Exchange Rate Considerations for Inflation Targeting Policies in Resource-Rich Countries

Arsenii Mishin
HSE University

January 2021

Abstract

The paper develops a theoretical model of an open economy to examine the role of the exchange rate for conducting inflation targeting policy. The relative importance of the exchange rate in the policy function and the parameter that characterizes the pass-through effect of the exchange rate on inflation determine the conditions under which the central bank becomes constraint in stabilizing inflation. The model does not confirm the hypothesis of optimality in meeting the inflation target only. On the empirical side, the paper presents a vector error-correction model estimated on Russian monthly data 2002:1 – 2013:4 to study long-run (cointegrated) relationships between inflation, output, exchange rate, real interest rate, and foreign reserves. I find that depreciation/appreciation of the nominal effective exchange rate by 1% leads to an increase/decrease in inflation by 0.44%. I provide evidence that a long-lasting importance of the exchange rate in policy objectives was the main factor that prevented the Central Bank of Russia to attain its stated inflation target.

Introduction:

Nowadays, many central banks give priority to inflation stabilization for monetary policy. They consider it as best practice to adopt inflation targeting as the nominal anchor. Svensson (2010) reviews the history, theory, practice, and future of inflation targeting. He points out that inflation targeting is never "strict" but always "flexible", in the sense that all inflation-targeting central banks do not only stabilize inflation around the inflation target, but also put some weight on stabilizing the real economy. For instance, they implicitly or explicitly account for a measure of resource utilization, such as the output gap between actual output and potential output.

At the same time, models of inflation targeting usually put zero weight on the exchange rate. These frameworks describe central banks as floaters which make price stability as the primary stated objective of the policy. Commitment to the inflation target enhances credibility. However, the recent advice from IMF challenges this view. Blanchard (2012) recommends that policymakers should use foreign exchange interventions for inflation targeting policy.

Countries care about their exchange rate for many reasons. The standard literature recognizes that the exchange rate affects the competitiveness of the exporting sector of the economy which can be a great source of revenue collection by the government, especially in export-oriented countries. From a different perspective, emerging market economies usually rely on capital inflows and external finance. Thus, unexpected movements in the financial account can lead to exchange rate variations, which then pose additional threats for financial stability. In the light of the global financial crisis, there is a growing literature on how the policy under inflation targeting regime relates to financial stability (Woodford (2012), King (2012)). The literature relates the stability of the exchange rate to one of the indicators of financial stability. This consideration particularly applies to emerging market economies.

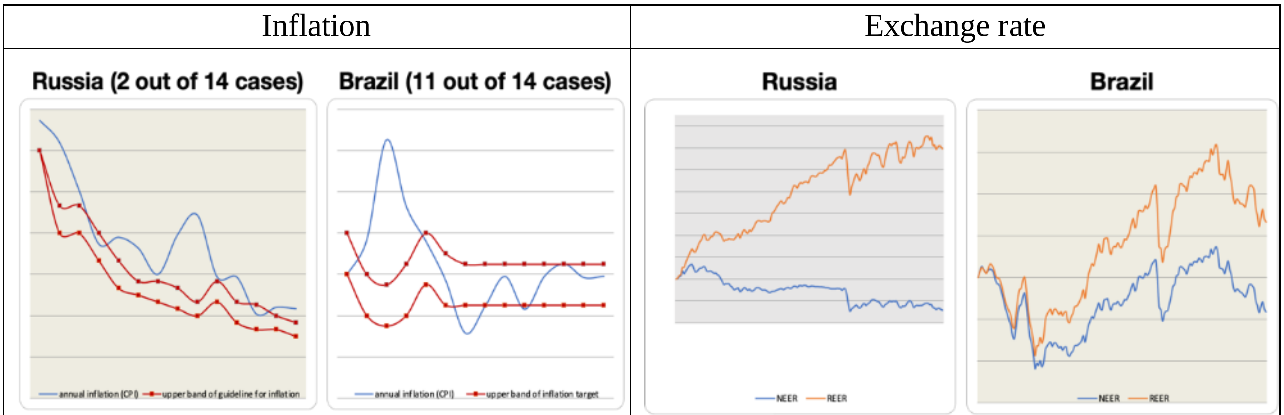
However, Canzoneri and Cumby (2014) develop a two-country DSGE model with imperfect substitutability of bonds and analyze the Ramsey optimal intervention policies under different monetary policy regimes. They provide some cautionary evidence about using foreign exchange interventions unless an appropriate intermediate exchange rate target can be identified. How seriously should inflation-targeting central banks take the exchange rate into consideration? It is an open question of the current research.

Motivation and a Question:

Let's consider two countries: Russia and Brazil. They are both emerging market economies with similar export-oriented structures. They have prioritized decreasing the rate of inflation since 2000. But they have different exchange rate regimes which affect their policies toward inflation stabilization. Before 2013, Russia used a managed floating exchange rate regime and took certain steps to inflation targeting by setting some medium-term guidelines for inflation. In contrast, Brazil has a freely floating exchange rate regime, and has officially adopted inflation targeting since June 1999.

The following two figures show the dynamics of inflation and the domestic exchange rate in two countries. Both Russia and Brazil set their inflation targets in the form of a range/tolerance interval. It has been usually about $\pm 2\%$ of a stated inflation target. The red line reflects this upper range (target value $+ 2\%$). We can see that Brazil succeeded in 11 out of 14 cases when its realized inflation lay within the stated range, while Russia achieved its inflation objective only in 2 out of 14 cases. At the same time, the exchange rate reveals the type of the exchange rate policy adopted by each of the central banks. Although Russia had used a managed floating exchange regime, its real effective exchange rate depreciated by a greater amount compared to Brazil's situation. This is because there are larger differences in inflation rates with its trading partners.

My primary question is: how and to what extent does the exchange rate policy of emerging market economies affect the incentives of a central bank to meet its stated inflation priority? I focus on resource-rich countries in which central banks have incentives to fine-tune their exchange rate for influencing the competitiveness of their export sector. Answering my question has clear implications for designing macroeconomic policies.



Sources: The Central Bank of Russia, The Central Bank of Brazil

Sources: Bank for International Settlements (basket of currencies comprising 61 countries) where $NEER = \frac{foreign\ basket\ of\ currencies}{1 unit\ of\ domestic\ currency}$, $REER = \frac{NEER \cdot P}{P^*}$, so in this formulation of the exchange rate an increase/decrease means appreciation/ depreciation of the domestic currency

Part I Theoretical model of monetary policy:

In this part I am going to propose a theoretical model in which the central bank follows two contradictory objectives: decreasing inflation to the earlier announced level and stabilizing the exchange rate due to large currency earnings inflows and hence the desire for not losing the competitiveness of the exporting sector of the economy. This model is relatively simple and can be used as a starting point to more rigorous analysis but it can still illustrate some important mechanisms. The model will examine the effectiveness of the type of monetary policy on the basis of the relative direction in pursuing either the inflation target or the exchange rate target. It will also identify conditions when it becomes optimal to change the relative direction of the chosen policy to one of its targets.

Let's consider a model of an open economy in which every period the central bank makes its decision about its instruments of monetary policy concerning the effects on inflation, output gap and exchange rate stability. Assume that targets are exogenously given. This can reflect the commitment to the targets which are set on a medium term basis, and hence they are results of a previous choice. Another possible intuition for this assumption is that the central bank uses short period targets (for example, monthly targets) which should be achieved for longer period targets (for example, yearly targets).

Let's define the variables as follows:

Variable	Name	Notes
y_t	log of real GDP	-
r_t	real interest rate	-
R_t	nominal interest rate	superscript * means foreign (exogenous variable)
e_t	log of nominal effective exchange rate	# units of domestic currency per 1 foreign basket of currencies
p_t	log of domestic price level	superscript * means foreign (exogenous variable)
q_t	log of real effective exchange rate	$q_t = e_t + p_t^* - p_t$
u_{yt}	exogenous output shock (change in productivity)	$\sim (0; \sigma_y^2)$
DC_t	log of domestic credit	from assets side of the central bank's balance sheet
FX_t	log of foreign reserves	-
m_t^d	log of real domestic money demand	-
m_t^s	log of real domestic money supply	-
u_{mt}	exogenous money market shock	$\sim (0; \sigma_m^2)$
$u_{\pi t}$	exogenous inflation shock	$\sim (0; \sigma_\pi^2)$
π_t	domestic inflation rate	$\pi_t = p_t - p_{t-1}$
π_t^*	foreign inflation rate	exogenous variable

Model parameters

IS curve: $$y_t = \alpha - \alpha_r \cdot r_t + \alpha_q \cdot q_t + u_{yt} \quad (1)$$

Central bank's balance sheet: $$m_t^s = DC_t + FX_t \quad (2)$$

Money demand: $$m_t^d = \beta + \beta_y \cdot y_t - \beta_r \cdot r_t - \beta_e \cdot e_t + u_{mt} \quad (3)$$

Money market equilibrium: $$m_t^s = m_t^d \quad (4)$$

Phillips curve in an open economy: $$\pi_t = \gamma_y \cdot \Delta y_t + \gamma_e \cdot \Delta e_t + \gamma_{SI} \cdot (\Delta DC_t - \Delta FX_t) + u_{\pi t} \quad (5)$$

Central bank's loss function: $$L_{t+1} = \left(\Delta\pi_{t+1} + \pi_t - \pi^{target}\right)^2 + \lambda \cdot \left(\Delta e_{t+1} + e_t - e^{target}\right)^2 \quad (6)$$

where slope coefficients ($\alpha_r, \alpha_q, \beta_y, \beta_e, \beta_r, \gamma_y, \gamma_e, \gamma_{SI}$) are all non-negative and λ shows the weight of the exchange rate relative to inflation in the loss function. Assume that the Marshall-Lerner condition holds, i.e. the sum of imports and exports elasticities is greater than 1, hence the impact of the real exchange rate on output is positive in (1). Here I include the exchange rate into the money demand function because due to dollarization and persistent inflation it is standard that households (especially in emerging markets economies) also hold foreign currency for precautionary motives.

Equation (5) captures both the effects of the exchange rate on the inflation rate (so called pass-through effect measured by γ_e) and the effects of sterilized interventions. So the implicit assumption is that home and foreign bonds are imperfect substitutes with the interest parity condition : $R_t = R_t^* + \Delta e_{t+1}^e + \rho\left(FX_t - DC_t\right)$ where $\rho(\cdot)$ is some increasing function. Therefore, with unchanged expectations of e_{t+1}^e, sterilized interventions depreciate the domestic exchange rate and this adds additional component to inflation reflected by γ_{SI}. Note that this mechanism goes through the exchange rate but I still want to separate these 2 channels for the further analysis.

The central bank has an objective to lower inflation, therefore $\pi_t > \pi^{target}$ in period t. At the same time, appreciation of the exchange rate is not a desirable outcome for the exporting sector and therefore its target is set at the rate which is not lower than the exchange rate in period t. In fact, due to the difference in inflation rates between domestic and foreign countries ($\pi_t > \pi_t^*$) the exchange rate target should be chosen even at a higher level, so $e_t < e^{target}$ is justifiable. This leads to the tradeoff: other things being equal, the required policy of reducing inflation results in the exchange rate appreciation and hence its greater deviation from the target and it increases the loss function. Equation (6) can be seen now as the most questionable assumption because in the standard analysis the output gap is targeted instead of inflation. I will explain this later and we will find out that it is not so strong taking into account the spirit of the model in which the output target can be seen as implicitly stated and be taken into account in the policy.

Using (2), (3) money market equilibrium implies:

$$DC_t = \beta + \beta_y \cdot y_t - \beta_r \cdot r_t - \beta_e \cdot e_t - FX_t + u_{mt} \quad (7)$$

Subtracting the previous period values from the current period value in eq. (1) and (7) we get:

$$\Delta y_t = -\alpha_r \cdot \Delta r_t + \alpha_q \cdot \left(\Delta e_t + \pi_t^* - \pi_t\right) + u_{\Delta yt} \quad (1)'$$

$$\Delta DC_t = \beta_y \cdot \Delta y_t - \beta_r \cdot \Delta r_t - \beta_e \cdot \Delta e_t - \Delta FX_t + u_{\Delta mt} \quad (7)'$$

Here I used the definition $q_t = e_t + p_t^* - p_t$. Substitute (7)' for ΔDC_t into (5) and express inflation in terms of Δy_t, Δr_t, ΔFX_t and Δe_t:

$$\pi_t = (\gamma_y + \beta_y \gamma_{SI}) \cdot \Delta y_t - \beta_r \gamma_{SI} \cdot \Delta r_t - 2\gamma_{SI} \cdot \Delta FX_t + (\gamma_e - \beta_e \gamma_{SI}) \cdot \Delta e_t + (u_{\pi t} + \gamma_{SI} u_{\Delta mt}) \tag{8}$$

Using (1)' substitute it for Δy_t into (8) to get:

$$\pi_t = \begin{array}{l} -\dfrac{(\alpha_r(\gamma_y + \beta_y\gamma_{SI}) + \beta_r\gamma_{SI})}{1+\alpha_q(\gamma_y + \beta_y\gamma_{SI})} \cdot \Delta r_t + \dfrac{(\alpha_q(\gamma_y + \beta_y\gamma_{SI}) + \gamma_e - \beta_e\gamma_{SI})}{1+\alpha_q(\gamma_y + \beta_y\gamma_{SI})} \cdot \Delta e_t + \\ + \dfrac{\alpha_q(\gamma_y + \beta_y\gamma_{SI})}{1+\alpha_q(\gamma_y + \beta_y\gamma_{SI})} \cdot \pi_t^* - \dfrac{2\cdot\gamma_{SI}}{1+\alpha_q(\gamma_y + \beta_y\gamma_{SI})} \cdot \Delta FX_t + \dfrac{(\gamma_y + \beta_y\gamma_{SI}) \cdot u_{\Delta yt} + (u_{\pi t} + \gamma_{SI} u_{\Delta mt})}{1+\alpha_q(\gamma_y + \beta_y\gamma_{SI})} \end{array} \tag{9}$$

Therefore, it can be rewritten as:

$$\pi_t = \omega_r \cdot \Delta r_t + \omega_e \cdot \Delta e_t + \omega_{FX} \cdot \Delta FX_t + \omega_{\pi^*} \cdot \pi_t^* + \eta_{\pi t}, \tag{9'}$$

where all coefficients follow (9) and it is expected that $\omega_r < 0,\ \omega_e > 0,\ \omega_{FX} < 0,\ \omega_{\pi^*} > 0$

This equation describes inflation rate in terms of the monetary policy instruments. Note that it is innocuous to use the real exchange rate instead of the nominal one because using the Fisher's equation $R_t = r_t + \pi_t^e$ and assumption of rational expectations $\pi_t = \pi_t^e$ we can rewrite (9)' in terms of R_t after some adjustment of coefficients.

The objective of the central bank is to minimize the stated loss function subject to (9)'. Let's take expectation at time t for period t+1 equation (9)':

$$E_t\pi_{t+1} = \omega_r \cdot E_t\Delta r_{t+1} + \omega_e \cdot E_t\Delta e_{t+1} + \omega_{FX} \cdot E_t\Delta FX_{t+1} + \omega_{\pi^*} \cdot E_t\pi_{t+1}^* + E_t\eta_{\pi t+1} =$$
$$= \omega_r \cdot E_t\Delta r_{t+1} + \omega_e \cdot E_t\Delta e_{t+1} + \omega_{FX} \cdot E_t\Delta FX_{t+1} + \omega_{\pi^*} \cdot E_t\pi_{t+1}^*$$

To ease the notation let's agree on that all variables with index t+1 are equivalent to ones with mathematical expectation at time t for period t+1. Therefore, the central bank follows the rule:

$$\pi_{t+1} = \omega_r \cdot \Delta r_{t+1} + \omega_e \cdot \Delta e_{t+1} + \omega_{FX} \cdot \Delta FX_{t+1} + \omega_{\pi^*} \cdot \pi_{t+1}^* \tag{10}$$

Let's denote $A_{t+1} = \omega_r \cdot \Delta r_{t+1} + \omega_{FX} \cdot \Delta FX_{t+1} + \omega_{\pi^*} \cdot \pi_{t+1}^*$ and hence (10) can be rewritten as:

$$\pi_{t+1} = A_{t+1} + \omega_e \cdot \Delta e_{t+1} \tag{11}$$

Here ω_e is a generalized pass-through effect of the exchange rate on inflation. Let's return back to the assumption for the objective loss function and the possible reasons for the non-inclusion of the output gap target. I want to make the model as tractable as possible for the purpose of the theoretical analysis. I do this through 2 sufficient statistics of λ and ω_e which capture the tradeoff between lowering inflation and stabilizing the exchange rate. In these settings the coefficient A_{t+1} reflects the implicit tradeoff between the three targets including the output gap. So the values of the stated statistics of λ and ω_e should be adjusted for this to convey the spirit of the model. For example, Reyes (2007) reviews the literature which finds out that the pass-through effect depends on the output gap.

Taking the first differential from (6):

$$dL_{t+1} = 2(\pi_{t+1} - \pi^{target}) \cdot d\pi_{t+1} + 2\lambda \cdot (e_{t+1} - e^{target}) \cdot de_{t+1} \tag{13}$$

Let's assume $\begin{array}{l} \Delta\pi_{t+1} \approx d\pi_{t+1} \\ \Delta e_{t+1} \approx de_{t+1} \end{array}$. Then using $\begin{array}{l} \pi_{t+1} = \pi_t + \Delta\pi_{t+1} \\ e_{t+1} = e_t + \Delta e_{t+1} \end{array}$:

$$\Delta L_{t+1} = 2\left(\pi_t + \Delta\pi_{t+1} - \pi^{target}\right)\cdot \Delta\pi_{t+1} + 2\lambda \cdot \left(e_t + \Delta e_{t+1} - e^{target}\right)\cdot \Delta e_{t+1} \quad (13)'$$

The central bank can choose the following types of policies:

I) Policy I: Pursuing inflation target only: $\Delta\pi_{t+1} = \pi^{target} - \pi_t$;

II) Policy II: Pursuing exchange rate target only: $\Delta e_{t+1} = e^{target} - e_t$;

III) Policy III: (combination of both targets): $\Delta\pi_{t+1} > \pi^{target} - \pi_t$; $\Delta e_{t+1} < e^{target} - e_t$.

Let's analyze whether the central bank has incentives to commit to the stated targets and how this result depends on the two stated sufficient statistics.

Theorem 1:

Under the model assumptions the following results can be applied to policies I and II:

1) Policies I and II are not optimal for the minimization of the loss function;
2) Greater λ makes the policy II relatively more effective in terms of decreasing losses;
3) Greater ω_e makes the policy I relatively more effective in terms of decreasing losses.

Proof:

Lemma 1: Under policy II $\dfrac{A_{t+1} - \pi_t}{\omega_e} + \left(e^{target} - e_t\right) > 0$

Proof: Since under this policy inflation increases, i.e. $\pi_{t+1} = A_{t+1} + \omega_e \cdot \Delta e_{t+1} > \pi_t$ where $\Delta e_{t+1} = e^{target} - e_t$, hence $A_{t+1} - \pi_t > -\omega_e \cdot \Delta e_{t+1}$. Therefore, $\dfrac{A_{t+1} - \pi_t}{\omega_e} + \Delta e_{t+1} > \dfrac{-\omega_e \cdot \Delta e_{t+1}}{\omega_e} + \Delta e_{t+1} = 0$. QED

Lemma 2: Under policy II $A_{t+1} - \pi_t + 2\omega_e \cdot \left(e^{target} - e_t\right) > 0$.

Proof: Using the same argument as in lemma 1 we can get $A_{t+1} + \omega_e \cdot \Delta e_{t+1} - \pi_t > 0$. Since $\omega_e > 0$, $\Delta e_{t+1} > 0$, hence $A_{t+1} + 2\omega_e \cdot \Delta e_{t+1} - \pi_t > A_{t+1} + \omega_e \cdot \Delta e_{t+1} - \pi_t > 0$. QED

Let's derive the expected change in losses under two types of policies:

Policy I: In order to achieve the inflation target $\pi^{target} = A_{t+1} + \omega_e \cdot \Delta e_{t+1}$, the exchange rate decreases $\Delta e_{t+1} = \dfrac{\pi^{target} - A_{t+1}}{\omega_e}$. Notice that π^{target} is wittingly less than A_{t+1} otherwise the central bank can increase the exchange rate without changing inflation and according to our assumptions this impossibility is captured by A_{t+1}. So the total change of losses equals:

$$\Delta L_{t+1}^{(I)} = 2\left(\pi^{target} - \pi^{target}\right)\cdot \Delta\pi_{t+1} + 2\lambda \cdot \left(e_t + \frac{\pi^{target} - A_{t+1}}{\omega_e} - e^{target}\right)\cdot\left(\frac{\pi^{target} - A_{t+1}}{\omega_e}\right) =$$

$$= 2\lambda \cdot \left(e^{target} - e_t + \frac{A_{t+1} - \pi^{target}}{\omega_e}\right)\cdot\left(\frac{A_{t+1} - \pi^{target}}{\omega_e}\right) > 0 \quad (*)$$

Here we are using the result of *Lemma 1*.

Policy II: In order to achieve the exchange rate target, inflation increases $\pi_{t+1} = A_{t+1} + \omega_e \cdot \Delta e_{t+1} = A_{t+1} + \omega_e \cdot \left(e^{target} - e_t\right)$. So the total change of losses equals:

$$\Delta L_{t+1}^{(II)} = 2\left(A_{t+1} + \omega_e \cdot \left(e^{target} - e_t\right) - \pi^{target}\right)\cdot\left(A_{t+1} + \omega_e \cdot \left(e^{target} - e_t\right) - \pi_t\right) + 2\lambda \cdot \left(e^{target} - e^{target}\right)\cdot \Delta e_{t+1} =$$

$$= 2\omega_e^2 \cdot \left(e^{target} - e_t + \frac{A_{t+1} - \pi^{target}}{\omega_e} \right) \cdot \left(\frac{A_{t+1} - \pi^{target}}{\omega_e} + \frac{\pi^{target} - \pi_t}{\omega_e} + \left(e^{target} - e_t \right) \right) > 0 \qquad (**)$$

Here we are using the result of *Lemma 1*.

Therefore, pursuing either one of the targets only we find that it results in positive increments in losses. This proves the result 1.

Note that the first bracket is the same for (*) and (**). Therefore, compare:

$$\lambda \cdot \left(\frac{A_{t+1} - \pi^{target}}{\omega_e} \right) \qquad \text{vs} \qquad \omega_e^2 \cdot \left(\frac{A_{t+1} - \pi^{target}}{\omega_e} + \frac{\pi^{target} - \pi_t}{\omega_e} + \left(e^{target} - e_t \right) \right).$$

Obviously, greater λ increases the total losses for policy I, so policy II becomes relatively more effective. This makes the result 2.

In order to analyze the effect of ω_e on the choice of two policies let's consider the following derivatives:

$$\frac{d\left(\lambda \cdot \left(\frac{A_{t+1} - \pi^{target}}{\omega_e} \right) \right)}{d\omega_e} = -\lambda \cdot \left(\frac{A_{t+1} - \pi^{target}}{\omega_e^2} \right) < 0$$

$$\frac{d\left(\omega_e^2 \cdot \left(\frac{A_{t+1} - \pi^{target}}{\omega_e} + \frac{\pi^{target} - \pi_t}{\omega_e} + \left(e^{target} - e_t \right) \right) \right)}{d\omega_e} = A_{t+1} - \pi_t + 2\omega_e \cdot \left(e^{target} - e_t \right) > 0$$

The last inequality follows from *Lemma 2*. This proves the result 3. QED

Theorem 2:

Let $\lambda_{bound} = \frac{\omega_e \left(A_{t+1} - \pi^{target} \right)}{e^{target} - e_t}$ be the boundary value of λ such that it is indifferent for the central bank to pursue the policy directed to either decreasing inflation or depreciating the exchange rate. Let Δe_{t+1}^{opt} be the optimal expected change of the exchange rate in minimization of (6). Under the model assumptions the following results can be applied to policy III:

1) If $\lambda < \lambda_{bound}$ then it becomes relatively more preferable to follow the policy directed to the inflation target. If $\lambda > \lambda_{bound}$ then it becomes relatively more preferable to follow the policy directed to the exchange rate target.
2) If the policy is directed to pursuing the exchange rate target ($\lambda > \lambda_{bound}$), then an increase/decrease in the pass-through effect of the exchange rate on inflation (captured by ω_e) makes that kind of policy less/more desirable, i.e. $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e} < 0$.
3) If the policy is directed to pursuing the inflation rate target ($\lambda < \lambda_{bound}$), then generally we cannot tell whether a change in the pass-through effect of the exchange rate on inflation (captured by ω_e) makes that kind of policy less/more desirable. But we can derive that for a fixed λ it depends on the initial value of ω_e. Let $\lambda_z = \frac{\omega_e^2 \left(A_{t+1} - \pi^{target} \right)}{A_{t+1} - \pi^{target} + 2\omega_e \left(e^{target} - e_t \right)}$ Then for a relatively small ω_e (when $\lambda_z < \lambda$) an

increase/decrease in ω_e makes the policy directed to pursuing the exchange rate target more/less desirable, i.e. $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e} > 0$. And for a relatively large ω_e (when $\lambda_z > \lambda$) the opposite is true, i.e. $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e} < 0$.

Proof: Let's solve the central bank's optimization problem:

$$\begin{cases} L_{t+1} = \left(\pi_{t+1} - \pi^{target}\right)^2 + \lambda \cdot \left(e_t + \Delta e_{t+1} - e^{target}\right)^2 \underset{\Delta e_{t+1}, \pi_{t+1}}{\rightarrow} min \\ s.t. \quad \pi_{t+1} = A_{t+1} + \omega_e \cdot \Delta e_{t+1} \end{cases} \qquad (***)$$

FOC: $\frac{dL_{t+1}}{d\Delta e_{t+1}} = 2\omega_e \cdot \left(A_{t+1} + \omega_e \cdot \Delta e_{t+1} - \pi^{target}\right) + 2\lambda \cdot \left(e_t + \Delta e_{t+1} - e^{target}\right) = 0$

Hence, $\boxed{\Delta e_{t+1}^{opt} = \frac{\omega_e\left(\pi^{target} - A_{t+1}\right)}{\omega_e^2 + \lambda} + \frac{\lambda \cdot \left(e^{target} - e_t\right)}{\omega_e^2 + \lambda}}$

SOC: $\frac{d^2 L_{t+1}}{d\Delta e_{e+1}^2} = 4\omega_e + 2\lambda > 0$. Therefore, it is the global minimum.

Using the result 1 of the Theorem 1: $\boxed{e^{target} - e_t < \Delta e_{t+1}^{opt} < \frac{\pi^{target} - A_{t+1}}{\omega_e}}$. So, if

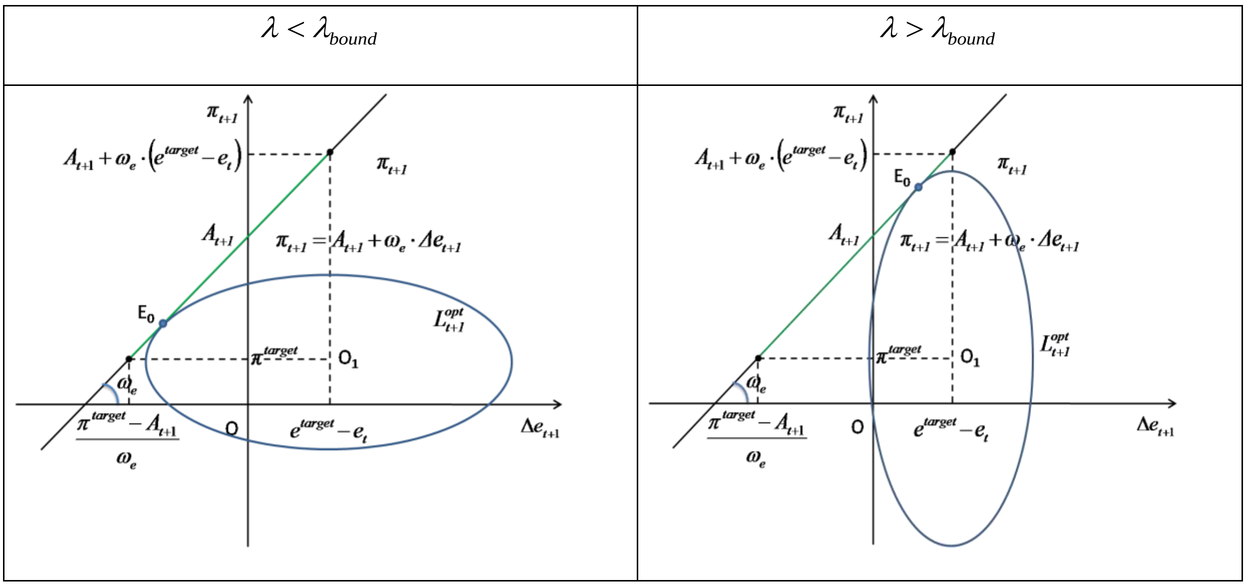
$\Delta e_{t+1}^{opt} < 0$, *following inflation targeting policy is more preferable than following exchange rate targeting*

$\Delta e_{t+1}^{opt} > 0$, *following exchange rate targeting policy is more preferable than following inflation targeting*

We can solve for $\Delta e_{t+1}^{opt} = 0 <=> \frac{\omega_e\left(\pi^{target} - A_{t+1}\right)}{\omega_e^2 + \lambda_{bound}} + \frac{\lambda_{bound} \cdot \left(e^{target} - e_t\right)}{\omega_e^2 + \lambda_{bound}} = 0$. Hence,

$\boxed{\lambda_{bound} = \frac{\omega_e\left(A_{t+1} - \pi^{target}\right)}{e^{target} - e_t}}$. So the result 1 follows accordingly.

Figure 1. Graphical representation of the solution to (***) depending on λ



Let's show this result graphically. Level curves of the objective function are ellipses with the center $(e^{target} - e_t; \pi^{target})$. The parameter λ describes the shape of the curve. The solution to the optimization problem is a tangency point of the constraint in (***) and the corresponding level curve. As can be seen from the figure 1, an increase in λ makes pursuing the policy directed to pursuing the exchange rate target more attractive. Mathematically, $\frac{d\Delta e_{t+1}^{opt}}{d\lambda}=\frac{\omega_e\left(A_{t+1}-\pi^{target}\right)+\omega_e^2\left(e^{target}-e_t\right)}{\left(\omega_e^2+\lambda\right)^2}>0$.

For the result 2 let's calculate $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e}=-\frac{\left(A_{t+1}-\pi^{target}\right)\left(\lambda-\omega_e^2\right)+2\omega_e\lambda\left(e^{target}-e_t\right)}{\left(\omega_e^2+\lambda\right)^2}$.

Let's consider the numerator of this expression at $\lambda=\lambda_{bound}$:

$$\left(A_{t+1}-\pi^{target}\right)\left(\lambda_{bound}-\omega_e^2\right)+2\omega_e\lambda_{bound}\left(e^{target}-e_t\right)\Big|_{\lambda=\lambda_{bound}}=\frac{\omega_e\left(A_{t+1}-\pi^{target}\right)^2}{e^{target}-e_t}+\omega_e^2\left(A_{t+1}-\pi^{target}\right)>0$$

Therefore, when $\lambda>\lambda_{bound}$, $\left(A_{t+1}-\pi^{target}\right)\left(\lambda-\omega_e^2\right)+2\omega_e\lambda\left(e^{target}-e_t\right)>0$. Hence, $-\frac{\left(A_{t+1}-\pi^{target}\right)\left(\lambda-\omega_e^2\right)+2\omega_e\lambda\left(e^{target}-e_t\right)}{\left(\omega_e^2+\lambda\right)^2}=\frac{d\Delta e_{t+1}^{opt}}{d\omega_e}<0$. That proves the result 2.

Figure 2. The effect of an increase in ω_e on the change in the relative priority of the policy $\lambda>\lambda_{bound}$

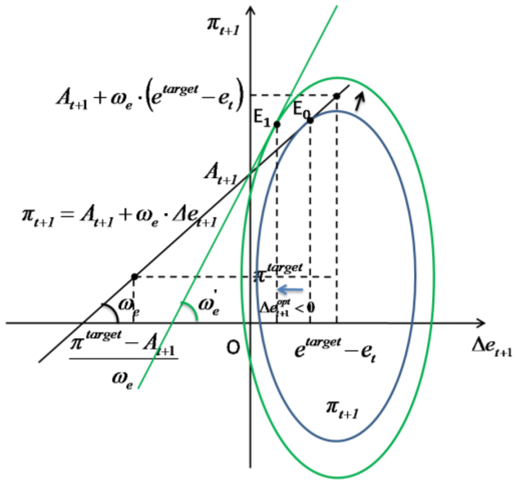


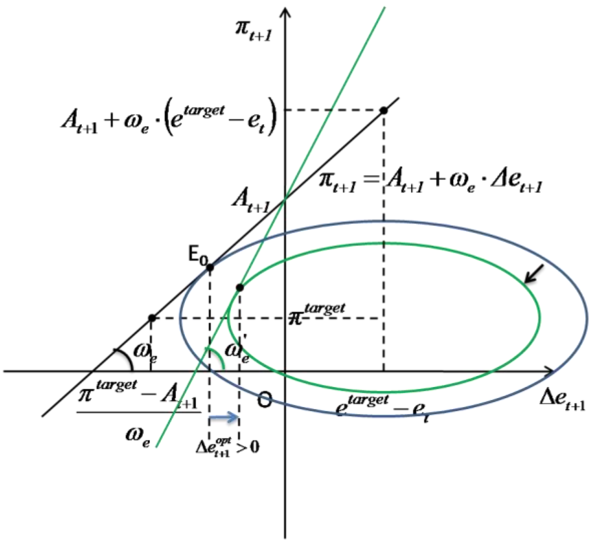
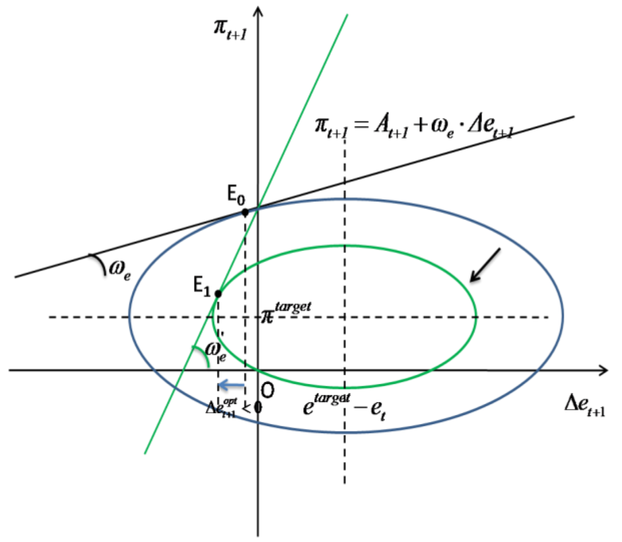
Figure 2 shows this case graphically when there is an increase in the pass-through effect. Note that ω_e can be interpreted as the cost of increasing the exchange rate in terms of additional inflation. So when ω_e increases it becomes less costly to decrease inflation in terms of the exchange rate sacrifice, therefore this increases the attractiveness of pursuing inflation target policy (substitution effect). Moreover, since $\lambda>\lambda_{bound}$ the choice of the initial policy rises its costs making it even less desirable (overall welfare effect). These two effects pointed at the same direction increase the desirability for pursuing the inflation rate target rather than the exchange rate target.

For the result 3 let's find λ_z that makes $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e}=0$. This implies $\lambda_z=\frac{\omega_e^2\left(A_{t+1}-\pi^{target}\right)}{A_{t+1}-\pi^{target}+2\omega_e\left(e^{target}-e_t\right)}$. It is evident that since $A_{t+1}>\pi^{target}$ and $\omega_e>0$ then $\lambda_z<\lambda_{bound}$.

Notice that for $\lambda>\lambda_z$ the following holds $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e}<0$. Moreover, since $\frac{d\lambda_z}{d\omega_e}>0$ the initial value of ω_e makes the result for the preferred direction of the policy if λ is unchanged.

The graphical representation is shown on figure 3. For example, if ω_e is relatively high initially such that $\lambda < \lambda_z$ then an increase in ω_e rises λ_z and hence it is still $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e} > 0$. Intuitively, the described overall welfare effect outweights the substitution effect. At the same time, if ω_e is relatively low initially such that $\lambda > \lambda_z$ then an increase in ω_e rises λ_z and this can make it either greater or still less than λ. In the former the substitution effect outweights the overall welfare effect and hence $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e} < 0$. And the latter is the same as inthe case 1 so $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e} > 0$. QED

Figure 3. The effect of an increase in ω_e on the change in the relative priority of the policy when $\lambda < \lambda_{bound}$

Case1: $\lambda < \lambda_z$ (relatively high initial ω_e)	Case 2: $\lambda > \lambda_z$ (relatively low initial ω_e)
	
$\Delta e_{t+1}^{opt} > 0$	$\Delta e_{t+1}^{opt} < 0$

Model implications:

Besides intuitive results for the effects of the relative importance of the exchange rate in the central bank's objective function (λ) and the pass-through effect (ω_e) on the relative direction in pursuing either the inflation target or the exchange rate target the model and the result of the theorem 2 (part 3) can offer an interesting implication applied to Brazil and Russia. In fact, since the pass-through effect is declining over time under inflation targeting due to fear of floating practices (Reyes (2007)) it becomes relatively less attractive to pursue the policy in the direction to the exchange rate target and hence the central bank has less constraints in lowering inflation. This applies to Brazil. At the same time, Russian situation can be modeled as an economy with relatively higher value of λ and the case 2 on the figure 3 can be applied. So even if ω_e is decreasing over time (due to the transition to inflation targeting) then in the language of the model it is still optimal to pursue the policy in the direction to the exchange rate target and hence there are more constraints in lowering inflation. Commitment issues for the inflation target play an important role here.

Part II Empirical findings:

In this part I am going to estimate the model using theoretical aspects suggested in Part I. I choose equation (8) as a baseline relation where r_t is used instead of Δr_t:

$$\pi_t = \theta_y \cdot \Delta y_t + \theta_r \cdot r_t + \theta_e \cdot \Delta e_t + \theta_{FX} \cdot \Delta FX_t + \varepsilon_{\pi t} \qquad (8)'$$

where coefficients follow (9) and it is expected that $\theta_y > 0, \theta_r < 0, \theta_e > 0, \theta_{FX} < 0,$ and $\varepsilon_{\pi t}$ is an additive inflation shock.

I do the estimation for Russia for the period when monetary authorities used a managed floating exchange rate regime taking some transition steps to inflation targeting by setting some medium-term guidelines for inflation. I give a particular attention to calculate the pass-through effect of the exchange rate on the inflation rate and the relative importance of the exchange rate in the policy implementation.

I use the vector autoregressive (VAR) and vector error-correction (VEC) methodology for estimation purposes to study possible relationships between inflation, output, exchange rate, real interest rate, and foreign reserves. I implement the Granger causality test which asks if the lags of certain variables belong in vector autoregression model. It gives some indication for the direction of variables relations. VEC models are used when the corresponding series are cointegrated which can be tested by the procedure suggested by Johansen (1988). They give additional scope for the analysis of the relationships in the long-run and their interpretation

Data:

I use monthly data 2002:1 – 2013:4. This period captures a transition time to inflation targeting when the exchange rate still played a role in monetary policy. Moreover, the same one person served as chairman of the Central Bank of Russia, so it can exclude some policy shifts and changes in priorities. The sources for the data are Rosstat (Russian statistical agency), Bank of Russia, and Bank for International Settlements (BIS).

As there are no monthly data for real output, I use a proxy of index of industrial production. I take logs of data series for smoothing and consider first differences in variables relative to their values in the previous year (12-month difference) following the theoretical model and for stationarity purposes as well. Therefore, there are 124 observations in total. Stationarity is tested by the Augmented Dickey-Fuller test. The variables are defined as follows:

Variable Name	Theoretical counterpart	Definition	Calculation
CORE_CPI	p_t	Core inflation Index (CII)	-
CORE_CPI_YOY	π_t	Change in CII year to year	$= log(core\_cpi) - log(core\_cpi(-12))$
Y	y_t	Index of Industrial Production (IIP)	-
Y_YOY	Δy_t	Change in IIP year to year	$= log(y) - log(y(-12))$
NEER	e_t	Nominal effective exchange rate	-
NEER_YOY	Δe_t	Change in NEER year to year	$= log(neer) - log(neer(-12))$
R_CORE	r_t	Real interest rate	difference between a weighted average 1-year ruble loan rate and CORE_CPI_YOY
IR	FX_t	International Monetary Reserves	-
IR_YOY	ΔFX_t	Change in IR year to year	$= log(ir) - log(ir(-12))$

INFLATIONF_YOY	π_t^*	Foreign inflation Rate	$\pi_t^* = \Delta q_t + \pi_t - \Delta e_t$
URALS_YOY	π_t^{oil}	Change in "URALS" crude oil price	*= log(urals) - log(urals(-12))*
ID	ID	dummy variable responsible for investment development period	$= \begin{cases} 1, & 2006:7 - 2008:7 \\ 0, & otherwise \end{cases}$
CRISIS	CRISIS	dummy variable responsible for crisis	$= \begin{cases} 1, & 2008:8 - 2009:10 \\ 0, & otherwise \end{cases}$
IT	IT	dummy variable responsible for transition to inflation targeting	$= \begin{cases} 1, & 2009:11 - 2013:4 \\ 0, & otherwise \end{cases}$

Stationarity tests show that overall at 5% and 10% significance level we cannot reject that all the series theoretical counterparts considered in Part I (with underscore YOY in the table above) are non-stationary but integrated of the order 1 (I(1)). Depending on the number of cointegrating vectors it suggests VEC estimation procedure.

Econometric model:

Let's start with unrestricted VAR model which includes 5 endogenous variables π_t, Δy_t, Δe_t, r_t, ΔFX_t following (8)'. Taking into account the oil structure of the economy, the theoretical model, and different macroeconomic stages, I choose π_t^{oil}, π_t^*, ID, CRISIS, and IT as exogenous variables. Time trend is insignificant, so I do not include it into the specification. The order of VAR is chosen by information criteria BIC and AIC and considering additional tests on residuals normality and the presence of ARCH effects. It implies that $p = 4$.

Granger causality tests show that the output and exchange rate Granger causes inflation at 5% significance level. Moreover, the exchange rate and output relate to each other in both directions. International reserves Granger causes the exchange rate that is rather intuitive as accumulation of reserves allows to sterilize excessive revenue from export affecting the exchange rate. Inflation is a Granger cause for both the real interest rate and reserves. Besides, international reserves are influenced by output and real interest rate.

Cointegrating vectors:

Johansen's test depends on the assumptions concerning the deterministic trend. I assume that the variables follow a stochastic trend which incorporates all the random shocks that have permanent effects implied by the Beveridge-Nelson decomposition result. The test shows that we cannot reject the presence of not more than 3 cointegrating vectors at 80% significance level, but we strongly reject the presence of 2 and less at 1% level. So I conclude that there are 3 cointegrating vectors, or in other words there are 2 independent stochastic trends that jointly drive the dynamics of these 5 endogenous variables. Moreover, this conclusion is robust under alternative choice of exogenous parameters.

Then I choose cointegrating relationships using the results of causality tests, economic principles and the model in Part I. It is needed to impose at least 2 zeros restrictions on endogenous parameters in each of equations for identification.

In fact, the general form of the long-run cointegrating inflation equation is given by $\pi_t = \theta_y \cdot \Delta y_t + \theta_r \cdot r_t + \theta_e \cdot \Delta e_t + \theta_{FX} \cdot \Delta FX_t + \varepsilon_{\pi t}$. Granger causality test shows that the output and exchange rate help to predict inflation. It can be explained by changes in import prices in the consumer basket and the Phillips curve result. So let the restrictions be $\theta_r = 0,\ \theta_{FX} = 0$. Hence,

$\pi_t = \theta_y \cdot \Delta y_t + \theta_e \cdot \Delta e_t + \varepsilon_{\pi t}$, where it is expected that $\theta_y > 0, \theta_e > 0$.

Assume that the interest rate follows the Taylor Rule which is here described as:

$$r_t = a \cdot (\Delta y_t - y^*) + b \cdot (\Delta e_t - e^*) + c \cdot (\pi_t - \pi^*) + \varepsilon_{rt}$$

where $a, b, c -$ elasticity parameters and * variables denote targeting values. I consider a more general case with the inclusion of the exchange rate due to reasons described in Part I. As in the theoretical section the objective function of the Central Bank takes into account inflation and exchange rate, so I impose a zero restriction on output. Therefore, the second cointegrating relationship is given by:

$$r_t = a_0 + b \cdot \Delta e_t + c \cdot \pi_t + \varepsilon_{rt},$$

where $a_0 -$ some constant and expected signs are $b < 0, c > 0$.

International reserves are modeled in the third cointegrating equation because it was found before that inflation, output and real interest rate Granger causes reserves. Intuitively, a rise in inflation can lead to a fall in reserves due to smaller real value. An increase in output is related to favorable oil prices, so under the chosen policy the excessive export revenue is sterilized in reserves. The effect of the real interest rate is less obvious or can be captured by both inflation and output, so I will impose a zero restriction on it.

$$\Delta FX_t = d_0 + g \cdot \pi_t + h \cdot \Delta y_t + \varepsilon_{\Delta FXt},$$

where it is expected that $g < 0, h > 0$.

Empirical results, interpretation and impulse response analysis:

The estimated cointegrating equations are described as:

$$\pi_t = 0.087 - \underset{[-2.830]}{0.248} \cdot \Delta y_t + \underset{[6.775]}{0.441} \cdot \Delta e_t$$

$$r_t = -0.034 - \underset{[-7.051]}{0.576} \cdot \Delta e_t + \underset{[3.562]}{0.759} \cdot \pi_t$$

$$\Delta FX_t = 0.386 - \underset{[-3.198]}{2.581} \cdot \pi_t + \underset{[4.571]}{2.047} \cdot \Delta y_t,$$

where t-statistics are shown in brackets. Explanatory power of the model measured by R^2 equals 76.64%. All coefficients are significant at 1% level and have the expected signs except for inflation. It can reflect a relatively large structural component specific to the Russian inflation due to inconsistency and imbalance of industries and markets, their imperfection. Poor links and interactions between different economic sectors lead to the fact that some of them cannot quickly saturate the market with goods. This results in a chronically unsatisfied demand for certain products, which increases prices. The growth of the economy of scale and the efficiency of production, which are reflected in the index, reduce the effect on the structural component of inflation in the long run. Besides, the issue of the negative impact on inflation can be explained by the imperfection of a proxy for output, which is calculated only in terms of basic industries, not taking into account the services.

From the results of estimation for the long run, all things being equal, we can draw the following conclusions:

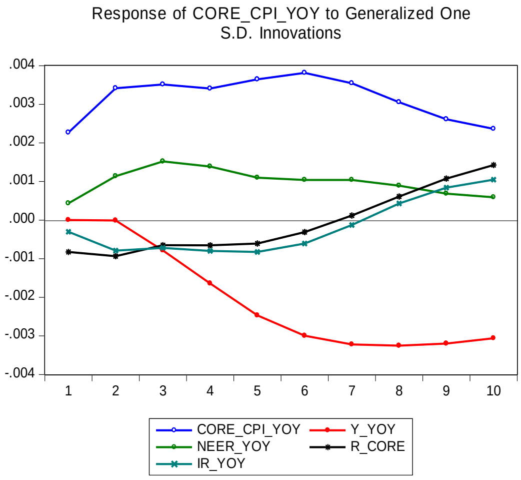
1) Impairment/strengthening of the nominal effective exchange rate by 1% leads to an increase/decrease in inflation by 0.44%. Therefore, the estimated long-term pass-through effect

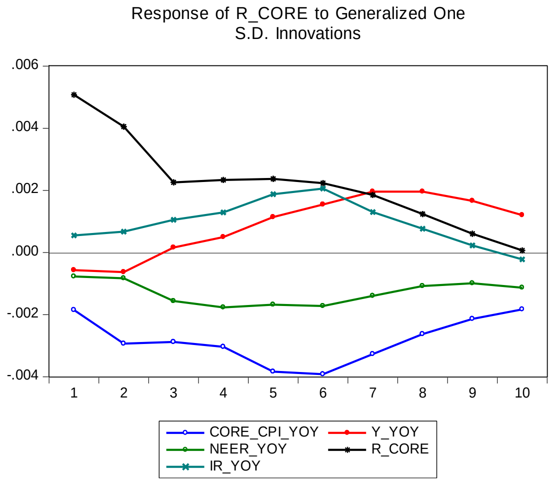
of the exchange rate on the inflation rate is 0.44 percentage points. An increase/decrease in the output by 1% leads to a decrease/increase in the inflation rate by 0.25%.

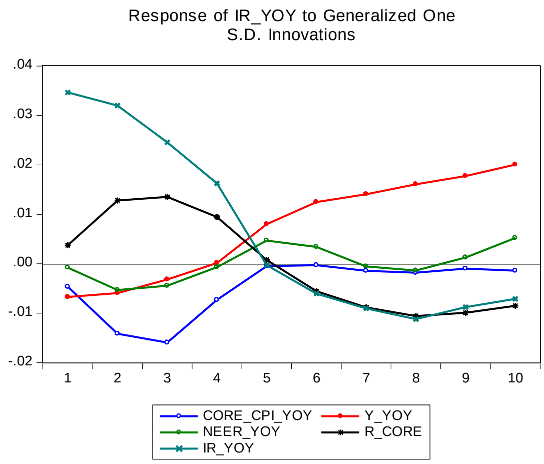
2) Impairment/strengthening of the nominal effective exchange rate by 1% reduces/increases the real interest rate by 0.24 percentage points $\left(= 0.441 \cdot 0.759 - 0.576 = -0.241\right)$. At the same time, a 1% increase/decline in inflation rises/falls the real interest rate by 0.76 percentage points. This result violates the "Fisher effect", which states that in the long run there is a one-to-one change in the nominal interest rate and inflation, so the real interest rate does not change. This may indicate the presence of several objectives in conducting monetary policy where price stability is not necessarily a priority. Also, the real interest rate determines the productivity of capital. An increase in inflation reduces the marginal product of capital because it becomes relatively more expensive. In practice, this is reflected in the unavailability of credit and, consequently, it reduces the investment potential.

3) An increase/decrease in inflation by 1% leads to a fall/rise in foreign exchange reserves by 2.58%. At the same time, a growth/decline in output by 1% causes 2.69% increase/decrease in reserves.

To assess the impact of shocks on the endogenous variables and to determine the dominant influences which drive variables dynamics, I use a generalized impulse response analysis (generalized impulse response (GIR)). I investigate how a 1 standard deviation shock of one of the variables affects other endogenous variables during a selected time interval. This method has the advantage of independence of how to order variables in VAR (Pesaran and Shin, 1998). I build a generalized impulse response functions of the dependent variables in the cointegrating relationship for 10 periods (months), shown in the figure below.







The results show that the one of the main factors creating inflationary pressure is the nominal effective exchange rate, the shock of which has especially pronounced effect on the third month. At the same time, output shock starts reducing inflation significantly and sustainably from the second period. Besides, there is a strong inertial component of inflation, such that its own shocks explain a significant portion of fluctuations. Inflation and exchange rate shocks constantly change the real interest rates over 10 months reducing their exposure after 5 periods. Meanwhile, international reserves shock as a whole does not consistently affect the real interest rate, increasing it for a while at first, then changing its direction after 6-7 months, and finally dying out in the tenth month. This is consistent with the results of the Granger causality test. Regarding international reserves there is a negative impact of inflation shock for 3 months, but then it levels off starting from the fifth period. However, output shock on reserves is persistent influencing positively with a lag of four months.

The results can also be interpreted using the error correction mechanism inherited in VEC specification. It shows the percentage of the short-run deviation from the long-run equilibrium which is covered each month. It can be also called as a speed of adjustment. You can find the estimated values in the Appendix for VEC section (cells in yellow). It turns out that this coefficient is insignificant from zero for the inflation rate. It is 22.5% and 40.3% for the real interest rate and reserves, respectively.

Application of estimated results to the theoretical model:

Let's make an additional assumption that the central bank determines the relative weight of inflation and exchange rate under consideration that its actions should not increase the real interest rate in the long run. This makes it possible to estimate the range for λ in (6), using the Result 2. This assumption can be applied to the Russian economy because low real interest rates are necessary for investment activity and for stimulation of economic growth.

The intuition is as follows: assume the central bank's policy is relatively shifted in the direction to the exchange rate target implementation, therefore 1% reduction in the level of inflation, ceteris paribus associated with a decrease in the real interest rate by 0.76%. At the same time, the same effect can be achieved if the exchange rate depreciates by $\frac{0.76}{0.24}\% = 3.167\%$. Consequently, the boundary value of λ equals $\lambda_{obj} = \frac{1}{3.167} = 0.316$ in the theoretical model. If $\lambda > \lambda_{obj}$, then the weight of relatively less efficient instrument increases, and under the assumption of the relative priority of reducing inflation this will decrease the real interest rates. If on the contrary, $\lambda < \lambda_{obj}$, under the same logic this will increase the real interest rate. Therefore, we can consider the reaction of the monetary policy to changes in the pass-through effect using the equation from the theoretical model.

$$\frac{d\Delta e_{t+1}^{opt}}{d\omega_e} = -\frac{\left(A_{t+1} - \pi^{target}\right)\left(\lambda - \omega_e^2\right) + 2\omega_e \lambda \left(e^{target} - e_t\right)}{\left(\omega_e^2 + \lambda\right)^2} < 0, \text{ because}$$

$$\left(A_{t+1} - \pi^{target}\right)\left(\lambda - \omega_e^2\right) + 2\omega_e \lambda \left(e^{target} - e_t\right) > \left(A_{t+1} - \pi^{target}\right)\left(0.316 - 0.441^2\right) + 2 \cdot 0.441 \cdot 0.316\left(e^{target} - e_t\right) =$$
$$= 0.122 \cdot \left(A_{t+1} - \pi^{target}\right) + 0.279\left(e^{target} - e_t\right) > 0$$

Therefore, the numerator $-\left(\left(A_{t+1} - \pi^{target}\right)\left(\lambda - \omega_e^2\right) + 2\omega_e \lambda \left(e^{target} - e_t\right)\right) < 0$ with the positive denominator in $\frac{d\Delta e_{t+1}^{opt}}{d\omega_e}$.

From this, we can draw a practical conclusion that in the Russian situation the accomplishment of decreasing inflation positively depends on the pass-through effect of the nominal effective exchange rate on inflation. Thus, the optimal reaction of the Central Bank of Russia to an increase in the pass-through effect, ceteris paribus, should be a relative shift in the direction of meeting the inflation target. And vice versa: a decrease in the exchange rate pass-through effect increases the attractiveness of the exchange rate target for the monetary authorities, so inflation increases. Therefore, decreasing the pass-through effect reduces incentives for inflation target accomplishment. The optimal response for the monetary authority to achieve the stated inflation target can be a fall in the relative weight of the exchange rate in the objective function of the Central Bank, λ.

References:

1) Blanchard, Olivier, 2012, “Monetary Policy *in the Wake of the Crisis*,” Chapter 1 of In the Wake of the Crisis, edited by Blanchard, Olivier, David Romer, Michael Spense, Joseph Stiglitz, MIT Press.
2) Canzoneri Matthew, Cumby Robert (2014), “Optimal Exchange Intervention in an Inflation Targeting Regime: Some Cautionary Tales”, Open Economies Review, Volume 25, Issue 3,pp 429-450.
3) Johansen, S., 1988. Statistical analysis of cointegration vectors. Journal of Economic Dynamics and Control 12, 231-254
4) King Mervyn, 2012: “Twenty years of inflation targeting”, *Text of the Stamp Memorial Lecture by Mr Mervyn King*, Governor of the Bank of England, London.
5) Pesaran, H.H., Shin, Y., 1998. Generalized Impulse Response Analysis in Linear Multivariate Models. Economics Letters 58, 17–29.
6) Reyes, Javier A., 2007, “Exchange Rate Passthrough Effects and Inflation Targeting in Emerging Economies: What is the Relationship?” Review of International Economics, 15, issue 3, p. 538-559.
7) Svensson, Lars 2010, “Inflation Targeting,” in Friedman, Benjamin M., and Michael Woodford, eds., Handbook of Monetary Economics, Volume 3b, chapter 22, Elsevier.
8) Woodford, Michael 2012, “Inflation Targeting and Financial Stability,” Sveriges Riksbank Economic Review, 2012:1

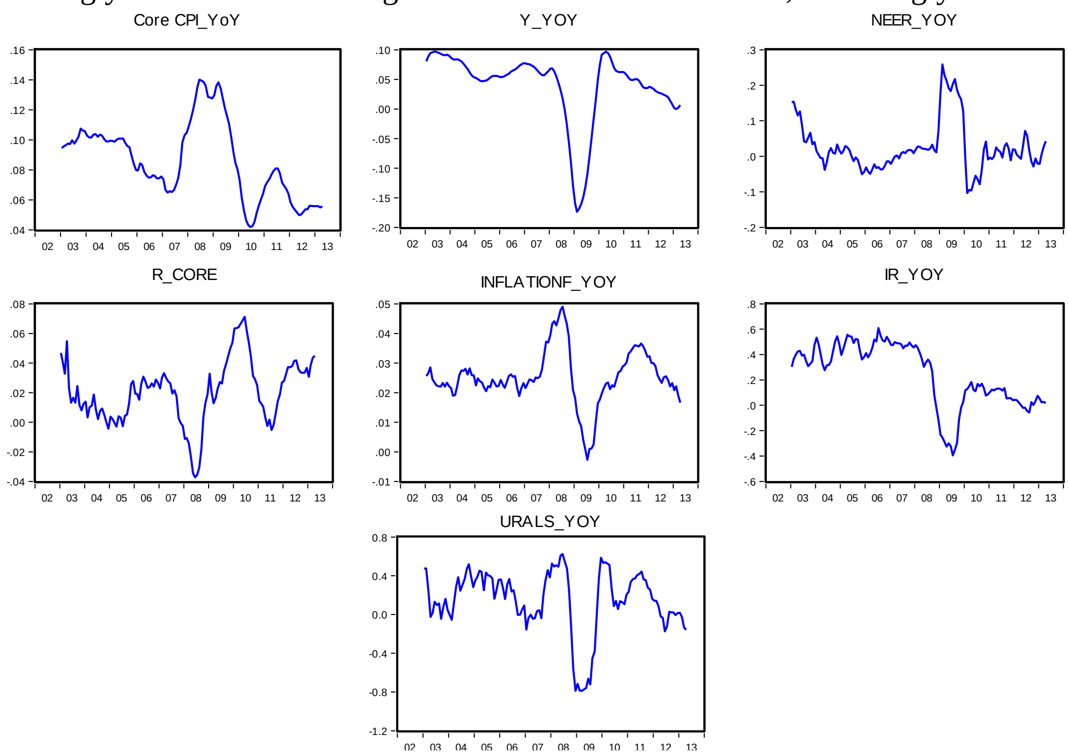
Appendix

Stationarity tests

Variable name	$ADF(\mu)$	$ADF(\tau)$	$ADF(\eta)$
CORE_CPI_YOY	-2.249	-2.884	-0.952
Y_YOY	-2.463	-2.626	-1.992
NEER_YOY	-2.867	-2.843	-2.788**
R_CORE	-2.139	-2.522	-1.510
IR_YOY	-1.697	-2.493	-1.524
INFLATIONF_YOY	-2.432	-2.404	-1.076
URALS_YOY	-3.190*	-3.224	-3.043**
D(CORE_CPI_YOY)	-4.997**	-5.093**	-1.390
D(Y_YOY)	-4.710**	-4.693**	-4.724**
D(NEER_YOY)	-8.100**	-8.101**	-8.130**
D(R_CORE)	-9.746**	-9.770**	-9.786**
D(IR_YOY)	-3.714**	-3.692*	-3.651**
D(INFLATIONF_YOY)	-6.593**	-6.575**	-6.614**
D(URALS_YOY)	-7.741**	-7.709**	-7.763**

Critical values	$ADF(\mu)$	$ADF(\tau)$	$ADF(\eta)$
1%	-3.48	-4.03	-2.58
5%	-2.88	-3.44	-1.94
10%	-2.58	-3.15	-1.62

Note: $ADF(\mu)$ $ADF(\tau)$ $ADF(\eta)$ – augmented Dickey-Fuller unit root tests for 3 different specifications, which include 1) constant only, 2) both trend and constant, and 3) no constant, correspondingly. * and ** denotes significance at 5% and 1% levels, accordingly.



Testing hypotheses in unrestricted VAR model

VAR Lag Order Selection Criteria
Endogenous variables: CORE_CPI_YOY Y_YOY NEER_YOY R_CORE IR_YOY
Exogenous variables: C ID CRISIS IT URALS_YOY INFLATIONF_YOY
Sample: 2002M01 2013M12
Included observations: 118

Lag	LogL	LR	FPE	AIC	SC	HQ
0	1415.524	NA	4.36e-17	-23.48346	-22.77905	-23.19745
1	1974.614	1013.943	5.11e-21	-32.53584	-31.24442	-32.01148
2	2126.490	262.5646	5.99e-22	-34.68627	-32.80784*	-33.92357*
3	2154.161	45.49228	5.78e-22	-34.73154	-32.26610	-33.73049
4	2181.878	43.21967*	5.62e-22*	-34.77759*	-31.72514	-33.53820
5	2199.553	26.06315	6.53e-22	-34.65343	-31.01397	-33.17571
6	2225.652	36.27354	6.66e-22	-34.67207	-30.44560	-32.95599

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

VAR Lag Exclusion Wald Tests
Sample: 2002M01 2013M12
Included observations: 120

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

	CORE_CPI_YOY	Y_YOY	NEER_YOY	R_CORE	IR_YOY	Joint
Lag 1	234.0481	479.7268	147.6496	63.57142	118.6549	1010.668
	[0.000000]	[0.000000]	[0.000000]	[2.22e-12]	[0.000000]	[0.000000]
Lag 2	20.10153	38.82296	34.70311	4.673656	3.825098	97.61782
	[0.001196]	[2.58e-07]	[1.72e-06]	[0.456990]	[0.574862]	[1.58e-10]
Lag 3	13.87383	1.532910	20.30670	8.271772	3.276204	42.09466
	[0.016431]	[0.909241]	[0.001094]	[0.141880]	[0.657487]	[0.017556]
Lag 4	13.34247	1.257697	10.67471	9.094381	16.94023	47.47510
	[0.020372]	[0.939224]	[0.058225]	[0.105358]	[0.004615]	[0.004308]
df	5	5	5	5	5	25

Some other results of diagnostic tests

VAR **Residual Normality Tests**
Orthogonalization: Cholesky (Lutkepohl)
Null Hypothesis: residuals are multivariate normal
Sample: 2002M01 2013M12
Included observations: 120

Component	Skewness	Chi-sq	df	Prob.
1	0.234740	1.102058	1	0.2938
2	-0.084524	0.142886	1	0.7054
3	-0.012248	0.003000	1	0.9563
4	0.348223	2.425184	1	0.1194
5	0.021170	0.008964	1	0.9246
Joint		3.682093	5	0.5960

Component	Kurtosis	Chi-sq	df	Prob.
1	3.706859	2.498249	1	0.1140
2	3.370884	0.687774	1	0.4069
3	3.447802	1.002632	1	0.3167
4	3.747090	2.790720	1	0.0948
5	3.021783	0.002372	1	0.9612
Joint		6.981748	5	0.2220

VAR Residual Serial Correlation LM Tests
Null Hypothesis: no serial correlation at lag order h
Sample: 2002M01 2013M12
Included observations: 120

Lags	LM-Stat	Prob
1	38.71270	0.0394
2	21.42483	0.6687
3	33.15433	0.1273
4	23.72586	0.5353
5	24.98416	0.4633
6	27.97502	0.3090
7	19.96364	0.7487
8	37.35410	0.0534
9	12.12302	0.9855
10	20.84374	0.7013

Probs from chi-square with 25 df.

Granger causality tests

VAR Granger Causality/Block Exogeneity Wald Tests
Sample: 2002M01 2013M12
Included observations: 120

Dependent variable: CORE_CPI_YOY

Excluded	Chi-sq	df	Prob.
Y_YOY	25.90695	4	0.0000
NEER_YOY	9.976968	4	0.0408
R_CORE	5.581958	4	0.2326
IR_YOY	7.561150	4	0.1090
All	49.55363	16	0.0000

Dependent variable: Y_YOY

Excluded	Chi-sq	df	Prob.
CORE_CPI_YOY	4.050318	4	0.3992
NEER_YOY	23.57970	4	0.0001
R_CORE	0.345867	4	0.9867
IR_YOY	1.513593	4	0.8242
All	38.18412	16	0.0014

VAR Granger Causality/Block Exogeneity Wald Tests
Sample: 2002M01 2013M12
Included observations: 120

Dependent variable: R_CORE

Excluded	Chi-sq	df	Prob.
CORE_CPI_YOY	21.27972	4	0.0003
Y_YOY	5.892936	4	0.2073
NEER_YOY	3.700290	4	0.4481
IR_YOY	2.853998	4	0.5825
All	60.75853	16	0.0000

Dependent variable: IR_YOY

Excluded	Chi-sq	df	Prob.
CORE_CPI_YOY	18.46662	4	0.0010
Y_YOY	16.97015	4	0.0020
NEER_YOY	2.488181	4	0.6468
R_CORE	12.30259	4	0.0152
All	50.56409	16	0.0000

Dependent variable: NEER_YOY

Excluded	Chi-sq	df	Prob.
CORE_CPI_YOY	1.390697	4	0.8458
Y_YOY	15.19291	4	0.0043
R_CORE	3.166340	4	0.5304
IR_YOY	20.26829	4	0.0004
All	46.05693	16	0.0001

Vector error-correction model of monetary policy

Johansen's cointegration test

Sample (adjusted): 2003M06 2013M04
Included observations: 119 after adjustments
Trend assumption: Linear deterministic trend
Series: CORE_CPI_YOY Y_YOY NEER_YOY R_CORE IR_YOY
Exogenous series: ID CRISIS IT URALS_YOY INFLATIONF_YOY
Warning: Critical values assume no exogenous series
Lags interval (in first differences): 1 to 4

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.421419	139.8105	69.81889	0.0000
At most 1 *	0.280740	74.69633	47.85613	0.0000
At most 2 *	0.226022	35.48205	29.79707	0.0099
At most 3	0.025946	4.992833	15.49471	0.8096
At most 4	0.015546	1.864459	3.841466	0.1721

Trace test indicates 3 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.421419	65.11412	33.87687	0.0000
At most 1 *	0.280740	39.21428	27.58434	0.0010
At most 2 *	0.226022	30.48922	21.13162	0.0018
At most 3	0.025946	3.128374	14.26460	0.9378
At most 4	0.015546	1.864459	3.841466	0.1721

Max-eigenvalue test indicates 3 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Models' estimation with 3 cointegrating vectors

Vector Error Correction Estimates
Sample (adjusted): 2003M06 2013M04
Included observations: 119 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:

B(1,1)=1,
B(1,4)=0,
B(1,5)=0,
B(2,4)=1,
B(2,2)=0,

B(2,5)=0,
B(3,5)=1,
B(3,4)=0,
B(3,3)=0

Convergence achieved after 1 iterations.
Restrictions identify all cointegrating vectors
Restrictions are not binding (LR test not available)

Cointegrating Eq:	CointEq1	CointEq2	CointEq3
CORE_CPI_YOY(-1)	1.000000	-0.759450	2.580562
		(0.21319)	(0.80700)
		[-3.56240]	[3.19771]
Y_YOY(-1)	0.247876	0.000000	-2.047115
	(0.08758)		(0.44778)
	[2.83039]		[-4.57173]
NEER_YOY(-1)	-0.441223	0.576129	0.000000
	(0.06512)	(0.08171)	
	[-6.77507]	[7.05074]	
R_CORE(-1)	0.000000	1.000000	0.000000
IR_YOY(-1)	0.000000	0.000000	1.000000
C	-0.086694	0.034347	-0.385760

Error Correction:	D(CORE_CPI_YOY)	D(Y_YOY)	D(NEER_YOY)	D(R_CORE)	D(IR_YOY)
CointEq1	0.028990	-0.094496	0.041178	-0.236870	0.017802
	(0.02949)	(0.02785)	(0.23315)	(0.06593)	(0.45013)
	[0.98314]	[-3.39286]	[0.17662]	[-3.59269]	[0.03955]
CointEq2	0.071360	-0.036644	-0.439066	-0.225173	-0.089715
	(0.02465)	(0.02328)	(0.19490)	(0.05511)	(0.37628)
	[2.89497]	[-1.57393]	[-2.25282]	[-4.08561]	[-0.23843]
CointEq3	-0.001666	-0.003522	-0.084834	0.014338	-0.402658
	(0.00454)	(0.00428)	(0.03586)	(0.01014)	(0.06923)
	[-0.36725]	[-0.82215]	[-2.36581]	[1.41399]	[-5.81617]
D(CORE_CPI_YOY(-1))	0.533652	0.064839	-1.267676	-0.716940	-2.218741
	(0.10877)	(0.10273)	(0.85998)	(0.24319)	(1.66033)
	[4.90642]	[0.63115]	[-1.47408]	[-2.94807]	[-1.33632]
D(CORE_CPI_YOY(-2))	-0.117126	0.040793	0.558772	-0.021560	1.796974
	(0.11882)	(0.11222)	(0.93944)	(0.26566)	(1.81373)
	[-0.98578]	[0.36350]	[0.59479]	[-0.08116]	[0.99076]
D(CORE_CPI_YOY(-3))	0.050310	-0.023350	-0.425332	-0.340326	4.080536
	(0.11870)	(0.11211)	(0.93851)	(0.26540)	(1.81195)
	[0.42385]	[-0.20827]	[-0.45320]	[-1.28233]	[2.25201]
D(CORE_CPI_YOY(-4))	0.180729	0.160189	0.448772	-0.431248	0.732547

	(0.10857)	(0.10255)	(0.85845)	(0.24276)	(1.65738)
	[1.66459]	[1.56209]	[0.52277]	[-1.77646]	[0.44199]
D(Y_YOY(-1))	-0.057602	1.133707	1.640431	-0.028442	-0.361228
	(0.10257)	(0.09688)	(0.81100)	(0.22934)	(1.56576)
	[-0.56158]	[11.7022]	[2.02273]	[-0.12402]	[-0.23070]
D(Y_YOY(-2))	-0.354254	-0.254333	-3.639161	0.514890	-0.486837
	(0.15752)	(0.14878)	(1.24549)	(0.35221)	(2.40463)
	[-2.24889]	[-1.70942]	[-2.92186]	[1.46190]	[-0.20246]
D(Y_YOY(-3))	0.178254	-0.337364	0.170352	-0.232081	-2.639385
	(0.16797)	(0.15865)	(1.32808)	(0.37556)	(2.56408)
	[1.06123]	[-2.12648]	[0.12827]	[-0.61796]	[-1.02937]
D(Y_YOY(-4))	-0.050877	0.241593	0.115291	0.225066	1.158131
	(0.11744)	(0.11092)	(0.92856)	(0.26258)	(1.79273)
	[-0.43322]	[2.17803]	[0.12416]	[0.85713]	[0.64602]
D(NEER_YOY(-1))	0.002440	0.018046	0.354466	0.027544	-0.071651
	(0.01351)	(0.01276)	(0.10685)	(0.03022)	(0.20629)
	[0.18057]	[1.41384]	[3.31739]	[0.91157]	[-0.34733]
D(NEER_YOY(-2))	-0.018748	-0.002677	-0.380591	-0.004825	0.199468
	(0.01314)	(0.01241)	(0.10386)	(0.02937)	(0.20052)
	[-1.42731]	[-0.21578]	[-3.66452]	[-0.16430]	[0.99478]
D(NEER_YOY(-3))	0.000793	-0.017052	-0.041731	0.013028	0.143571
	(0.01299)	(0.01226)	(0.10267)	(0.02903)	(0.19822)
	[0.06109]	[-1.39033]	[-0.40646]	[0.44873]	[0.72431]
D(NEER_YOY(-4))	-0.000484	0.013329	0.028272	-0.010367	0.240303
	(0.01271)	(0.01201)	(0.10051)	(0.02842)	(0.19405)
	[-0.03805]	[1.11010]	[0.28128]	[-0.36474]	[1.23835]
D(R_CORE(-1))	0.012105	0.016883	0.265577	-0.102703	1.397372
	(0.04250)	(0.04014)	(0.33600)	(0.09502)	(0.64871)
	[0.28485]	[0.42063]	[0.79040]	[-1.08089]	[2.15407]
D(R_CORE(-2))	-0.004117	0.017955	-0.029211	-0.235653	1.101786
	(0.04082)	(0.03855)	(0.32274)	(0.09127)	(0.62311)
	[-0.10085]	[0.46570]	[-0.09051]	[-2.58202]	[1.76821]
D(R_CORE(-3))	-0.054621	0.004311	0.064356	-0.018316	1.410130
	(0.04132)	(0.03903)	(0.32671)	(0.09239)	(0.63076)
	[-1.32190]	[0.11045]	[0.19698]	[-0.19825]	[2.23559]
D(R_CORE(-4))	0.005530	0.027811	-0.232047	-0.114839	-0.015064
	(0.03924)	(0.03707)	(0.31028)	(0.08774)	(0.59905)
	[0.14091]	[0.75031]	[-0.74785]	[-1.30880]	[-0.02515]
D(IR_YOY(-1))	-0.009420	0.000215	0.022242	-0.013586	0.281601
	(0.00604)	(0.00571)	(0.04777)	(0.01351)	(0.09224)
	[-1.55898]	[0.03770]	[0.46556]	[-1.00568]	[3.05309]

D(IR_YOY(-2))	0.004757	0.000269	0.075585	-0.002713	0.124460
	(0.00612)	(0.00579)	(0.04843)	(0.01369)	(0.09350)
	[0.77663]	[0.04652]	[1.56077]	[-0.19808]	[1.33115]
D(IR_YOY(-3))	-0.010888	0.000268	-0.128611	-0.001401	0.130000
	(0.00591)	(0.00558)	(0.04669)	(0.01320)	(0.09014)
	[-1.84376]	[0.04814]	[-2.75450]	[-0.10614]	[1.44212]
D(IR_YOY(-4))	-0.000329	-0.007802	-0.019603	0.011692	-0.176743
	(0.00596)	(0.00563)	(0.04709)	(0.01332)	(0.09092)
	[-0.05526]	[-1.38695]	[-0.41625]	[0.87799]	[-1.94394]
C	0.001292	0.007851	0.036664	-0.007315	0.116133
	(0.00157)	(0.00149)	(0.01244)	(0.00352)	(0.02401)
	[0.82155]	[5.28470]	[2.94802]	[-2.07990]	[4.83657]
ID	0.002770	0.001379	0.031567	-0.005504	0.045179
	(0.00099)	(0.00094)	(0.00783)	(0.00222)	(0.01512)
	[2.79617]	[1.47331]	[4.02957]	[-2.48463]	[2.98718]
CRISIS	-0.001159	-0.001747	0.005904	-0.001854	-0.011248
	(0.00130)	(0.00123)	(0.01028)	(0.00291)	(0.01985)
	[-0.89113]	[-1.42254]	[0.57437]	[-0.63776]	[-0.56675]
IT	-0.000904	-0.001693	0.003180	0.001953	-0.121070
	(0.00177)	(0.00167)	(0.01396)	(0.00395)	(0.02696)
	[-0.51183]	[-1.01518]	[0.22777]	[0.49457]	[-4.49123]
URALS_YOY	0.007596	0.007110	0.019447	-0.017198	0.185762
	(0.00228)	(0.00215)	(0.01804)	(0.00510)	(0.03482)
	[3.33011]	[3.29999]	[1.07820]	[-3.37190]	[5.33463]
INFLATIONF_YOY	-0.114816	-0.335153	-2.010881	0.414660	-4.346904
	(0.07187)	(0.06788)	(0.56824)	(0.16069)	(1.09707)
	[-1.59760]	[-4.93745]	[-3.53881]	[2.58052]	[-3.96228]
R-squared	0.766436	0.970863	0.676218	0.545376	0.658832
Adj. R-squared	0.693771	0.961799	0.575486	0.403937	0.552691
Sum sq. resids	0.000464	0.000414	0.029004	0.002319	0.108112
S.E. equation	0.002270	0.002144	0.017952	0.005077	0.034659
F-statistic	10.54761	107.1035	6.713033	3.855921	6.207124
Log likelihood	572.2104	579.0037	326.1529	476.4581	247.8673
Akaike AIC	-9.129587	-9.243760	-4.994166	-7.520304	-3.678441
Schwarz SC	-8.452322	-8.566495	-4.316901	-6.843039	-3.001176
Mean dependent	-0.000349	-0.000760	-0.000702	0.000183	-0.003469
S.D. dependent	0.004103	0.010972	0.027553	0.006575	0.051822

Determinant resid covariance (dof adj.)	1.80E-22
Determinant resid covariance	4.46E-23
Log likelihood	2217.868
Akaike information criterion	-34.58601
Schwarz criterion	-30.84937