JEL Classification: E31, E43, E52
Keywords: monetary policy shock, dynamic general equilibrium model, Kalman filtration

The History of Inflation Targeting in the Czech Republic Through the Lens of a Dynamic General Equilibrium Model*

Jaromír HURNÍK – Czech National Bank (jaromir.hurnik@cnb.cz) – corresponding author
Ondřej KAMENÍK – International Monetary Fund
Jan VLČEK – Czech National Bank

Abstract
Using a dynamic general equilibrium model calibrated for the Czech Republic, we first estimate the impact of structural shocks on the observed realizations of the interest rate and inflation, while the main focus is put on the estimation of monetary policy shocks. These occur whenever monetary policy is not set in accordance with the observed state of the economy and the inflation target. Our results suggest that monetary policy was more restrictive than implied by the observed state of the economy and the inflation target in three periods: 1998Q2–1999Q1, 2001Q3–2003Q2, and 2004Q3–2005Q4. On the contrary, the period from 2003Q3 to 2004Q2 was characterized by relatively loose monetary policy. Based on the assumption that monetary policy focuses on a different inflation target than the officially announced one, we estimate the implicit trajectory of the inflation target for the Czech Republic. This implied target fluctuates between 2 and 3 percent in 2002–2007.

1. Introduction

The inflation targeting regime was introduced by the Czech National Bank (CNB) in January 1998. During the first six months of that year, inflation was above the first inflation target set for the end of 1998. It then dropped well below the target during fall 1998, and the CNB subsequently also undershot its targets for the year-ends of 1999 and 2000. It was only in 2001 that the CNB actually hit the inflation target. The introduction of a continuous target in January 2002 failed to bring a clear improvement in target fulfillment. Holub and Hurník (2008) report that from January 2002, when the continuous target was introduced, till the end of 2007, inflation moved below the target midpoint for some 90 percent of the time and below the target interval for 51 percent of the time.

The Czech economy was not the only transition economy that experienced disinflation following the introduction of inflation targeting[1], but it stands out in terms of inflation being below the declared inflation targets most of the time. This undershooting of the inflation target was undoubtedly due to many reasons. In this paper, we focus in more detail on one of the possibilities, namely, on the role that may have been played by monetary policy itself.

* This paper represents the authors' own views and does not necessarily reflect those of the Czech National Bank or the International Monetary Fund. We would like to thank Michal Andrle, Aleš Bulíř, Martin Čihák, Viktor Kotlán and two anonymous referees for helpful comments. However, all errors and omissions remain entirely the fault of the authors.

[1] Battini, Kuttner, and Laxton (2005) and Bulíř et al. (2008) have documented successes in decreasing inflation in numerous developing economies that introduced inflation targeting in the late 1990s and early 2000s.

Using a dynamic general equilibrium model, we analyze monetary policy with respect to the publicly declared inflation target. The underlying rationale of our approach is that monetary policy should be analyzed with the help of an economic model that contains monetary policy, but is such that its parameterization is independent of monetary policy (Lucas, 1976).[2] A structural economic model, encompassing central bank behavior and certain sets of observed economic variables, should therefore be used in order to understand the historical development of monetary policy properly. Similarly to Smets and Wouters (2007), both the economic model and the set of observed economic variables are then used to estimate economic (structural) shocks, including a monetary policy shock. The heart of the method used thus consists in explaining, with the help of the economic model, the observed dynamics of the economic variables with economic shocks. Those shocks include changes in technology, changes in consumer preferences, exchange rate shocks, and monetary policy shocks.

Monetary policy shocks and their impact on nominal interest rates and inflation are obviously of primary interest in this type of analysis. If any part of the observed realization of nominal interest rates can be attributed to a monetary policy shock, we conclude that the central bank set interest rates either above or below the level consistent with the observed state of the economy and the published inflation target. An error in the monetary policy settings (i.e., a monetary policy shock) occurs whenever the central bank misinterprets the observed state of economy or sets interest rates otherwise than would be consistent with the observed state of the economy and the inflation target.

With a lag, we then identify the impact of the monetary policy shocks on the deviations of inflation from the inflation target. That does not mean, of course, that whenever, for example, a positive monetary policy shock occurs, observed inflation will necessarily, with some lag, appear below the inflation target. In practice, as a result of other shocks, inflation may well hit the target precisely or even exceed it. The virtue of the method applied is that even in such a case, we are able to estimate the impacts of monetary policy shocks and document whether or not monetary policy was set consistently with the declared inflation target. Another advantage of the method consists in the fact that, in order to identify monetary policy shocks, it makes no difference what analyses the central bank actually based its decisions on. The resulting identification of monetary policy shocks, while being subject to the specification of the economic model used, is in fact independent of the analytical framework used within the central bank.

It definitely applies, on the other hand, that the identification of monetary policy shocks in itself only provides information on when the central bank set nominal interest rates below or above the level consistent with the observed state of the economy and the inflation target, without actually revealing why the central bank did so. Some conclusions, albeit only quite *weak* ones, on the reasons may be arrived at through analysis of other shocks identified at the same time as the monetary policy shock, or before or after such time. If, for example, we identify a strong monetary policy shock together with a counteracting exchange rate shock both affecting observed

[2] This condition gains even more in importance when the hypothesis cannot be excluded that monetary policy actually did something else than that which it publicly committed itself to doing.

interest rates, we may be able to judge a slow response of monetary policy vis-à-vis the exchange rate shock. The isolated presence of a monetary policy shock may then actually be a sign of incorrectly directed interest rates.[3]

The presence of monetary policy shocks, especially when they generally point in one direction, could lead economic agents to assume that the central bank de facto targets an inflation rate that is different from the declared target. In such circumstances, the inflation target may be treated as an unobserved variable and estimated by methods applied to other unobserved variables.

The rest of the paper is structured as follows. Section 2 contains a description of the model and the estimation method. Section 3 follows up with a description of the estimated results, i.e., an analysis of the deviation of nominal interest rates and inflation from their long-term values in response to different shocks. Section 4 presents an estimate of the inflation target in the absence of monetary policy shocks, and Section 5 summarizes all the results.

2. The Model and the Estimation Method

As indicated above, the basic principle of our method consists in identifying economic shocks (directly unobserved) using a structural model of the Czech economy and information contained in the observed variables, where the link between the observed and unobserved variables is represented by the economic model itself. The model selection criteria are then defined by the questions we attempt to answer. In our case, analyzing the economy under the inflation targeting regime requires the model to include endogenous monetary policy and to reflect its transmission mechanism fairly. The point is that if monetary policy were absent from the model, the expectations of economic agents could not be accurately described (Lucas, 1976). The model should at the same time have a sufficiently rich supply (production) structure to enable it to be calibrated on the observed data and to enable the use of the information contained within the GDP components.

2.1 Structure of the Model

The economy is described using a dynamic general equilibrium model, an earlier version of which was described in (Beneš, Hlédik, Kumhof, Vávra, 2005). The version that we use is discussed in detail by Andrle, Hlédik, Kameník, and Vlček (2008). In this paper, we therefore provide only a verbal description of the key features of the model. The model includes the sectors of households, intermediaries in the financial market, domestic producers of intermediate goods, importers of intermediate goods, producers of final consumption goods, exporters, and producers of capital goods. The model also includes the central bank and government.

Households consume the final goods basket and accumulate capital, lend capital, and supply differentiated labor force to domestic producers of intermediate goods. Furthermore, households directly trade in domestic bonds and, through financial market intermediaries, also in foreign currency denominated bonds. Households own all firms and, in proportion to their investments, share in the firms' profits. In

[3] "Incorrectly directed" should be taken to include leaving the interest rate at its current level in a situation requiring a change of rate.

addition to corporate profits, households are recipients of government transfer payments. Households' wage contracts are rigid, i.e., households cannot re-optimize their wage contracts in each period. Those households which are not able to optimize their wage contracts then index their wages to the last observed increase in wages. Finally, households move within a competitive insurance market (Yaari, 1965) that ensures that heterogeneous wages have no impact on the distribution of wealth among households. This enables us to use the representative household concept. When accumulating capital, i.e., during their investment activity, households face adjustment costs associated with the required capital level (Kim, 2003).

Financial market intermediaries operate in a perfectly competitive financial market and their operations are expected to always cover two periods. During the first period, intermediaries obtain funds from households and invest them in the international financial market; in the second period, they close their positions and return the invested funds to households. There are always two intermediary groups in each of the periods, one of them in the first stage of the financial operation and the other in the second stage. When investing, intermediaries face transaction costs, the existence of which is necessary for achieving model stationarity (Schmidt-Grohé, Uribe, 2003). The transaction costs are a government revenue (one can think of this as a fee imposed on the financial intermediation sector).

Domestic producers of intermediate goods hire capital and labor force from households and, while operating on a monopolistically competitive market, each of them produces one type of intermediate good. For production, they use identical technology that involves labor-augmenting technological progress. Producers maximize their profits subject to constraints represented by the technologies used, the costs of production factors, and the non-zero probability that they will be unable to optimize their product price in every period. Differentiated intermediate goods are then combined with no additional costs into a composite intermediate good that is sold to producers of final goods (for private consumption, export, and government consumption).

In addition to the sector of domestic intermediate goods producers, there is also a sector of intermediate goods importers included in the model. Each importer combines its imported intermediate good from various foreign goods, the prices of which are derived from the prices of those goods in the relevant currencies and the nominal exchange rate. Similarly to domestic intermediate goods producers, importers of intermediate goods face a non-zero probability that they will be unable to optimize their product price in every period. Imported intermediate goods are then sold to the sectors of consumer, export, and capital goods producers.

Final consumption goods producers also operate on a monopolistic market and use domestic and imported intermediate goods as production inputs. The proportions in which the two types of intermediate goods are used are determined by production technology with constant elasticity of substitution. Rigid nominal prices exist in this sector like in other sectors, i.e., producers are unable to optimize their price in each period.

Exporters, too, use both domestic and imported intermediate goods for production, while the proportions of the goods used are again determined by production technology with constant elasticity of substitution. Exporter prices are rigid, as in other sectors. The difference is that they are rigid in the foreign currency rather than the domestic currency. Exports from the local economy compete with exports from various other countries and share imports of the foreign economy. Foreign demand for domestic export goods then may be expressed as a share of foreign imports, with the proportion being determined by the relative price of export goods to the price of foreign goods.

Capital goods producers use only imported intermediate goods for production. This specification is based on the high share of imports in investment expenditures as well as on our effort to avoid quick overflow of increased capital accumulation into the production of domestic value added. As in other sectors, producers in this one are unable to optimize their prices every period.

The last production sector comprises government consumption goods producers. Similarly to the capital goods sector, in this sector producers use only a single production input, specifically a domestic intermediate good. Once again, producers are unable to optimize their production price in each period.

Finally, the model contains the government and the central bank. On the government revenue side, there are taxes and transaction costs (fees) from financial intermediation and accumulation of capital. On the expenditure side, the government makes transfer payments and purchases government consumption goods. The government may accumulate debt, but must remain intertemporally solvent. This is achieved by applying a fiscal rule that adjusts the flow of government transfer payments in a way that ensures governmental intertemporal solvency. Government consumption is then coupled with household consumption. The central bank is expected to carry out credible monetary policy under the inflation targeting regime. In order to achieve its inflation target, the bank manipulates the nominal interest rate, taking into consideration the current value of the interest rate and responding to deviations of expected inflation from the inflation target. Specifically, the central bank responds to deviations of year-on-year consumer price index growth from the inflation target at a one-year horizon. The potential impacts of different specifications of the monetary rule on the results are discussed in section 2.4.

2.2 Technology Trends and Long-term Growth

It is important for our method to avoid any ad hoc de-trending of the observed time series. Therefore, the model structure is extended for both nominal and technology trends so as to enable direct use of the observed nonstationary time series.

While the nominal trend is a single one and is determined by targeted inflation, six different real technology trends have to be used to replicate the observed data. The most important of these include general labor-augmenting technology, which enters the production function in the domestic intermediate goods producer sector; the specific technology of the export sector, which maintains the competitiveness of exporters in foreign markets; and the specific technology of the investment sector, which helps to explain increases (decreases) in the share of investment in gross domestic product.

In addition to the above-mentioned real trends, the model employs a specific trend in the labor supply, which enables us to explain long-term changes in the participation rate; a specific technology trend in government consumption goods production, which helps to explain changes in the share of government consumption in gross domestic product; and a specific technology trend describing changes in the quality of export goods. The latter helps to explain the observed increase in the share of domestic exports in foreign imports taking place despite no observed change in relative prices of domestic exports to foreign prices.

The use of all of the above trends is driven both by economic logic and by the need to explain the observed data of a converging economy. It holds that real variables do not grow necessarily at an identical growth rate, while the nominal shares of the components of gross domestic product stay constant.[4] The trend growth rates of technologies, as well as the shocks hitting those rates, are estimated as unobserved variables jointly with an estimate for all other structural shocks.

2.3 Calibrating and Testing

Andrle, Hlédik, Kameník, and Vlček (2008) discuss in detail the calibration methods and tests of the model based on the data sample for the period from 1996Q1 to 2007Q4. The main idea followed in the model calibration is the "minimal econometric approach" as suggested by Geweke (1999), and the methods used involve analysis of impulse responses, forecast error variance decomposition, analysis of the model properties over time and spectral domains (King, Watson, 1996), and recursive forecasting. Andrle, Hlédik, Kameník, and Vlček (2008) report *inter alia* on the ability of the model to forecast inflation at a 2-year horizon.

2.4 Estimation Method

The first step in identifying structural shocks is to solve the model for its reduced form (Blanchard, Kahn, 1980), or (Uhlig, 1995), which involves substitution of forward-looking (non-predetermined) variables with a linear combination of past shocks. However, given the non-linear nature of the model, its equations have to be log-linearised first.

A reduced-form of the model serves as a starting point for the estimation of structural shocks based on the method of Kalman filtration. The Kalman filter applies a reduced form of the model extended for measurement equations that map the observed variables to the unobserved. Together they represent the "state description of the model." The form is as follows:

$$\mathbf{y}_t = Z\mathbf{x}_t + \boldsymbol{\varepsilon}_t \tag{1}$$

$$\mathbf{x}_t = T\mathbf{x}_{t-1} + v_t \tag{2}$$

where $\mathbf{x}$ denotes the vector of unobserved state variables, $\mathbf{y}$ denotes the vector of observed (measurement) variables, $\boldsymbol{\varepsilon}$ is a random vector we call process noise, and v is measurement noise. For that, we assume a Gaussian distribution of random vectors and of the $\mathbf{x}$ state vector's initial state.

Based on the state form of the model and using observed variables, the Kalman filter identifies all unobserved variables that are part of the model, including structural shocks. For linear systems it represents an optimum estimate in terms of the least squares criterion (Hamilton, 1994). Application of the filter itself takes on the recursive algorithm form, wherein the conditional probability density of the state

[4] For a more detailed discussion, see (Andrle, Hlédik, Kameník, Vlček, 2008).

TABLE 1 Observed Variables for Structural Shock Estimates

CPI (index)	Foreign 3M interest rates (EURIBOR)
Regulated prices (index)	Nominal exchange rate (CZK/EUR)
Net inflation (CPI adjusted for regulated prices, index)	Nominal wage (average wage in business sector)
Consumption deflator (index)	Real consumption (index)
Investment deflator (index)	Real investment (index)
Export deflator (index)	Real exports (level)
Import deflator (index)	Real imports (level)
Government consumption deflator (index)	Real government consumption (level)
Foreign prices (PPI, euro area, index)	Foreign demand (real imports of euro area, level)
3M interest rates (PRIBOR)	

variables gets updated based on observed variables. The variables used as observed in the estimation are set out in *Table 1*.

The first step of the algorithm under Kalman filtration is the prediction step. During this step, equation (2) is used to estimate the predictive probability density of the states at time t based on the previous conditional probability density at time t-1. This probability density is, however, nonexistent in the first period of the data sample and is therefore substituted with a random vector with a mean value and the unconditional variance of the state variables as described by equation (2). Due to the presence of trends within the model and resulting non-stationarity of certain variables, the unconditional variance does not have a finite value and that is why a diffuse Kalman filter is applied (De Jong, 1991).

The filtration step follows after the prediction step, representing an update of the predictive probability density based on the information contained in the observed data. The measurement equation (1) is used for that purpose. Additional information drawn from the observed data enables a refined estimate of the state variables, including an estimate of the shocks. In addition to the above Kalman filter steps, we use a smoothing step of the filter, which, as opposed to the prediction and filtration steps, uses complete information from the observed data (Harvey, 1989).

Application of the Kalman filter results in identification of the unobserved state variables, including the structural shocks. Similarly to Smets and Wouters (2007), the estimated realizations of the different shocks are used in the next stage for historical simulations of the model, with the help of which we quantify the exact impacts of different shocks on the nominal interest rate and inflation. In the historical simulation, we therefore simulate the impact of each particular estimated realization of shocks (such as an exchange rate shock, a shock to regulated prices, etc.) on the deviation of nominal interest rates and inflation from their long-term values. While different shocks naturally have different impact directions and strengths in particular periods of the data sample, we obtain the actually observed realizations of nominal interest rates and inflation by summing the impacts of all the shocks.

Hence, a solved structural model with endogenous monetary policy is used to identify structural shocks, including monetary policy shocks. Using a particular type of central bank reaction function may raise doubts as to the robustness of our results with respect to the form and calibration of the central bank's reaction function. In reality, there is no such issue. If we assume that, given the structural form of the model, we are able to identify absolutely correctly all structural shocks except for the monetary policy shock, then, irrespective of the concrete form of the monetary policy rule, it is the monetary policy shock that remains as the only one replicating the observed data. That is why this shock is determined unambiguously regardless of the specific form of the monetary policy rule.

3. Basic Decomposition of Monetary Policy

This section provides a detailed description of the historical decomposition of monetary policy, wherein the observed realizations of nominal interest rates and inflation are analyzed with the impacts of different economic shocks. More precisely, we do not analyze the effects of shocks on the nominal interest rate and inflation levels, but rather we examine the effects economic shocks have on the deviation of the nominal interest rate and inflation from their long-term levels. This follows from the key assumption of our analysis – that only economic shocks cause deviations of any variable from its long-term level. Such a long-term level is represented by the inflation target in the case of inflation and by the sum of the equilibrium real interest rate and inflation expectations (or the inflation target in the long run) in the case of nominal interest rates.

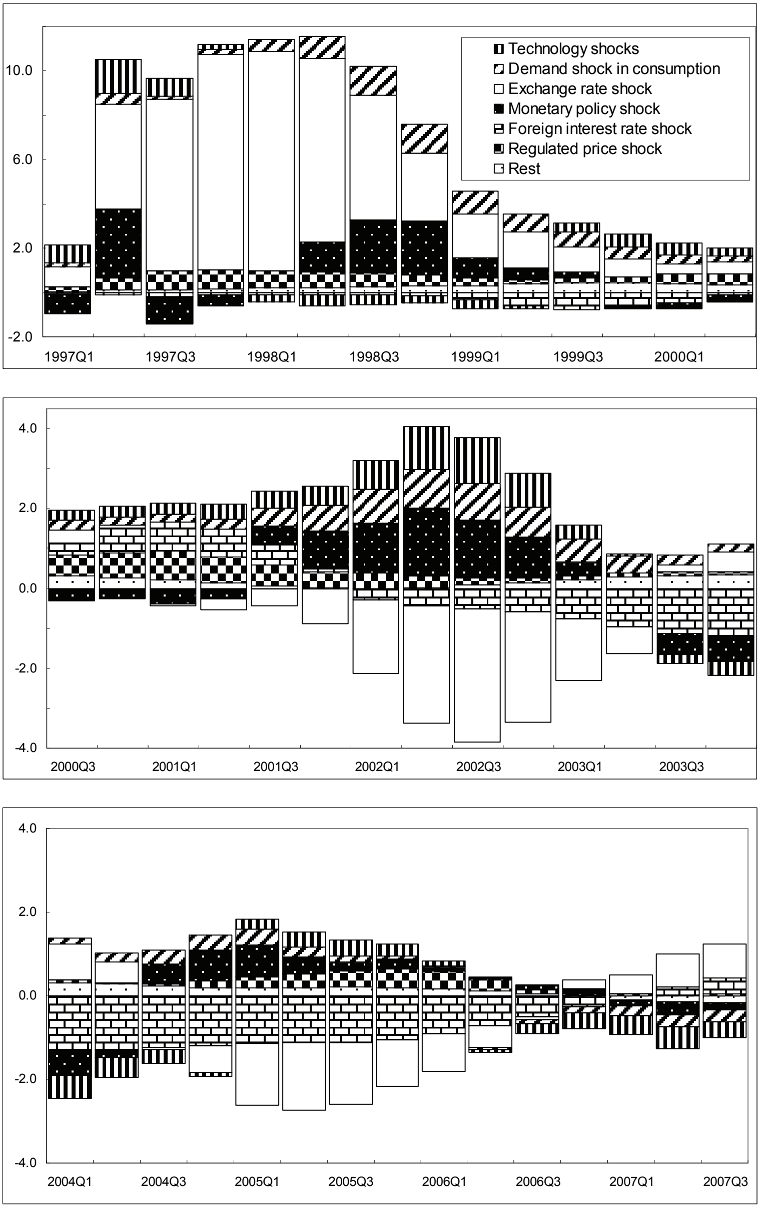
Figure 1 shows the decomposition of nominal interest rates into the contributions of the estimated shocks in the period from 1997Q1 to 2007Q3.[5] In order to facilitate orientation, *Table 2* then sets out brief interpretations of those shocks, while *Table 3* contains exact numbers for the monetary policy shocks. It follows from *Figure 1* that exchange rate shocks were the key determinant of the nominal interest rate (its deviation from the long-term level). The other determinants are shocks to foreign interest rates and monetary policy shocks. The latter are crucial for the purpose of our analysis. A monetary policy shock appears in the figure whenever the nominal interest rate was not fully consistent with the observed state of the economy and the inflation target. It also holds that whenever such a shock is positive (negative), nominal interest rates were set higher (lower) than ideally consistent with the observed state of the economy and the inflation target.

The first period following the introduction of inflation targeting for which we identify a sequence of positive monetary policy shocks starts in 1998Q2 and ends in 1999Q3. The largest contribution of the monetary policy shock is estimated for 1998Q3–Q4. As a result, we may note that especially during the second half of 1998, monetary policy was more restrictive than corresponded to the observed state of the economy and the inflation target. At the same time, the behavior of the other shocks suggests that the monetary policy shock occurs due to an insufficiently quick response by the central bank to the fading anti-inflationary effect of the exchange rate shock. We can only speculate on the reasons for such a slow response.

An explanation may be suggested by considering the monetary policy risk aversion at the launch of inflation targeting. At that time, monetary policymakers faced numerous uncertainties regarding the estimation of equilibrium trends and the power

[5] In order to obtain a more robust estimate, we use the data since 1996.

FIGURE 1 Decomposition of Interest Rates (deviation from the long-term level in pp)



Source: Own calculation

of the transmission channel, as well as an inefficient banking sector and under-developed financial market. They were probably also aware that had the declared disinflation been unsuccessful, any subsequent attempt would have been much more expensive. Therefore, the decision to decrease the interest rate more slowly than would

TABLE 2 Basic Interpretation of Shocks

Technology shocks	Sum of shocks identified in all technology trends.
Demand shock in consumption	Shock identified in household consumption.
Exchange rate shock	Shock identified in the exchange rate equation (the uncovered interest rate parity)
Monetary policy shock	Shock identified in the monetary policy rule.
Foreign interest rate shock	Shock identified in foreign interest rates.
Regulated price shock	Shock identified in the regulated price development.
Rest	Sum of all other identified shocks (such as foreign demand, investments and government consumption).

TABLE 3 Impact of Monetary Policy Shocks on the Deviation of the Nominal Interest Rate from Its Long-term Level (in pp)

1997Q1	-0.91	2000Q4	-0.25	2004Q3	0.49
1997Q2	3.13	2001Q1	-0.38	2004Q4	0.74
1997Q3	-1.24	2001Q2	-0.26	2005Q1	0.76
1997Q4	-0.49	2001Q3	0.48	2005Q2	0.40
1998Q1	-0.01	2001Q4	0.95	2005Q3	0.21
1998Q2	1.35	2002Q1	1.26	2005Q4	0.25
1998Q3	2.38	2002Q2	1.68	2006Q1	0.12
1998Q4	2.43	2002Q3	1.44	2006Q2	0.07
1999Q1	0.92	2002Q4	1.02	2006Q3	0.12
1999Q2	0.51	2003Q1	0.36	2006Q4	0.15
1999Q3	0.30	2003Q2	-0.02	2007Q1	-0.13
1999Q4	-0.09	2003Q3	-0.52	2007Q2	-0.31
2000Q1	-0.27	2003Q4	-0.61	2007Q3	-0.17
2000Q2	-0.34	2004Q1	-0.63		
2000Q3	-0.30	2004Q2	-0.19		

Source: Own calculation

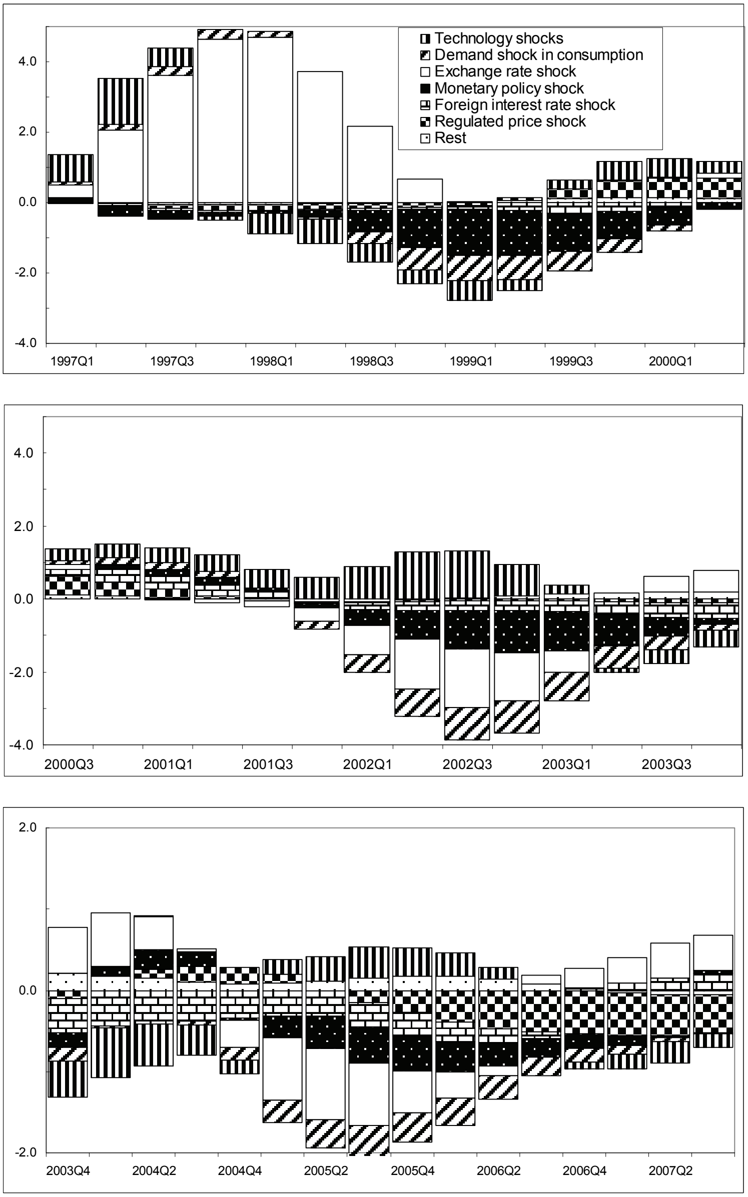
otherwise have been optimal might have been motivated by risk aversion that led monetary policymakers to transfer into the present time a portion of the expected costs of future disinflation attempts.

Figure 2 and *Table 4* consistently describe monetary policy as a significant and comparatively long-term factor of negative deviations of inflation from the inflation target. The above-discussed monetary policy shock itself pushes inflation below the inflation target during the period from 1998Q2 to 2000Q2, i.e., over the first two years of the new monetary policy regime.

During the second half of 1999 and then until the second half of 2001, we identify no marked monetary policy shocks. It is therefore possible to say that, during that period, nominal interest rates were set consistently with the inflation targets and the observed economic developments.

However, as illustrated in *Figure 1*, the situation began to change in the second half of 2001, when a marked exchange rate shock hit the economy, followed by another shock of falling foreign interest rates. A positive monetary policy shock arose

FIGURE 2 Decomposition of Inflation (deviation from the long-term level in pp)



Source: Own calculation

concurrently with a negative exchange rate shock. This may indicate that the reason behind the monetary policy shock might have been an insufficiently quick response by the central bank. The size of the monetary policy shock rises gradually, while the central bank succeeds in damping the tendency as late as in 2002Q3, when the ab-

TABLE 4 Impact of Monetary Policy Shocks on the Deviation of Inflation from Its Long--term Level (in pp)

1997Q1	0.14	2000Q4	0.12	2004Q3	0.17
1997Q2	-0.31	2001Q1	0.20	2004Q4	-0.03
1997Q3	-0.24	2001Q2	0.23	2005Q1	-0.26
1997Q4	-0.12	2001Q3	0.11	2005Q2	-0.40
1998Q1	-0.04	2001Q4	-0.12	2005Q3	-0.45
1998Q2	-0.20	2002Q1	-0.42	2005Q4	-0.43
1998Q3	-0.61	2002Q2	-0.77	2006Q1	-0.37
1998Q4	-1.09	2002Q3	-1.04	2006Q2	-0.29
1999Q1	-1.29	2002Q4	-1.16	2006Q3	-0.23
1999Q2	-1.27	2003Q1	-1.08	2006Q4	-0.19
1999Q3	-1.08	2003Q2	-0.85	2007Q1	-0.12
1999Q4	-0.79	2003Q3	-0.51	2007Q2	-0.03
2000Q1	-0.47	2003Q4	-0.17	2007Q3	0.04
2000Q2	-0.20	2004Q1	0.11		
2000Q3	0.00	2004Q2	0.25		

Source: Own calculation

solute size of the monetary policy shock gets decreased, despite the culminating exchange rate shock.[6] The described monetary policy shock then adds to the pressure on inflation to decrease below the inflation target, as can be seen from the inflation decomposition in *Figure 2* and *Table 4*. The shock itself ebbs away in the second half of 2003, although its impact on inflation is present until the end of that year.

The period from 2003Q3 to 2004Q2 was a time of negative monetary policy shocks. Nominal interest rates were kept lower during this period than was consistent with the observed state of the economy and the inflation target. We identify the most marked negative shock in 2004Q1, during the concurrent effects of a positive exchange rate shock.[7] In 2004Q3, however, a positive monetary policy shock appears once again and survives, albeit very modestly, until 2006Q1. Identically to the previous example, the positive monetary policy shock is accompanied by a negative exchange rate shock. As opposed to the previous period, the exchange rate shocks tend to follow the monetary policy shocks. As can be seen in *Figure 1*, while a positive monetary policy shock occurs in 2004Q3, a negative exchange rate shock follows only in the fourth and subsequent quarters. That might suggest that the central bank itself could possibly have partly contributed to the exchange rate shock occurrence, as the foreign interest rate caused strong pressure for a low level of domestic interest rates during that period.[8] It is therefore possible that the observed state of the economy was not entirely accurately assessed in the analyses or monetary policy decision or that the monetary policy settings were adjusted at an unsuitable point in time.

[6] Interest rates were lowered by 0.75 pp in July 2002. During the first half of 2002, the CNB was additionally making efforts to stop the exchange rate appreciation by intervening in the foreign exchange market.

[7] In 2004Q1, the temporary depreciation of the koruna peaked. The koruna recorded an average of 32.90 in that quarter.

[8] In August 2004, the interest rate was increased by 0.25 pp. The decision to increase it followed the July forecast, which was consistent with a rising trajectory of interest rates (see the July 2004 Inflation Report).

Looking more closely at the results, one cannot ignore the fact that the impact of monetary policy shocks on inflation is more persistent than the very existence of the shocks. Out of the 39 observed periods (counted from 1998Q1), monetary policy was more anti-inflationary than was consistent with the observed state of the economy and the inflation target during 30 periods (and to a comparatively limited extent, i.e., less than 0.1 pp, in three out of these observations).

Whatever the reasons for this behavior, an argument can be certainly made that economic agents, based on their own observations, might gradually begin to perceive the central bank as asymmetric in terms of meeting the published inflation target. In such case, economic agents, instead of regarding the central bank as an institution that, while making mistakes, nevertheless keeps on following its declared inflation target, would perceive it as an institution that in fact pursues another target without actually making many mistakes. In the next section, we therefore discuss the inflation target estimate as an unobserved (state) variable under the circumstances where the central bank monitors the state of the economy and avoids mistakes in the monetary policy settings, while being perceived as such by other economic agents.

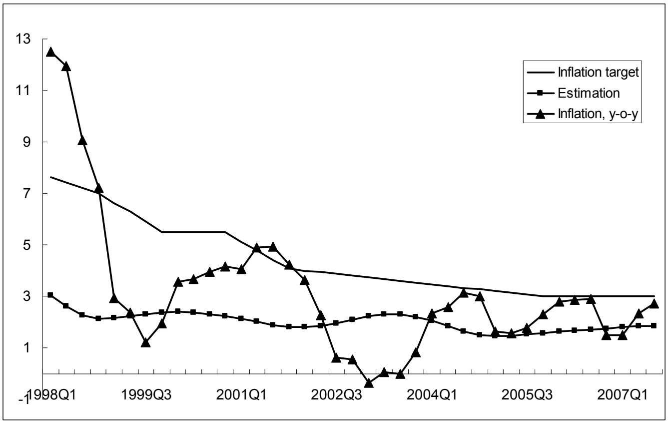
4. The Inflation Target as an Unobserved Variable

In this section we estimate the inflation target as an unobserved variable, while the central bank is assumed to be an inflation targeting central bank that does not make systematic errors. Observed inflation is thus explained also by a time-varying inflation target that may differ from the officially declared one. This approach is similar to the one applied by Ireland (2007), who, based on U.S. data, tried to explain persistent changes in U.S. inflation by the time-varying implicit inflation target of the Federal Reserve. In contrast to Ireland (2007), however, we do not intend to identify factors influencing the inflation target.[9] In our view, the main weakness of the methodology applied by Ireland (2007) is that he assumes a stable policy rule (stable preferences of the FOMC members) over the estimated period and attributes the observed policy stance given the state of the economy to the time-varying inflation target and structural shocks entering its reduced form equation in particular.

We cannot be sure that the policy rule remained stable over the estimated period. In reality the policy rule might have been changing with changes in the composition of the policy body. The methodology applied in Ireland (2007) as well as here is in our view indecisive in terms of identifying the true causes of persistent changes in observed inflation, e.g., whether the central bank simply varies its reactiveness and allows for more or less persistent deviations of inflation from the target, or whether it adjusts its target in the face of structural shocks. Ireland (2007) works with two additional implicit assumptions. First, he assumes that the policy rule is stable over the estimated period and second, he makes a prior assumption that structural shocks do influence the inflation target by designing the model structure so as to get structural shocks present in the reduced form equation for the inflation target. While we also view the policy rule as implicitly stable over the estimated period, we are not confident in allowing the structural shocks to enter the equation for the inflation target.

[9] Contrary to Ireland (2007), structural shocks are not part of the equation for the inflation target once the model is solved for its reduced form.

FIGURE 3 Inflation, the Declared Inflation Target and the Estimate Thereof (in percent)



Source: Own calculation

We therefore estimate the time-varying inflation target without any ambition to explain why the estimated target differs from the declared one. We only show how the inflation target would look if the target was perceived by economic agents as the central bank's real target, while at the same time also being the target truly pursued by the central bank. Obviously, an ideal approach would be to estimate the implicit inflation target understood by economic agents as being the one followed by the central bank, while the bank would in fact follow the formally declared target, with mistakes (monetary policy shocks) being allowed. The present economic literature on heterogeneous expectations and information, however, is still making its first strides and is so far unable to provide a sufficiently robust toolkit for practical application with real data.

Figure 3 presents the inflation target estimate together with the declared target and inflation. The estimate robustness is at the same time derived from the stability of the estimates for other unobserved variables (technology trends, in particular), compared with the situation where the target is observed and monetary policy mistakes are allowed. In other words, the robustness and reliability of the estimate is derived from an identical estimate of the business cycle.

Figure 3 shows that the estimated target was below the declared target level throughout the period under review, and that the absolute difference between the two decreased over time. The earlier periods may have been affected by the rapid disinflation during 1998 and 1999 as well as by our approximation of the inflation target (which was declared only for net inflation for the respective year-ends, and only as a corridor).[10] In 2002–2007, when an explicit continuous inflation target trajectory was in effect, the estimated target moves within the band of 2–3 percent. The es-

[10] A detailed description of the history of the CNB's inflation targets can be found in (Kotlán, Navrátil, 2003) or, more recently, in (Holub, Hurník, 2008). The approximation of the inflation target in headline inflation prior to 2002 is based on the targets published for net inflation. To the midpoints of these targets (the targets were declared as a corridor), 1 pp is added as the estimated average contribution made by regulated prices to headline inflation, while the targets are interpolated to individual quarters using a linear trend (the targets were declared for the year-ends).

timated inflation target may be interpreted as being an explanation for the central bank's behavior in the absence of mistakes in monetary policy implementation, while the business cycle is estimated as in the previous case.

5. Conclusions

The inflation targeting regime was effectively introduced by the CNB at the beginning of 1998. By the fall of that year, observed inflation had fallen markedly below the inflation target published for that year-end. The inflation targets defined for the subsequent year-ends were also undershot in 1999 and 2000. Holub and Hurník (2008) further report that from January 2002, when the continuous target was introduced, till the end of 2007, inflation was below target for some 90 percent of the time, and even below its lower tolerance limit for 51 percent of the time.

The above outline history of the fulfillment of inflation targets necessarily evokes the question of the reasons for their undershooting, including an obvious emphasis on the role of monetary policy itself. This paper has attempted to provide an answer to the question from the perspective of a dynamic general equilibrium model designed and calibrated to fit the Czech economic data.

The strong conclusion of our analysis, derived from the estimation of structural economic shocks, is that in three periods, Czech monetary policy was more restrictive than was consistent with the observed state of the economy and the declared inflation target. Those periods were as follows: 1998Q2–1999Q1, 2001Q3––2003Q2, and 2004Q3–2005Q4. For one period, specifically 2003Q3–2004Q2, we identify a relatively loose monetary policy.

The weak conclusion is our view that the most probable reasons were, in the first period, a slow response to an already fading previous pro-inflationary shock, in the second period, a slow response to an exchange rate appreciation shock in progress, and, in the third period, erroneous directing of interest rates in a situation that no longer justified such a step.

Given the relatively frequent undershooting of the declared inflation target, it is conceivable that the de facto inflation target as perceived by economic agents deviated from the inflation target declared by the CNB. While the latter hypothesis cannot be rigorously tested, our experiment with an unobserved inflation target may provide an approximation. An inflation target fluctuating between 2 and 3 percent allows us to explain well the CNB's behavior in 2002–2007.

REFERENCES

Andrle M, Hlédik T, Kameník O, Vlček J (2008): Putting in Use the New Structural Model of the Czech National Bank. *Proceeding CNB Working paper*.
http://www.iiw.uni-bonn.de/content/institut/summerschool/andrle_cnb_wp_2007.pdf

Beneš J, Hlédik T, Kumhof M, Vávra D (2005): An Economy in Transition and DSGE: What the Czech National Bank's New Projection Model Needs. *CNB, Working Paper Series*, no. 12.

Blanchard OJ, Kahn CM (1980): The Solution of Linear Difference Models under Rational Expectations. *Econometrica*, 48(5):1305–1312

Bulíř A, Šmídková K, Kotlán V, Navrátil D (2008) Inflation Targeting and Communication: It Pays Off to Read Inflation Reports. *IMF Working paper*, no. 08/234.
http://www.imf.org/external/pubs/ft/wp/2008/wp08234.pdf

De Jong P (1991): The Diffuse Kalman filter. The *Annals of Statistics*, 19(2):1073–1083.

Hamilton JD (1994): *Time Series Analysis*. Princeton University Press, Princeton.

Harvey AC (1989): *Forecasting, structural time series models and the Kalman filter*. Cambridge University Press, Cambridge.

Holub T, Hurník J (2008): Ten Years of Czech Inflation Targeting: Missed Targets and Anchored Expectations. *Emerging Economies Finance and Trade* (forthcoming).

Geweke J (1999): Computational Experiments and Reality. Society for Computational Economics, *Computing in Economics and Finance*, no. 401.

Ireland PN (2007): Changes in the Federal Reserve's Inflation Target: Causes and Consequences. *Journal of Money Credit and Banking*, 39(8):35–53.

King R, Watson M (1996): Money, Prices, Interest Rates and the Business Cycle. *Review of Economics and Statistics*, 78:35–53.

Kim J (2003): Functional equivalence between intertemporal and multisectoral investment adjustment costs. *Journal of Economics Dynamics & Control*, 27:533–549.

Kotlán V, Navrátil D (2003): Inflation Targeting as a Stabilisation Tool: Its Design and Performance in the Czech Republic. *Finance a úvěr-Czech Journal of Economics and Finance*, 53(5-6):220–242.

Lucas R (1976): Econometric Policy Evaluation: A Critique. *Carnegie-Rochester Conference Series on Public Policy*, 1:19–46.

Schmidt-Grohé S, Uribe M (2003): Closing Small Open Economy Models. *Journal of International Economics*, 61:163–185.

Smets F, R. Wouters R (2007): Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review*, 97(3, June):586–606.

Yaari M (1965): Uncertain Lifetime, Life Insurance, and the Theory of the Consumer. The *Review of Economic Studies*, 32:137–150.

Uhlig H (1995): A toolkit for analyzing nonlinear dynamic stochastic models easily. *Discussion Paper*, no. 97 (*Tilburg University*, Center for Economic Research).