova, 2018), corporate yield spreads (Dionne et al., 2011), and modelling the impact of changing monetary regimes on the financial and economic development of transition economies (Lukianenko & Zhuk, 2011) etc.

Unsolved parts of the problem. Despite a large number of publications dedicated to the estimation, modelling, and forecasting of inflation and inflation expectations, the question of studying the dependence of inflation expectations on changes in the key policy rate and the current inflation within different monetary frameworks remains relevant. There are numerous macroeconomic models aimed to

investigate inflation, but they are classically developed on the data that cover either inflation targeting or a fixed exchange rate period. So, it has become due to date to estimate the effect of the monetary policy conduction on inflation expectations and inflation covering the period before and after shift of the monetary regime in one single model.

Research goal and questions. The purpose of the article is to evaluate the influence of the inflation and key policy rate on inflation expectations during two regimes using a Markov switching model. The outcomes of the investigation may be applied for defining a combination of instruments to conduct reasonable and rational monetary policy aimed at maintaining price stability.

Main findings. The switching regression models are the linear ones with nonlinearities, which eventuate from the discrete change of the regime. This type of models allows two options, with simple and Markov switching. The model with switching mechanism presumes two (or more) different regressions related to each of the regimes, for example first describes state with the high volatility, second with moderate, and third with low. Dynamic specifications are applicable in case of using a lagged dependent variable as explanatory one, what lead to occurrence of auto-correlated errors.

Supposing that the process which variable of interest y_t is following depends on some unobserved state (or regime) denoted as s_t , there are M possible regimes, and the process is assumed to be in the state m in period t , so $s_t = m$, for $m = 1, \dots, M$.

Markov switching autoregression (MSAR) firstly used in Sclove (1983), became an important extension of the classic Markov switching models especially for analyzing economic time series such as GDP. In MSAR hidden Markov chain is included in the model with a random shift of the regime:

$$Y_t - \mu_{s_t} = \delta_1 (Y_{t-1} - \mu_{s_{t-1}}) + \dots + \delta_p (Y_{t-p} - \mu_{s_{t-p}}) + \varepsilon_t,$$

where $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$.

Markov switching is an extended form of simple framework, which assumes that probability being in current state depends on the previous one, so estimated probabilities are:

$$P(s_t = j | s_{t-1} = i) = p_{ij}(t).$$

The probabilities are time-invariant, so $p_{ij}(t) = p_{ij}$ for all t , and may be written as transition matrix

$$P(t) = [p_{11}(t) \dots p_{1M}(t) \dots p_{M1}(t) \dots p_{MM}(t)],$$

where the ij -th element shows the probability of transition from regime i in the period $(t - 1)$ to regime j in period t .

Both models with Markov and simple switching traditionally parametrize the probabilities as a multinomial logit for each row i of the matrix

$$p_{ij}(G_{t-1}, \delta_i) = \frac{\exp(G_{t-1}' \delta_{ij})}{\sum_{s=1}^M \exp(G_{t-1}' \delta_{is})},$$

where G_{t-1} denotes vector of exogenous observables, δ_{ij} – coefficients; for $j = 1, \dots, M$ and $i = 1, \dots, M$ with the normalized.

Commonly Markov models apply to constant probabilities, so that G_{t-1} in the model usually consists only with the constant as described in Hamilton (1989) on the example of GDP modelling. However, the alternative approach also takes place in Diebold, Lee, and Weinbach (1994), the scientists successfully used time-varying logistic parametrized probabilities in the model with two states.

Based on the literature review and research purposes for the inflation expectations modelling two-state Markov model was chosen. The analysis is based on the monthly frequency data and captures the period from January 2013 to November 2019. The variables are inflation expectations, consumer price index, key policy rate and index of real wage. The error variance is assumed to be different across the regimes. The model satisfies all the adequacy criteria, in particular inverse AR roots lying inside the unit circle, with coefficients statistically significant, residuals normally distributed, etc.

The estimated Markov model has two regimes with the state-specific error variances (LOG(SIGMA)), which allows heteroskedasticity across the regimes. The specified equations for regimes 1 and 2 presented in Table 1. Inflation expectations depend on its own lagged value, inflation (CPI), key policy rate (KPR) and index of real wage (IRW). Officially published CPI dynamics influences economic agent's considerations about the further inflationary processes, also they take into account their own estimates of future economic situation (Lukianenko & Faryna, 2016). Besides that, inflation expectations may be driven by own previous values, which are included in the model as an autoregressive component common for both regimes. An increase in inflation in the current period by 1 % leads to a hike of inflation expectations in the first and second regimes by 0.12 % and 0.25 % respectively.

An important component, which also determines inflation expectations is the level of the key policy rate, since judgments about future price are defined

Table 1. Markov Switching Model estimation results

№	Specification of the equation	DW stat.
1	$Infl_exp_t = 9,1\alpha_t + 0,87infl_exp_{t-1} + 0,12Inflation_t - 0,45D(KPR_{t-2}) + 0,07D(IRW_{t-2})$ <p style="text-align: center;">(9005,5) (6615,9) (1067,0) (-188,6) (563,7)</p> $LOG(SIGMA)=0.25$	2,16
2	$Infl_exp_t = 8,8\alpha_t + 0,87infl_exp_{t-1} + 0,25Inflation_t + 0,16D(KPR_{t-2}) + 0,16D(IRW_{t-2})$ <p style="text-align: center;">(10395,4) (6615,9) (1630,7) (629,6) (1089,6)</p> $LOG(SIGMA)=-7.18$	

Source: author's estimates based on calculations in EViews 10

where $Infl_exp_t$ – inflation expectations on 12 months ahead, in %; $Inflation_t$ – consumer price index to the corresponding month of the previous year, in %; KPR_t – key policy rate, in percentage points; IRW_t – index of real wage; D – first differences; z-statistic in parentheses; $SIGMA$ – standard deviation.

Table 2. Matrix of constant transition probabilities

Number of regime	1	2
1	0,91	0,09
2	0,67	0,33
Constant expected durations		
For all periods	11,32	1,49

Source: author's estimates based on calculations in EViews 10

by the type of monetary policy (quantitative easing or tight conditions). The key policy rate according to the NBU's data fully influences inflation only after 9-18 months, but inflation expectations are more sensitive to the decisions of the central bank, so the key rate is used in the model with a smaller lag. In addition, a sample was taken from 2013, despite the fact that the inflation targeting regime was actually implemented in 2016, respectively, the expectation channel was weaker until the shift of monetary regime. A raise of the key policy rate by 1 percentage point in the first regime contributes to a decrease in inflation expectations by 0.45 %, and in the second leads to its increase by 0.16 % (this effect is possible due to a synchronous increase of the discount rate and inflation expectations during the last crisis).

The real wage index is an indicator of macroeconomic conditions in the country, which also should be taken into account. The one-point index's increase leads to a hike in inflation expectations by 0.07 % in the first regime and 0.16 % in the second. Considering past crises, economic agents tend to associate wage increases with further rise of prices.

Markov switching models provide unique instruments, which allow to conduct analysis of probabilities being in one or another regime. Based on the obtained values of logarithmic standard deviation, it was defined that the first equation describes a regime with a high volatility and the second with low. In the Table 2 below the probability matrix and the expected durations

being in regime are shown. The probability to stay in the first regime is 91 %, and to go to the second – 9 %. It is possible to stay in the second regime with much smaller probability than in the first regime – 33 %, while at the same time the probability to go from the second to the first regime is 67 %. Therefore, the system more likely remains in the first mode. This also confirms by the duration of the regimes, the first lasts 11 months, and the second only 1.5 months in average.

Fig. 1 displays the smoothed probabilities being in regime one and two in comparison with the real data on inflation expectations. As was mentioned earlier, the first regime defines more significant volatility than the second. From the beginning of 2013 and to the end of 2015 inflation expectations have been rising dynamically that is why during this period the first regime dominated. In the stabilization period in 2016, accompanied by a fall in prices due to rigid monetary policy, the second regime prevailed. Later, 2017–2018 were mostly indicated as high volatility years, and last quarter of 2019 characterized by the rapid changes of regimes.

An important criterion of the quality of the designed model is how accurate it reproduces the real time-series, which are taken as the basis of modelling. Figure 2 shows inflation expectations calculated using the developed model in comparison with the real data. The accuracy of the model may be measured using the Mean Absolute Percentage Error (MAPE). This indicator for the inflation expectations obtained from the Markov switching

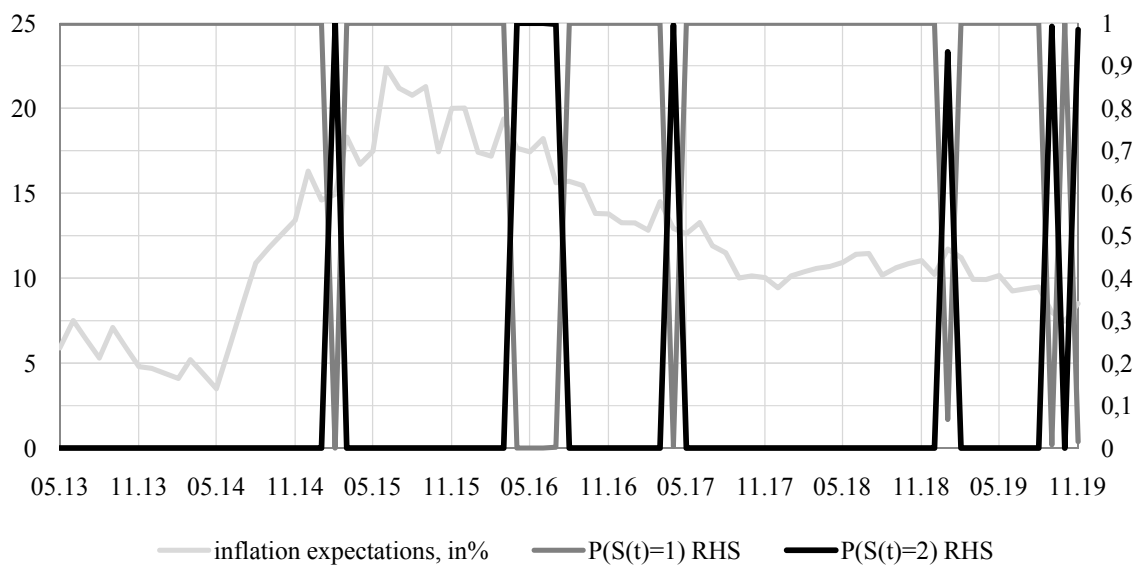


Fig. 1. Markov Switching Smoothed Regime Probabilities comparing with inflation expectations dynamics
Source: author’s estimates based on calculations in EViews 10

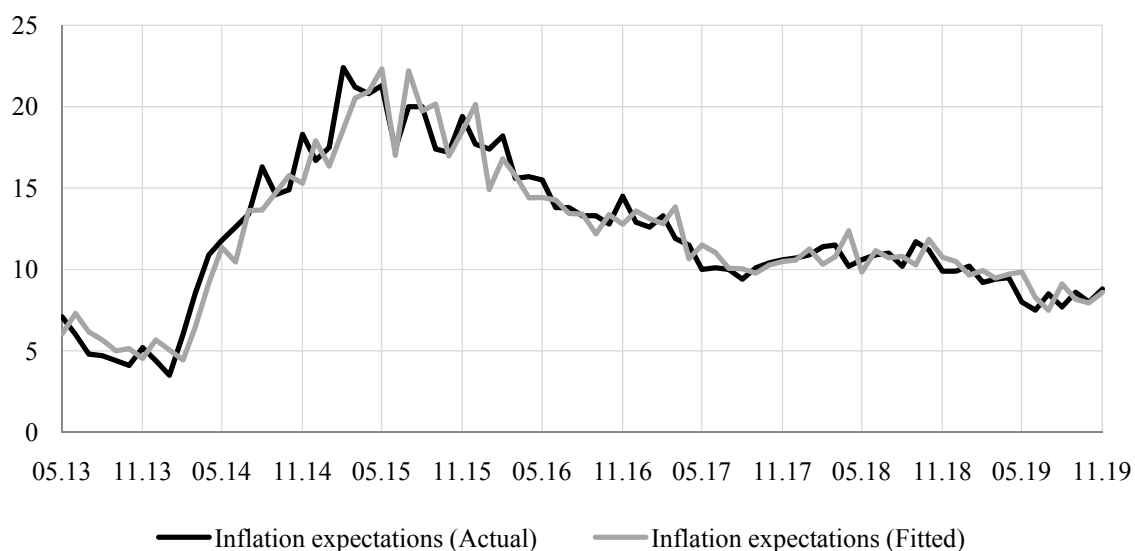


Fig. 2. Inflation expectations: calculated on the basis of the model (fitted) vs actual data
Source: author’s estimates based on calculations in EViews 10

model is equal to 9.52 %, which allows to conclude that the model provides very exact results, since MAPE is under 10 %.

Therefore, the designed model provides reliable outcomes, allows judging about periods of high and low volatility of inflation expectation, and what is also essential estimate elasticities between variables and probabilities being in one or another regime. Applying to modelling with two regimes gives the possibility to replicate the real situation of shift from fixed exchange rate to inflation targeting. Besides that, a developed Markov model may be used for forecasting, since it satisfies MAPE criterion.

Conclusions and further research proposals.

Conducted wide analysis of literature dedicated to the examining of monetary policy during different monetary regimes and application of modern macroeconomic modelling has revealed that Markov switching approach is the most suitable to answer the research question about sensitivity of inflation expectation to the key policy rate and inflation. The model allows defining the probability of switching the regime – from high to low volatility and vice versa; for example probability to be in first with the high volatility regime is equal to 91 %. Besides that, the duration of each regime can be defined; in particular a high volatility state lasts for

11 month, and the other one with low fluctuations of inflation expectations only for 1 month. There are various types of the models which potentially can be used to replicate the break of the trend, but based on the research results described in the Hamilton (1989), Amisano and Fagan (2010), Davig and Doh (2009) Markov switching approach allows to take into account both several regimes and autoregression component together with unlimited number of independent variables.

During the investigated period regime, which assumes high volatility of inflation expectations has dominated due to the significant inflation uncertainty provoked by the crises and switch of the monetary framework. Significance of all the coefficients in both equations testifies to the explicit accuracy of the model. Relying on own calculations it can be argued that one of many, but a powerful and explicit method of estimating dynamics of inflation expectations in Ukraine is Markov switching autoregression. The main

advantages of this type of models in comparison with the other modelling tools are the ability to have separate regimes for high and low volatility, calculate the durations of the regimes and at the same time define the elasticities between variables. Specifically, all this information obtained from the model is important for policymakers to make effective and reasonable decisions in the field of monetary policy.

In the future, it would be advisable to refine the model by expanding the sample. Moreover, since inflation and inflation expectations in Ukraine are unstable, volatile and sensitive to the external destabilizing factors it is due to date to try specifications with three or four regimes. Also, with the aim of estimation the consequences of the switch from fixed exchange rate to inflation targeting will be relevant to experiment with the different dependent variables in the framework of Markov model approach, specifically with inflation and key policy rate.

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МОДЕЛЮВАННЯ ІНФЛЯЦІЙНИХ ОЧІКУВАНЬ НА ОСНОВІ МАРКІВСЬКОЇ АВТОРЕГРЕСІЙНОЇ МОДЕЛІ З ПЕРЕМИКАЧАМИ

Впровадження Національним банком інфляційного таргетування (ІТ) наприкінці 2016 р. значно вплинуло на інфляційні процеси в Україні, зокрема, інфляція сповільнилася з майже 60 % у середині 2015-го до 2,3 % у 2020 р. До того ж канал інфляційних очікувань став більш значущим, що актуалізувало потребу поглибленого аналізу механізму його дії, а також основних факторів впливу на інфляційні очікування. Метою статті є проведення емпіричного аналізу динаміки інфляційних очікувань, а також дослідження впливу на неї таких важливих показників, як інфляція, облікова ставка та індекс реальної заробітної плати, на основі застосування сучасного економетричного інструментарію, зокрема Марківської авторегресійної моделі з двома режимами. Основними особливостями обраного модельного інструментарію є можливість виокремлення двох станів – з високою волатильністю інфляційних очікувань та з низькою, а також оцінювання ймовірностей переходу між ними з розрахунком тривалості кожного зі станів, що значно підвищує цінність та практичну значущість отриманих результатів моделювання для підтримки ухвалення фінансових управлінських рішень. Побудована та оцінена на реальних даних економетрична модель складається з двох рівнянь, одне з них визначає режим із високою волатильністю, а друге – з низькою. Отримані результати розрахунків свідчать про домінування режиму високої волатильності протягом майже всього періоду дослідження через істотну невизначеність щодо інфляції та нестабільну ситуацію в країні загалом, спричинену кризою. Зокрема, інфляційні очікування протягом 2013–2019 рр. характеризувалися високою волатильністю з ймовірністю 91 %, водночас утриматись у стані помірних коливань було ймовірно лише на 33 %. Режим високої волатильності згідно з розрахунками на основі розробленої моделі триває значно довше, ніж період помірних та низьких коливань інфляційних очікувань, а саме 11 місяців, тоді як тривалість низької волатильності в середньому становить близько одного місяця. Загалом, розрахунки на основі Марківської авторегресійної моделі з перемикачами дають змогу детальніше дослідити динаміку інфляційних процесів в Україні, наприклад, визначити ймовірність переходу від одного режиму до іншого, розрахувати їхню тривалість, отримати значення еластичностей між залежною та незалежними змінними тощо. Подальші дослідження щодо оцінювання наслідків зміни режимів грошово-кредитної політики на цінову стабільність можуть базуватись на ускладненій версії Марківської моделі, а саме з трьома або чотирма перемикачами для високої, низької, помірної волатильності тощо. Крім того, можливе проведення експериментів із використанням додаткових незалежних змінних з метою підвищення точності розробленої моделі та її застосування для дослідження й прогнозування широкого спектра монетарних показників, зокрема облікової ставки та інфляції.

Ключові слова: інфляційні очікування, Марківська модель із перемикачами, грошово-кредитна політика, інфляція, монетарні режими.

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