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Inflation Targeting Flexibility: The CNB's Reaction Function under Scrutiny

Jan Filáček and Ivan Sutóris*

Abstract

This note deals with the issue of inflation targeting flexibility from the perspective of the Czech National Bank and other relevant central banks. We discuss possible ways of increasing the flexibility of the CNB's monetary policy, namely narrowing the targeted and communicated measure of inflation, prolonging the policy horizon, lowering the aggressivity of the rule to deviations of expected inflation from the target, increasing the smoothing of interest rates and responding to real economic developments. Our simulations show that these adjustments in the CNB's reaction function would slightly improve the stability of real output, while at the same time leading to large costs in terms of less stable and less anchored inflation.

Abstrakt

V této výzkumné práci zkoumáme flexibilitu cílování inflace z pohledu České národní banky a dalších relevantních centrálních bank. Diskutujeme možné cesty, jak zvýšit flexibilitu měnové politiky ČNB, konkrétně zúžení cílované a komunikované míry inflace, prodloužení měnověpolitického horizontu, snížení agresivity pravidla na odchylky očekávané inflace od cíle, zvýšení vyhlazování úrokových sazeb a přidání ukazatele reálné ekonomické aktivity do reakční funkce. Provedené simulace ukazují, že tyto úpravy reakční funkce ČNB by vedly k mírně stabilnější reálné aktivitě, avšak za cenu výrazně kolísavější a méně ukotvené inflace.

JEL Codes: C32, E37, E47.

Keywords: Inflation targeting flexibility, monetary policy rules, optimal reaction function.

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1. Introduction

In recent decades, many central banks have adopted the inflation targeting framework, according to which they attempt to keep inflation stable around an announced target. However, it is not necessarily desirable to focus excessively on hitting the target at all times. For example, if the economy overheats while inflation is too low, perhaps as a result of positive supply shocks, a monetary expansion called for by a strict reading of the inflation target would come at the cost of amplifying the business cycle. In practice, central banks thus apply some amount of discretion and may take into account output and financial stability considerations as well. Similarly, at any point in time, the inflation target is usually understood as a commitment to achieve inflation close to the announced target in the near future, not immediately. These approaches are often summarily labelled as flexible inflation targeting.

But how much flexibility should there be? On the one hand, too much flexibility could clearly be in conflict with the central bank's credibility and the anchoring of inflation expectations. On the other hand, central banks' experience of the financial crisis, the subsequent use of unconventional tools and frequent undershooting of their inflation targets have sparked a debate on whether central banks should be more flexible. Therefore, some central banks are considering moving in the direction of greater flexibility. For example, the Reserve Bank of New Zealand was in 2018 given the secondary objective of contributing to supporting maximum sustainable employment, while in the US, the Federal Reserve Bank is currently evaluating its framework and considering alternative approaches, such as average inflation targeting.

In this research and policy note, we discuss the flexibility of inflation targeting in the context of the Czech National Bank's monetary policy. We understand the concept of flexibility broadly as meaning the various considerations that the central bank takes into account in addition to a strict focus on the inflation target. On a theoretical level, this might include an explicit weight on output volatility or other variables in its loss function. From a more applied perspective, flexibility can be viewed through the lens of the central bank's reaction function, which links the interest rate to the current state of the economy, and especially to expected inflation. The reaction function can be made more flexible either by including additional terms beyond the inflation forecast, or by choosing parameters that control the smoothing of interest rates or the forecast horizon. Finally, flexibility can also be achieved in practice by other, less formal means, such as by communicating secondary mandates, escape clauses or variation bands.

This note consists of four parts. In the first part, we briefly outline the theoretical concepts and discuss different specifications of loss and reaction functions in macroeconomic models. In the second part, we contrast these theoretical concepts with the practical experience of both the CNB and other relevant central banks. In the third part, we describe possible adjustments to the monetary policy reaction function which could lead to greater flexibility in the inflation targeting regime. The fourth part, by means of simulations in the Czech National Bank's core prediction model, quantifies the effects of different specifications of the reaction function on key economic variables. Our findings suggest that further attempts to achieve greater flexibility in inflation targeting by the CNB would lead to more volatile and less anchored inflation while providing only a small benefit from additional output stability.

2. Theory

Bernanke and Mishkin (1997) used the notion of "constrained discretion" for a monetary policy that applies some degree of flexibility in response to short-term shocks. However, this flexibility is limited by the need to keep inflation low and inflation expectations anchored. For example, in the event of cost-push shocks, the central bank cannot raise interest rates aggressively in order to keep inflation at its target. This would have significant adverse effects on the economy, for example in the form of a significant slowdown in output growth, and could also potentially harm financial stability. The central bank therefore responds to the shock only gradually, which results in inflation returning to the target with a certain delay.

The notion of flexible inflation targeting was defined by Svensson (1999). He described flexible inflation targeting as a situation where the central bank minimizes a quadratic loss function which includes both the deviation of inflation from the target (the inflation gap) and the deviation of output from its potential (the output gap). If the loss function consists of the inflation gap only, the central bank conducts strict inflation targeting. Woodford (2003) shows that in New Keynesian models, which assume monopolistic competition and rigidity of prices and wages, social welfare is maximized if we minimize the following quadratic loss function:

$$L_t = \pi_t^2 + \lambda y_t^2, \quad (1)$$

where π_t stands for the inflation gap and y_t for the output gap. Coefficient λ determines the relative weight between the two objectives. In the theoretical case of strict inflation targeting $\lambda = 0$, whereas under flexible inflation targeting $\lambda > 0$. A large proportion of theoretical models assume a relatively simple economic setup where no conflicts in achieving both objectives emerge. The central bank can thus focus on attaining the inflation target, and as a side effect it also achieves a zero output gap. This case is called "divine coincidence" (see Blanchard and Galí, 2007). In such models, the optimal value of λ is close to zero. In more complicated models, however, such coincidence no longer applies and the optimal value of λ in the loss function increases.

Some models, including those used by central banks, use more sophisticated loss functions which include other variables besides inflation and output. For example, they might account for interest rate smoothing (Rudebusch and Svensson, 1999):

$$L_t = \pi_t^2 + \lambda y_t^2 + \gamma(i_t - i_{t-1})^2. \quad (2)$$

A similar loss function is defined by Norges Bank, which also takes into consideration financial-stability objectives and aims to minimize the deviation of interest rates from equilibrium (Evjen and Kloster, 2012):

$$L_t = \pi_t^2 + \lambda y_t^2 + \gamma(i_t - i_{t-1})^2 + \tau(i_t - i_t^*)^2, \quad (3)$$

where the parameters are set to the following values: $\lambda = 0.75$, $\gamma = 0.25$ and $\tau = 0.05$, and i^* stands for the policy-neutral interest rate.

The specification of the loss function and the other equations of a model determine the "reaction function". The reaction function is an equation describing the optimal behaviour of a central bank given the structure and parametrization of the model (which *inter alia* reflects the chosen monetary policy regime). In other words, the reaction function yields minimalized values of the loss function.

The reaction function should not be confused with the statistical relationship between interest rates and inflation that can be derived from historical data, the most famous example being the well-known Taylor rule (Taylor, 1993):

$$i_t = \pi_t + 0.5y_t + 0.5(\pi_t - 2) + 2\ . \qquad (4)$$

The original Taylor rule assumed a real equilibrium interest rate of 2% per annum and an equal weight set on the deviation of inflation from the implicit 2% target and the output gap. This rule quite accurately captured the Fed's behaviour in 1987–1993. Therefore, the Taylor rule was not originally intended to be normative, i.e. to provide guidance on what the central bank should do. Instead, it provided only an approximation of the observed relationship between inflation, output and interest rates. Over time, however, the "Taylor rule" notion has been increasingly used to describe the normative reaction function.

Woodford (2001) shows that if economic agents are forward-looking, the "Taylor principle" must be met to ensure convergence of all variables to their long-term equilibrium values, including convergence of inflation to the central bank's target. Nominal interest rates have to rise by more than inflation has risen, i.e. the real interest rate should increase to ensure policy tightening and thus bring inflation back to the target. In the logic of New Keynesian models with rational expectations[1] – as Cochrane (2009, 2011) shows – this is a key stabilizing mechanism, because the promise and willingness of the central bank to respond adequately to an inflationary shock is a necessary condition for inflation to be anchored at the target.[2]

While the implied reaction function is (in addition to other equations of the model) derived from the loss function, this does not mean that its specification unconditionally copies the loss function. Svensson (1997), using a simple three-equation model, shows that in the case of strict inflation targeting (i.e. the loss function contains only the inflation gap), an optimal reaction function might include an output gap even with a higher weight than in the case of flexible inflation targeting (where the output gap with non-zero weight appears directly in the loss function). Flexible inflation targeting in this simple illustrative model leads to lower coefficients in the reaction function for both inflation and output as a result of a less aggressive response of the central bank to shocks.

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[1] Taylor's principle can be relaxed under certain circumstances. One example is when economic agents have limited rationality (see McCallum, 2009); another is an open economy model where foreign policies implicitly contribute to stabilizing domestic inflation. In these cases, the nominal anchor can be ensured for an inflation coefficient of less than one.

[2] However, this willingness of the central bank does not mean that a rate increase must fully comply with the reaction function. This is because economic agents will, in anticipation of the central bank's response, project nominal shocks into prices less than if they expected no reaction of the central bank. Therefore, the observed elasticity of interest rates to the inflation gap can be significantly different from the parameter in the reaction function. As Andrle and Brůha (2014) show, the relationship between the observed elasticity and the reaction function parameter is typically inverse. From this dichotomy between the statistical relationship and the normative reaction function, it follows that econometric estimates of the reaction function based on historical data face the problem of endogeneity and may not be suitable for monetary policy purposes. Calibrating the reaction function solely on the basis of observed correlations can lead to loss of the nominal anchor and to significant monetary policy errors.

Ball (1999) and Svensson (2000) propose to extend the reaction function of a central bank which governs a small open economy to include the real exchange rate and possibly also foreign interest rates and a risk premium. On the other hand, Leitemo and Söderström (2005) in the open economy model show that the simple Taylor rule is an optimal reaction function even under such circumstances, and that the benefits of extending the rule to include the exchange rate are rather marginal. Moreover, the rule with the exchange rate surprisingly results in a negative exchange rate coefficient, i.e. the central bank responds to a depreciation of the exchange rate by setting lower interest rates than in the Taylor rule.

In models with forward-looking expectations, it is possible to consider replacing the actual inflation gap and other relevant variables in the reaction function with their expected values (Woodford, 2003). Batini and Haldane (1999) argue that forward-looking reaction functions yield higher social welfare. Batini and Nelson (2001) investigate the optimal horizon at which inflation should be on target in the future depending on the model specification. In the model without forward-looking expectations (VAR model), a relatively long horizon (about four years) is optimal, while in the model with forward-looking expectations (structural model), the optimal horizon is much shorter. The explanation is that in their decisions today, forward-looking agents take into account the future settings of monetary policy, thereby shortening the monetary policy transmission.

In response to the global financial crisis, it has recently been debated whether financial variables (in addition to interest rates) or asset prices should be included in the loss and reaction functions. Gourio et al. (2018) introduce a credit gap as the deviation of the actual credit volume from the situation that would exist if the economy operated without shocks and under flexible prices. This extended reaction function has advantages especially when loans are subject to considerable fluctuations and the economy is sensitive to these developments. Prior to the financial crisis, the possibility of responding to asset prices was discussed ("leaning against the wind", e.g. Bernanke and Gertler, 1999). On the other hand, Tonner and Brůha (2014) show for the Czech Republic that including real estate prices in the reaction function would have very little impact on the volatility of inflation or on the volatility of domestic real variables.

All the above literature assumes the existence of a point target and seeks to minimize the deviation of actual inflation from the point target. This premise is related to the linearity of the models, in which targeting a band would lead to nonlinear, time-inconsistent behaviour of the central bank. At the same time, a point target is considered to be the state-of-the-art when referring to central bank transparency (Al-Mashat et al., 2018).

3. Flexibility of Selected Central Banks

Inflation targeting is, in principle, a regime based on a rule that is more or less explicit across central banks. However, no central bank follows the rule strictly (on "autopilot"). On the contrary, central banks tend to diverge from their rules, and their policies might be best described as constrained discretion. With regard to flexible inflation targeting, which we interpret as meaning accounting for other variables in addition to the inflation gap in the reaction function, central banks are hampered by several obstacles. These include data uncertainty (the existence of revisions) when measuring output, and uncertainty in the estimates of potential output (there are a number of alternative definitions, e.g. trend output, equilibrium output, steady-state output). Even for a given definition of potential output, different output gap estimation methods provide contradictory results and might lead to persistent bias in monetary policy decisions (Cukierman, 2008). Also, assigning relative weights to variables in the loss/reaction function is a non-trivial task. In this section, we describe the current practice of the Czech National Bank and take a look at the application of the key elements of flexibility over twenty years' of inflation targeting. We then compare this experience with the current flexibility of another eleven central banks from around the world.

3.1 Flexibility of the Czech National Bank – Past and Present

The CNB started targeting inflation in 1998. The first targets were set for the end of the year in the form of an interval for year-on-year "net inflation" (CPI inflation adjusted for regulated prices and the effects of indirect tax changes). Targeting this narrow consumer price index brought a considerable amount of flexibility to the inflation targeting regime right from the start. The CNB did not respond to the then significant and unpredictable first-round effects of changes in regulated prices and indirect taxes. At the same time, a relatively wide range of "escape clauses" (exceptions, caveats) were set, defining types of shocks whose price effects the CNB would look through.

In the early years, the macroeconomic model was not used in the decision-making process. The decisions were based on a "conditional", more or less expert macroeconomic forecast that assumed stability of nominal interest rates at the current level. This forecast signalled only the direction, not the magnitude, of the necessary rate adjustments. It did not contain a reaction function whose parameters could be analysed. However, the decision of the Bank Board was already oriented towards the future about one year ahead, and even from the minutes of the Bank Board's meetings at that time it is clear that the decisions were derived from the evolution not only of inflation, but also of other macroeconomic variables.

In 2002, the CNB switched to headline inflation targeting. However, it retained the option of applying escape clauses in the event of swings in regulated prices or indirect taxes. In practice, however, the escape clauses were applied mainly to changes in indirect taxes, and for this reason the CNB began publishing inflation adjusted for the first-round effects of indirect tax changes (later referred to as monetary policy-relevant inflation). In the summer of 2002, the CNB switched to "unconditional forecasts" and the Quarterly Prediction Model (QPM) became the core prediction tool. The QPM was a small, gap model inspired by New Keynesian economics. The model contained a reaction function with the following specification:

$$i_t = 0.5 i_{t-1} + 0.5(\tilde{\imath}_t + 5(E_t \pi_{t+4} - \tilde{\pi}_t) + \bar{y}_t) + \varepsilon_t \,. \quad (5)$$

The reaction function included both the deviation of expected annual (monetary policy-relevant) inflation from the target $(E_t \pi_{t+4} - \tilde{\pi}_t)$ and the output gap $\bar{y}_t$. The weight of the output gap was only a fifth of that of the inflation gap (Coats, Laxton and Rose, 2003). $\tilde{\imath}_t$ stands for the policy-neutral interest rate.

The time horizon of the inflation gap in the reaction function was set to one year (the central bank responds to expected inflation four quarters ahead). The selection of this horizon means that the central bank does not respond to observed one-off inflation shocks (at time *t*), since these shocks by definition fall out of the year-on-year inflation calculation after four quarters (at time *t*+4).

Monetary policy thus reacts only to possible second-round impacts of inflation shocks, which can occur through inflation expectations, wage bargaining, price rigidities and so on.

In public communications, the concept of the horizon of most effective transmission – later renamed the monetary policy horizon – was used. This horizon is set as the time period from 12 to 18 months ahead in which a change in interest rates at time t has the greatest impact on inflation and on which the Czech National Bank focuses when deciding on interest rates at time t.

Compared with the basic version of Taylor's rule (4), the reaction function (5) included interest rate smoothing, which can be viewed as another element of inflation targeting flexibility (see the box in section 3). On the other hand, the reaction function (5) was more aggressive to the inflation gap than the original Taylor rule would imply – the product of the coefficients 0.5 and 5 in (5) exceeds the sum of the coefficients 1 and 0.5 in (4).

In 2006, the previous target in the form of a continuously decreasing band for overall inflation was replaced by a point target. At the same time, a variation band (officially called a tolerance band) of ±1 percentage point was used, and it was announced that "the CNB will endeavour to ensure that the actual inflation outturn does not differ by more than one percentage point in either direction from this target". However, the existence of the band does not mean that the CNB does not strive to achieve the point target, or that it can choose the targeted inflation value within the band. The variation band is only a communication tool that reflects the impossibility to accurately achieve the point inflation target on a permanent basis.

In mid-2008, the QPM model was replaced by a structural model of general equilibrium (a DSGE-class model) called "g3" (Andrle et al., 2009). g3 is not a gap model by construction, so it does not include the output gap, and only the inflation gap appears in the logarithmic reaction function:

$$\log\ i_t = 0.75 \log\ i_{t-1} + 0.25 \left(\log\ \tilde{\imath}_t + 2\left(\log\ E_t\pi_{t+4} - \log\ \tilde{\pi}_t\right)\right) + \varepsilon_t\ . \tag{6}$$

This is a calibrated reaction function with similar impulse responses (dynamic simulation properties of the model) as the QPM model used to have. In this sense, the g3 reaction function corresponds to and describes the previous behaviour of the CNB in setting interest rates.

The absence of the output gap in the reaction function (6) does not mean that the CNB does not take into account information from the real economy, as this information is reflected in the inflation forecast through endogenous mechanisms of the model (Svensson, 1997) and also through expert judgement when setting the initial conditions of the forecast.

Identically to the QPM model, the g3 model works with ex-ante explicit escape clauses, which have been routinely applied to changes to indirect taxes. Monetary policy-relevant inflation (inflation adjusted for the first-round effects of changes to indirect taxes) enters the reaction function (6). Developments in regulated prices are incorporated into the forecast as unexpected shocks. This limits the monetary policy reaction as compared to the reaction to other assumptions of the forecast, which are treated as expected shocks, and results in occasional deviations of forecasted headline inflation from the 2% inflation target at the monetary policy horizon.

3.2 Flexibility of Selected Other Central Banks

In this section, we describe the experience of flexible inflation targeting in a sample of countries. Our sample includes three major central banks – the U.S. Federal Reserve System (Fed), the European Central Bank (ECB) and the Bank of England (BoE), selected inflation-targeting central banks in the European Union – the Sveriges Riksbank, the Magyar Nemzeti Bank (MNB) and the Narodowy Bank Polski (NBP), and major inflation-targeting central banks from countries outside the European Union – the Reserve Bank of New Zealand (RBNZ), the Norges Bank, the Schweizerische Nationalbank and the Bank of Canada. Together with the Reserve Bank of Australia (RBA) and the Czech National Bank, we look at twelve countries in total.

All these central banks label their monetary policy as flexible, and they emphasize that monetary policy is focused on the medium term and that inflation might deviate from the target in the event of significant shocks. Interestingly, the degree of flexibility is not directly linked to the legal definition of the central bank's mandate, which typically mentions only the primary objective of price stability. In this section, we analyse the key elements of the flexibility of the monetary policy regime in the banks reviewed: the existence of a dual mandate or a secondary target, communication of a variation band around the target, communication of a monetary policy horizon, and the existence of explicit escape clauses in fulfilling the inflation target. We also scrutinize whether the central bank's reaction function as represented by the core model includes other variables besides inflation, and what the time horizon of the inflation gap is. It needs to be said that although we tried to achieve the maximum degree of objectivity and comparability of central banks, we could not avoid some degree of subjectivity in several cases, mainly due to a lack of accurate information. We should also stress that our review covers only the officially communicated procedures and policy frameworks, which might differ from the day-to-day decision-making of the banks' boards. For example, some central bankers might prefer more flexible treatment of escape clauses, whereas others might prefer more rule-based policy. Also, some central banks rely heavily on the core model in their forecast formulation and decision-making, whereas others use the model as only one of many relevant inputs when shaping the expected economic outlook and policy decision.

According to the Treaty on the Functioning of the European Union (EU), the ECB's primary objective is to maintain price stability; its secondary objective is to support the general economic policies in the Union with a view to contributing to the achievement of the objectives of the Union. The ECB interprets its primary mandate as keeping inflation below, but close to 2%. It uses neither a variation band nor a monetary policy horizon in its communications. In the event of cost-push shocks, it declares only a gradual monetary policy response (ECB, 2011). It uses a range of models, and the two key ones – NAWM II (New Area-Wide Model II) and NMCM (New Multi-Country Model) – work with an output gap. While the NMCM is estimated by the GMM method using real-time data (Dieppe, Pandiella and Willman, 2011), NAWM II is a DSGE model that uses the European Commission's estimate of potential output (Coenen, Karadi, Schmidt and Warne, 2018). In both models, the reaction function contains the current (contemporaneous) output gap. The NAWM II reaction function operates with the current inflation gap, while the NMCM uses the inflation gap one quarter ahead. However, these models serve only as analytical or simulation tools. The ECB's macroeconomic forecasts are based on market outlooks for future interest rates and not on the endogenous monetary policy rule (ECB, 2016).

By law, the Federal Reserve is obliged to achieve three goals: maximum employment, stable prices and moderate long-term interest rates. Stable prices and moderate long-term interest rates can effectively be attained by keeping inflation low, so the Fed's statutory mandate is broadly interpreted as a dual mandate. Since January 2012, the FOMC has claimed that achieving its dual mandate is consistent with maintaining annual inflation at 2%. The targeted variable is the PCE (Personal Consumption Expenditures) index, which is less volatile than the CPI index. The Fed does not use a variation band, a monetary policy horizon or escape clauses. It uses several models for forecasting. These are run both by economists at the Fed's Board of Governors and by the economists of several Reserve Banks (the Chicago Fed, the New York Fed and the Philadelphia Fed). The model with the longest tradition and most citations is the FRB/US Model. This large-scale estimated general equilibrium model of the U.S. economy has been in use at the Federal Reserve Board since 1996. The model allows for different specifications of the reaction function, but typically these rules consist of the current inflation gap and the current output gap (Fed, 2018).

The Bank of England became independent in 1998, with maintaining price stability defined as its primary legal objective and supporting the economic policy of the government as its secondary objective. The inflation target is set at 2% without any variation band. However, the BoE is required to send an open letter to the Chancellor if inflation moves away from the target by more than 1 percentage point, which can be considered a de facto variation band. The Bank of England has announced neither an explicit policy horizon nor escape clauses. Similarly to the ECB and the Fed, the Bank of England uses a suite of forecasting models. The central model is a DSGE model called COMPASS (Burgess et al., 2013). In this model, monetary policy sets interest rates according to the average quarterly inflation gap over the last four quarters and to the current output gap. The output gap is measured either as the difference between value added and the level of value added that would prevail if all prices were perfectly flexible, or as the difference between output and the level of output implied by the value-added production function with inputs measured at trend from the production function. In a similar vein to the ECB, the BoE's official forecast is conditioned on market interest rates and not on the endogenous reaction function.

The Sveriges Riksbank's legal mandate is to maintain price stability, which is interpreted as 2% inflation. Since September 2017, the Riksbank has used a variation band of 1–3% to illustrate the fact that monetary policy is not able to steer inflation in detail. It does not communicate a monetary policy horizon or escape clauses. Its core DSGE model RAMSES II captures the stabilizing role of monetary policy using a reaction function featuring the current inflation gap, current hours worked and the first differences of those gaps (Adolfson et al., 2013). The reason for using hours worked (estimated using the Hodrick-Prescott or KAMEL filter[3]) instead of the output gap is that hours worked is an observed variable and that this specification has a slight empirical advantage.

The Magyar Nemzeti Bank's statutory primary objective is to achieve and maintain price stability. Its secondary objective is to support the economic policy of the government. The price stability objective is interpreted as 3% inflation, which since 2015 has been complemented with a ±1 percentage point variance band. A monetary policy horizon with a span of 5–8 quarters is used in communication. The MNB explicitly allows for the possibility of not reacting to the first-round effects of certain one-off shocks. In its core gap MPM (Monetary Policy Model), it sets interest

[3] KAMEL is a model developed by the National Institute of Economic Research for demographic description of labour market variables.

rates corresponding to the inflation gap four quarters ahead and to the current output gap (Baksa at al., 2013).

The Narodowy Bank Polski is given the legal objective to maintain price stability. Its secondary objective is to support the economic policy of the government. The NBP pursues an inflation target set at 2.5% with a ±1 percentage point fluctuation band. This band has been used in an ex ante manner in recent years, as the NBP tolerates the inflation forecast being close to the boundary of the variation band.[4] The NBP does not set its monetary policy horizon explicitly; the length of the monetary policy transmission horizon is stated to be several quarters and this length can change over time. The NBP does not use explicit escape clauses. Its hybrid core model NECMOD, in which the long-term equilibrium is based on theoretical foundations while the short-term dynamics are dependent on econometric estimates, describes monetary policy as a function of the inflation gap one quarter ahead and the current output gap (Greszta et al., 2012).

According to the Norges Bank Act, the bank is owned by the government, and the King and the Ministry of Finance play a significant role in its decision-making (for example, the King is given the right to make decisions on the exchange rate arrangement[5] and the Ministry of Finance has a say in decisions of "special importance"[6]). The mandate of the Norges Bank is defined rather broadly in the Act (issuing currency, promoting an efficient payment system and monitoring developments in the money, credit and foreign exchange markets). A more specific objective is provided by a royal decree giving the bank the obligation to maintain monetary stability by keeping inflation low and stable. The inflation target is set to 2% without any variation band. The decree also states that inflation targeting should be flexible so that it can contribute to high and stable output and employment and to counteracting the build-up of financial imbalances. However, the Norges Bank communicates neither a monetary policy horizon nor escape clauses. The core DSGE model NEMO (Norwegian Economy Model) incorporates a reaction function containing the current inflation gap and the current output gap (Kravik and Paulsen, 2017).

The Schweizerische Nationalbank is legally obliged to ensure price stability. In doing so, it takes account of economic developments. The SNB does not use an explicit inflation targeting framework, although its framework is often qualified as de facto inflation targeting. Price stability is defined as inflation below 2%, with no variation band. The SNB does not communicate a monetary policy horizon and applies escape clauses to one-off shocks such as a sudden surge in oil prices or strong exchange rate fluctuations. A suite of models is used, among them a DSGE model (Rudolf and Zurlinden, 2014) which has a reaction function featuring the current inflation gap, the output gap and change in the output gap.

[4] See, for example, the November 2018 forecast (NBP, 2018), which expected annual price growth in the range of 1.7–1.9% in 2018, 2.6–3.9% in 2019 and 1.9–3.9% in 2020. The minutes of the November 2018 meeting read: "…most Council members emphasised that in line with the November NBP forecast – based on conservative assumptions on the scale of energy price increases – inflation should remain within a band for deviations from the NBP inflation target…" and "In line with the projection, inflation in 2019 will probably exceed 2.5%, boosted, among others, by a rise in energy prices remaining beyond the impact of monetary policy, but will remain within a band for deviations from the target". Based on this forecast, the Monetary Policy Committee decided to keep interest rates unchanged. The NBP's band can thus be considered a "tolerance range" or "control range" in the Al-Mashat et al. (2018) methodology.

[5] "The King makes decisions regarding the exchange rate arrangement for the krone and changes in the exchange rate level of the krone."

[6] "Before the Bank makes any decision of special importance, the matter shall be submitted to the ministry."

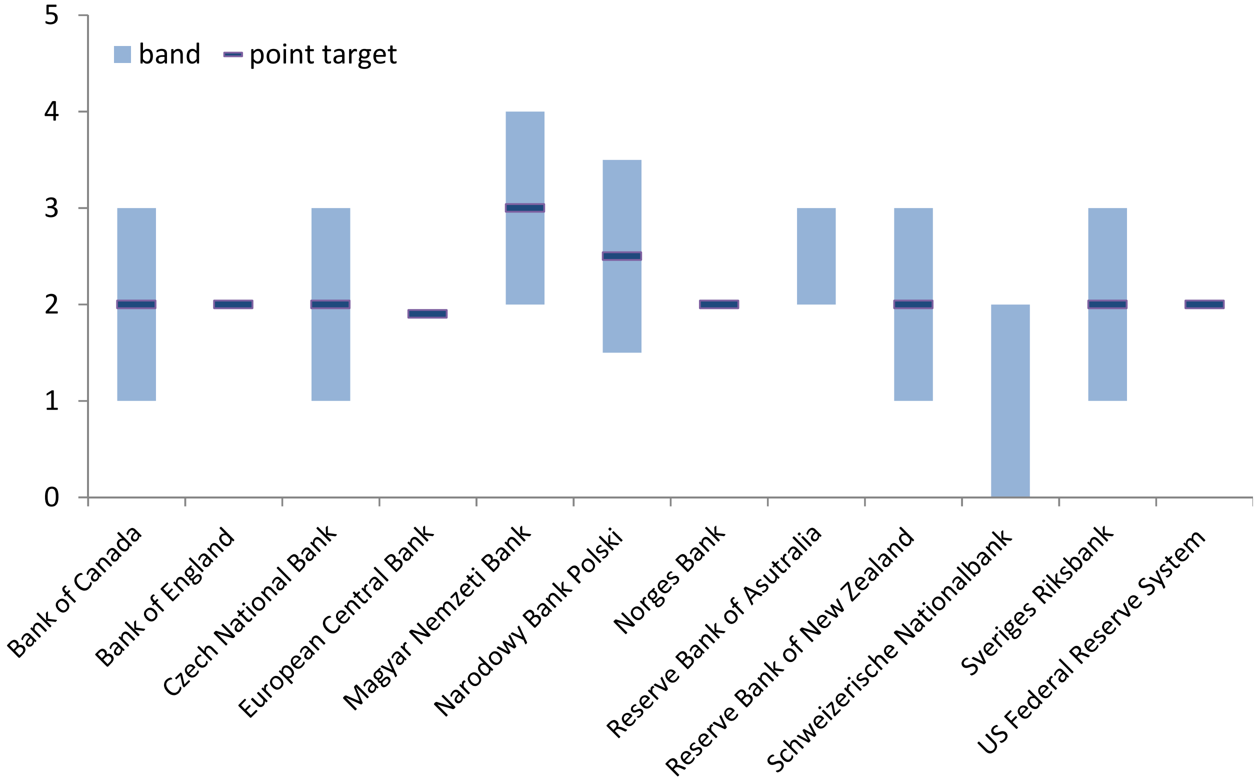
The objectives of the Reserve Bank of Australia are set out in the Reserve Bank Act as contributing to the stability of the currency, the maintenance of full employment and the economic prosperity and welfare of the people of Australia. Since the early 1990s, this statutory mandate has been interpreted as inflation between 2% and 3%. Monetary policy aims to achieve this over the medium term so as to encourage strong and sustainable growth in the economy. Within this framework, the RBA does not use a variation band or a monetary policy horizon. Its decisions are based on a DSGE model which assumes that the central bank reacts to the current inflation gap, the current output gap and its change, and to change in the real exchange rate (Rees, Smith and Hall, 2015).

The Reserve Bank of New Zealand Act sets the main objective of achieving and maintaining price stability over the medium term and reducing undesirable fluctuations in employment and economic activity. This legal objective is interpreted by the Minister of Finance in the Remit to the Monetary Policy Committee. The current (February 2019) Remit requires the RBNZ to keep inflation between 1% and 3% on average over the medium term, with a focus on keeping future average inflation near the 2% target midpoint. The Remit also states that the RBNZ should support maximum sustainable employment and should discount events that have only transitory effects on inflation. The monetary policy horizon is 6–8 quarters (Plantier, 2002) but is not actively used in communication. In the past, the Policy Target Agreement (PTA) included a list of escape clauses. The RBNZ no longer explicitly lists situations in which it is willing to tolerate inflation outside the target. The DSGE model KITT (Kiwi Inflation Targeting Technology) uses a rather simple reaction function using the inflation gap one quarter ahead (Lees, 2009).

The Bank of Canada has a rather broadly defined legal mandate "to promote the economic and financial welfare of Canada". This goal is achieved using an inflation targeting framework. The target is set at 2%, the midpoint of a 1–3% target range. The BoC stresses the flexibility of the regime. This is reflected in, among other things, a rather long monetary policy horizon of 6–8 quarters, which varies depending on the nature and persistence of the shocks hitting the economy. The BoC explicitly mentions three situations that may lead to an extension of the horizon: (i) large and persistent shocks to inflation, caused, for example, by an increase in oil prices or the disinflationary effects of a serious global economic slowdown, including the possible constraints of the zero lower bound on interest rates, (ii) financial imbalances, for example when a tighter monetary policy that keeps inflation below target longer than usual could help to prevent a build-up of financial imbalances, (iii) "risk management" of future inflation developments, for example when there is a relatively high risk that a negative shock will materialize, the bank can, through a longer-than usual horizon, "buy some insurance" against that risk. The monetary policy in the core DSGE model TOTEM II (Terms-of-Trade Economic Model) sets interest rates according to the inflation gap (two quarters ahead) and the current output gap (Dorich et al., 2013).

Confronting the experience of the central banks reviewed above in the field of inflation targeting flexibility (summarised in Appendix 1) with the current practice of the CNB, it can be said that the CNB ranks among the banks with the most flexible policy frameworks. Like other EU countries, and in line with the EU legislation, the CNB's primary mandate of price stability is accompanied by a secondary target (9 of the 12 banks in our sample have a dual mandate or a secondary target). The CNB's inflation target is complemented by a variation band (which 6 out of the 12 banks have) which takes into account the fact that meeting the target with a precision of a tenth of a percentage point is rather unlikely due to natural inflation volatility. The vast majority of the banks in our sample with a variation band do not interpret it as a band of action/inaction (called a "tolerance range" in Al-Mashat et al., 2018). It is interpreted rather as a tool for communicating the uncertainty that the central bank faces in achieving its mandatory goal (a variation band), or as a metric for ex-post assessment of how successful the central bank was in meeting its targets. Two central banks – the Reserve Bank of Australia and the Schweizerische Nationalbank – have targets in the form of a band (see Figure 1).

Figure 1: Comparison of Inflation Targets



The flexibility of the CNB is strengthened by active and explicit communication of escape clauses (which 5 out of the 12 banks have). The communication of the CNB differs from that of the other central banks in terms of the length of the monetary policy horizon. Most of them (8 banks) do not communicate a horizon at all. Those that do usually have a longer horizon (typically 6–8 quarters). Regarding the reaction function, on the one hand the CNB does not have real economy variables in its model equation (unlike 10 banks). On the other hand, it has a much longer horizon (4 quarters) when looking at the inflation gap (other central banks usually have 0–1 quarter). This allows the CNB to ignore the first-round effects of one-off shocks to inflation and to focus on their second-round effects.

4. Considerations Regarding Potential Adjustments to the CNB's Reaction Function

Although, as argued above, the CNB's approach to inflation targeting already allows for a high degree of flexibility, in this section we consider some other possible ways of further increasing the flexibility of the inflation targeting framework. The flexibility of setting interest rates in terms the CNB's modelling framework can be influenced by the choice of parameters and variables that enter the reaction function. We do not consider replacing the point target with an accommodation band due to the possibility of interference with the anchoring of inflation expectations. The possible ways of increasing the flexibility of inflation targeting thus include:

(1) narrowing the targeted and communicated measure of inflation by focusing on inflation adjusted for volatile items, or core inflation,

(2) prolonging the horizon over which inflation returns to the target and which appears in the reaction function,

(3) lowering the aggressivity of the response to deviations of expected inflation from the target.

(4) increasing the smoothing of interest rates,

(5) enriching the reaction function with additional variables (e.g. the output gap and financial stability indicators).

With regard to (1), the CNB's main forecasting model (g3) considers changes in three price indices: headline inflation, "monetary policy-relevant" inflation and "net" inflation (the latter two are compiled by the CNB based on Czech Statistical Office data). The forecast of net inflation is then decomposed into the remaining components (food prices, fuel prices and core inflation) using a small structural model and the Kalman filter. The model defines headline inflation as the sum of endogenous net inflation and exogenous changes in regulated prices. A switch to targeting core inflation would require extending the model to include additional equations describing the individual components of inflation. This could have costs in terms of credibility and anchoring of inflation expectations, since a persistent episode of divergence of the headline and core measures could lead to the public questioning the commitment to the official 2% target, which is expressed in terms of headline inflation.

For example, core inflation was more than 2 percentage points lower than headline inflation on average between 2005 and 2013, with the latter averaging 2.5%. Achieving the 2% target for core inflation would thus have required headline inflation to exceed 4% over a nine-year period. Such a situation (or even the possibility of such a situation occurring) would require changes in the CNB's communication putting a greater focus on comparing core (not headline) inflation with the target. The CNB could subsequently be criticized for compiling the crucial measure of core inflation by itself, which could raise doubts about its credibility. A similar issue would arise if core inflation stayed substantially above headline inflation and above the target. Subsequent contractionary policy could drive headline inflation into negative values (i.e. deflation), a state which could threaten the real economy and the anchoring of inflation expectations if it persisted for an extended period of time. A potentially desirable deviation of monetary policy from its reaction function would then certainly present a communication conundrum.

Regarding (2), the length of the horizon that enters the reaction function controls which shocks the central bank does or does not respond to. The current horizon of one year abstracts from the first-round impacts of already realized one-off shocks and is among the longest when compared to other central banks (see the previous section). Increasing flexibility would require an even longer horizon, which might lead to some of the second-round impacts of shocks to prices being discounted as well. As a consequence, inflation would return to the target more slowly. The simulations in the following section show that a longer horizon would lead to a substantial increase in the volatility of inflation but only a small decrease in the volatility of real variables.

As for (3), lowering the aggressivity of the policy response would have a similar effect as prolonging the horizon, i.e. higher inflation volatility and slightly lower output volatility. However, too small a value of the coefficient on the deviation of inflation might endanger the stabilization role of the central bank. In the event of large shocks, monetary policy would then be unable to return inflation to the target, which, in the worst case, could lead to an inflationary or deflationary spiral.

With respect to (4), an increase in the smoothing parameter would have similar effects and risks as the previous modifications. Moreover, in practice interest rates are smoothed more than the reaction function would imply due to deliberations in later phases of the monetary policy process, i.e. in staff recommendations and in the decision-making of the board. Too much smoothing could be problematic, especially when the economy faces large shocks or crises like the recent global financial crisis, during which the CNB lowered rates in steps of up to 0.75 percentage point. Also, the bank would not be able to compensate flexibly for exchange rate shocks and resulting undesired tightening or loosening of monetary conditions. The issue of the optimal amount of smoothing has been discussed in more detail by Komárek and Rozsypal (2009), whose arguments are summarized in the box below. Another, more technical reason for smoothing interest rates is the existence of censoring, since the minimum possible change in policy interest rates is usually 0.25 percentage point.

BOX: Motivation for Interest Rate Smoothing

Komárek and Rozsypal (2009) describe the following reasons for interest rate smoothing:

(i) **Forward-looking market participants.** It is the nature of expectations to be forward-looking. If the central bank is credible and rates are perceived as persistent, even a small change in interest rates has large effects on long-run expectations and leads to a strong and immediate reaction of short-run interest rates. Thus, even a large monetary policy response can be implemented with a small change in short-term rates and suitable communication of the future outlook. In this case, the central bank's credibility is key, due to its effect on the anchoring of inflation expectations near the target, which leads the public to perceive deviations from the target as temporary shocks rather than signs of the central bank's incompetence. These deviations are then not incorporated into the formation of long-run inflation expectations.

(ii) **The presence of uncertainty.** The majority of reaction function estimates are based on historical, revised data. In reality, however, decisions are made based on real-time data, which can be subject to later revisions. If the central bank's models are correctly specified, so that forecast errors and revisions are not systematically biased in either direction and shocks have zero means, the certainty equivalence principle would suggest that optimal choices would not depend on the presence of uncertainty. In such case, uncertainty would not, by itself, imply less responsive monetary policy. However, empirical studies (Orphanides, 2001; Sauer and Sturm, 2003) do find substantial differences between reaction functions estimated on historical and real-time data. These differences do not necessarily speak about how aggressively central banks do react (or how they should react, in a normative sense), but rather suggest that estimates based on revised data could lead to misinterpretation of central banks' actions.

(iii) **Decision-making outside the model.** A central bank's actions are not derived solely from numerical models and simulations. In the end, the decisions are made by the bank's board, whose members bring their own insights and judgements about economic developments. It is very likely that individual opinions differ, due to different weights being assigned to different factors, and are reconciled only over time as new data are revealed, leading to certain delays. The use of expert judgement is introduced into the decision-making process precisely to deal with uncertainties about the latest data and model parameters.

(iv) **Not surprising the financial sector.** Unexpected movements in interest rates can lead to losses and higher uncertainty among financial intermediaries. Increased volatility might lead to lower willingness of the financial sector to lend to firms, especially over a longer horizon, which can lead to a fall in investment and economic growth. Interest rate smoothing can avoid these losses, as the initial change in rates is relatively small and further changes become anticipated by financial markets. More solidly anchored inflation expectations allow central banks to focus more on the medium-term horizon, since transitory shocks (i.e. those with effects too short-lived to affect inflation at the monetary policy transmission horizon) are not incorporated into long-term inflation expectations. This advantage of higher credibility is, however, conditional on achieving stable inflation consistent with past expectations and would disappear if central banks tried to exploit it actively.

(v) **The risk of losing credibility.** If the central bank reacted to every new piece of information, it might try to adjust interest rates relatively often. Markets could, on the other hand, evaluate frequent policy changes and switches between raising and lowering rates as central bank incompetence. At the same time, credibility cannot be gained for free and must be based on a clearly demonstrated willingness to maintain the inflation target, which may in the end imply a more aggressive response.

Regarding point (5) above, in terms of including additional variables in the reaction function it would make sense to focus on those that are not strongly correlated with deviations of inflation from the target. For example, the output gap tends to move in the opposite direction to inflation in response to supply shocks. Figure 2 and Table 1 show that, regardless of methodology, output gap measures are positively correlated with the inflation gap, the correlation coefficients taking values of 0.37–0.58 and being statistically significant from zero.

The financial cycle indicator (Plašil, Konečný, Seidler and Hlaváč, 2015) attains an even higher correlation with inflation, with a coefficient of 0.65, as illustrated by Figure 3 and Table 1. Including this indicator directly in the reaction function would not necessarily lead to any substantial changes in the interest rate path. In addition, the use of a financial stability indicator in the reaction function is still regarded as debatable. Therefore, the CNB has, in recent years, used a different approach in which financial stability considerations are accounted for in the monetary policy process through regular opinions of the Financial Stability Department presented at the monetary policy meetings.

Figure 2: Output Gap and Inflation Gap

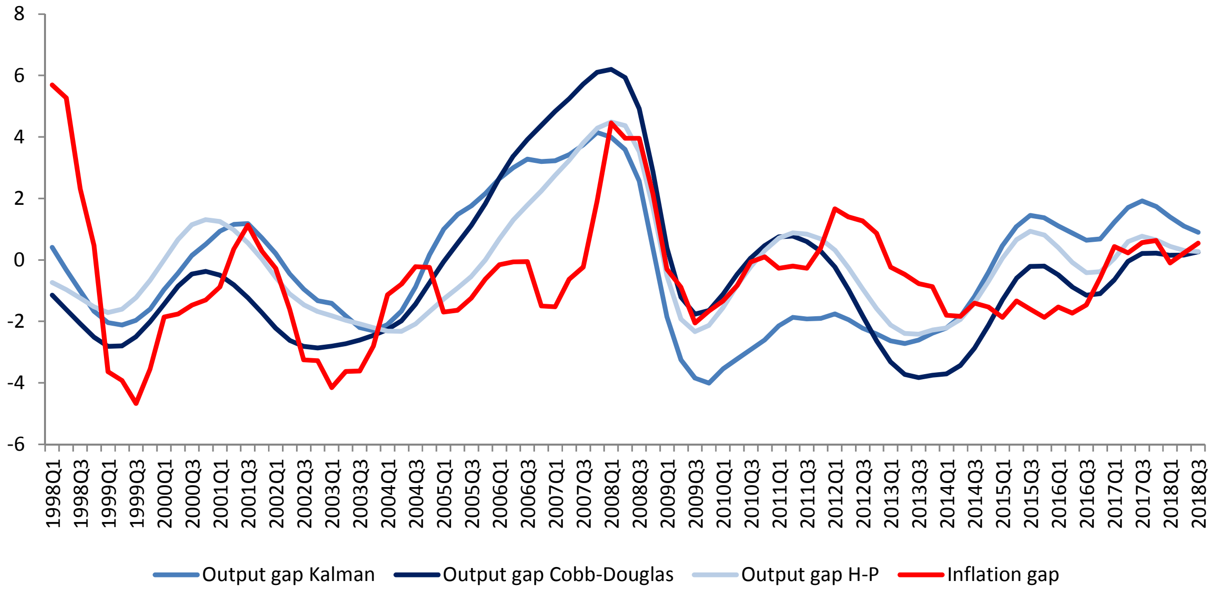


Figure 3: Financial Cycle and Inflation Gap

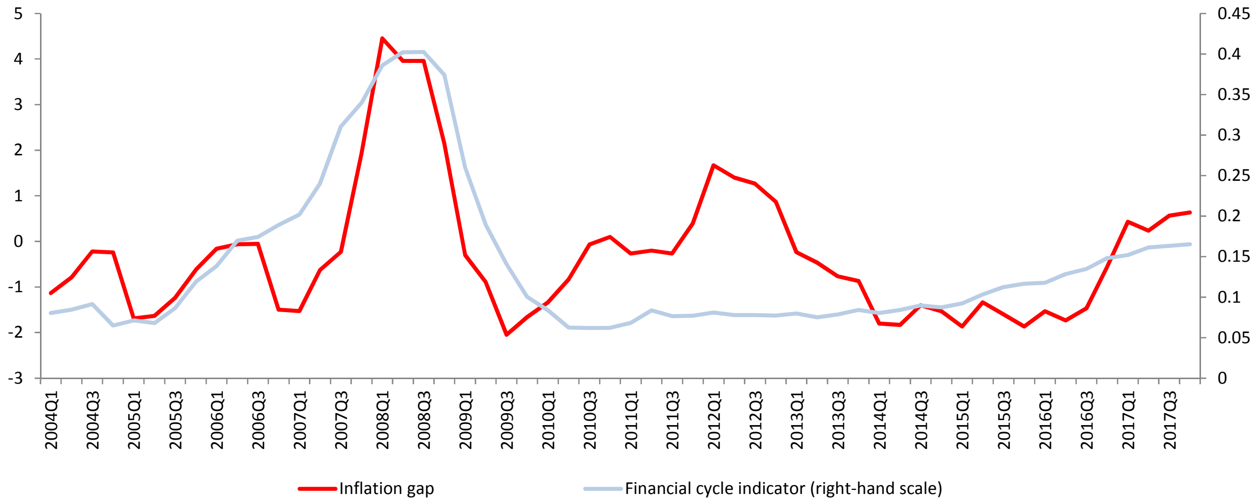


Table 1: Correlations with Inflation Gap Series

	Output gap – Kalman filter	Output gap – Cobb-Douglas	Output gap – HP filter	Financial cycle indicator
correlation	0.37	0.56	0.58	0.65
N	83	83	83	55
p-value	0.0006	<0.0001	<0.0001	<0.0001

Note: Pearson correlation coefficients; p-values correspond to the two-sided test of zero correlation.

5. Model Simulations

In this section, we study in more detail the possible benefits and costs of flexibility through the lens of the g3 model, the CNB's core forecasting tool. Our starting point is the central bank's reaction function, given in equation (7):

$$\log(i_t) = \rho_i \log(i_{t-1}) + (1-\rho_i)\big(\log(\bar{\iota}_t) + \psi \log\big(\widehat{\Pi}^{4q}_{t+h}\big)\big) + \epsilon^{mp}_t, \qquad (7)$$

which links the policy rate to its lagged value and to expected future year-on-year inflation. We will look at three margins of flexibility by adjusting three key parameters in the reaction function: (i) the strength of the reaction to expected inflation, i.e. aggressivity, governed by parameter ψ; (ii) the degree of smoothing of interest rates over time, determined by parameter ρ_i; and (iii) the horizon h at which expected inflation is evaluated.

First, we consider the impact of the parameters on the unconditional volatility of selected variables, which would correspond to their second moments in a long simulation of the model driven by all the shocks. To better understand how the parameters affect the key tradeoffs faced by monetary policy, we also evaluate how they affect the economy's response to two particular kinds of shocks: a permanent change to the inflation target (i.e. disinflation), and a negative shock to technology growth.[7] Next, we extend the reaction function by incorporating an explicit response of monetary policy to real activity, specifically real GDP growth. We repeat the above analysis but now study the impact of aggressivity and horizon with respect to the output growth term.

There are, of course, other possible additions to the reaction function that could be understood in terms of flexibility, such as inclusion of the output gap, core inflation[8] or the financial cycle. These extensions would, however, require more extensive changes to the model and are thus outside the scope of the current paper, although they could certainly be a relevant subject of future research.

5.1 Horizon, Aggressivity and Smoothing

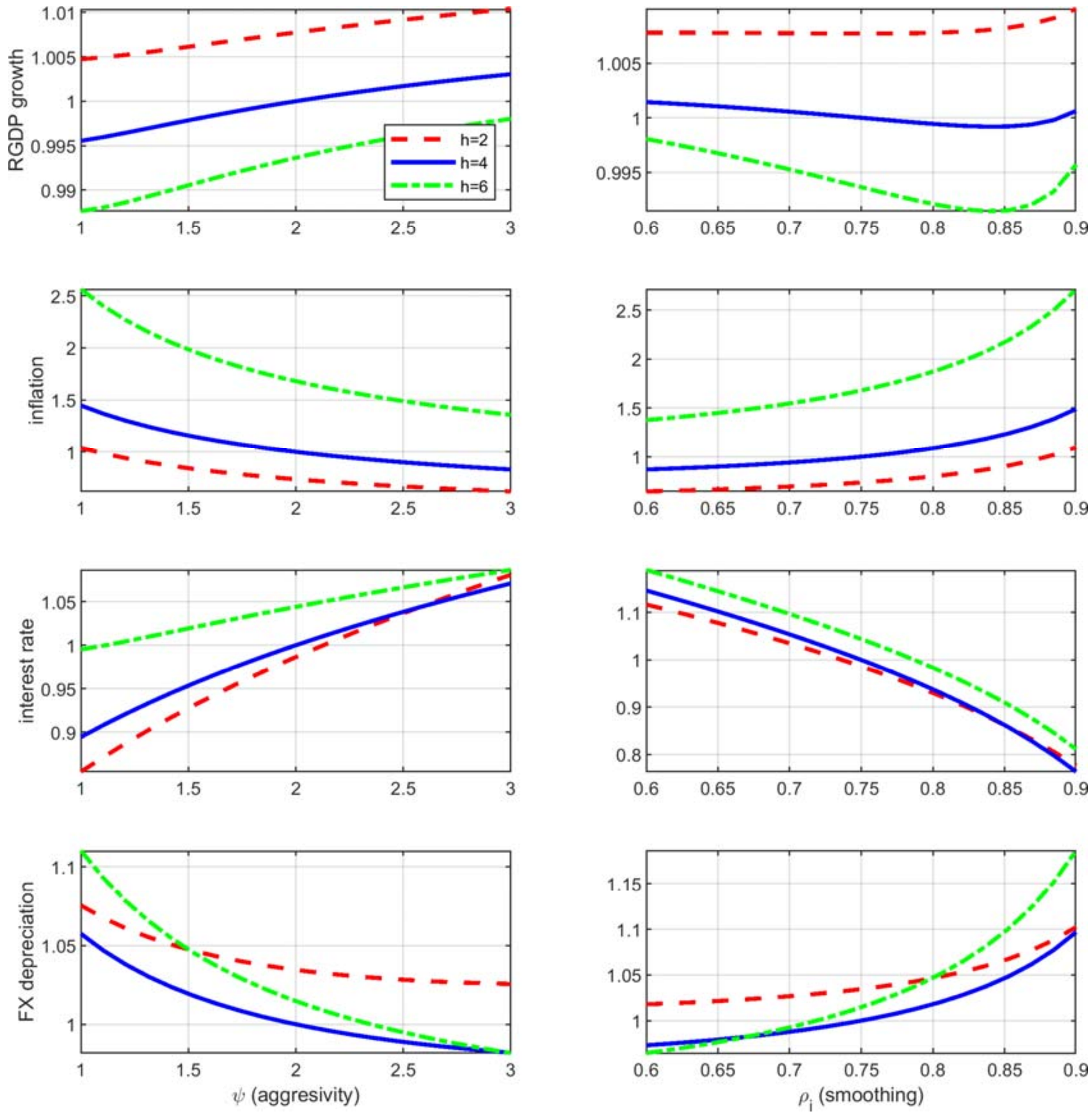
Starting with the reaction function (7), we first analyse how changes in parameters h, ψ and ρ_i affect the stability of inflation, output growth, interest rates and exchange rates. We consider alternative parameter values for horizon $h \in \{2,4,6\}$ (baseline calibration: 4), aggressivity $1 \leq \psi \leq 3$ (baseline: 2) and smoothing $0.6 \leq \rho_i \leq 0.9$ (baseline: 0.75). Figure 4 shows the effect of different parameter values on the unconditional volatility of output growth, inflation, interest rates (represented in the model by the 3-month PRIBOR) and nominal exchange rate growth (all growth rates are in quarter-on-quarter terms). The unconditional volatility would correspond to the standard deviation of the variable from a long simulation of the model with all the shocks turned on, although in practice it is obtained analytically from the linear state space representation

[7] A similar analysis can be found, for example, in Batini and Haldane (1999). Stráský (2005) focuses specifically on the previous generation of the CNB's forecasting model (QPM). Sacrifice ratios of disinflation in DSGE models are studied, for example, by Ascari and Ropele (2012). A comparison of policy rules with different degrees of forward-lookingness can be found, for example, in Clark, Laxton and Rose (2001).

[8] The g3 model does not contain an explicit concept of core inflation. The decomposition of net inflation (i.e. inflation adjusted for changes in administered prices) into core inflation and food and energy prices is currently done outside the core model using a small satellite structural model and the Kalman filter.

of the model. The left panels plot the relationship with respect to aggressiveness and the right panels that with respect to smoothing, with the different horizons shown by colours in each subplot. The volatility is always normalized relative to the baseline calibration (which is set to a value of 1).

Figure 4: Volatility of Selected Variables (relative to baseline calibration)



Note: Unconditional standard deviations from the g3 model (with all shocks turned on) for different horizons and for various aggressivity and smoothing parameters (with the other parameters held fixed at the baseline value). Values are normalized relative to the baseline calibration.

In accordance with economic intuition, less aggressive monetary policy leads to higher volatility of inflation and lower volatility of interest rates. The impact on output volatility is negative but quantitatively very small. Lower aggressivity also leads to more volatile changes in the exchange rate.[9] A less aggressive policy rule would therefore have relatively substantial costs by making

[9] Given the lower volatility of interest rates, this result is perhaps not straightforward to interpret. Under the uncovered interest rate parity (UIP) condition, smaller fluctuations in rates could be argued to lead to more stable exchange rates. The UIP condition, however, holds for *expected* change in the exchange rate and thus allows for higher volatility arising from transitory shocks even if the interest differential is less volatile.

inflation less stable (possibly risking the loss of anchored inflation expectations), while its benefits in terms of stabilizing the real economy are negligible.

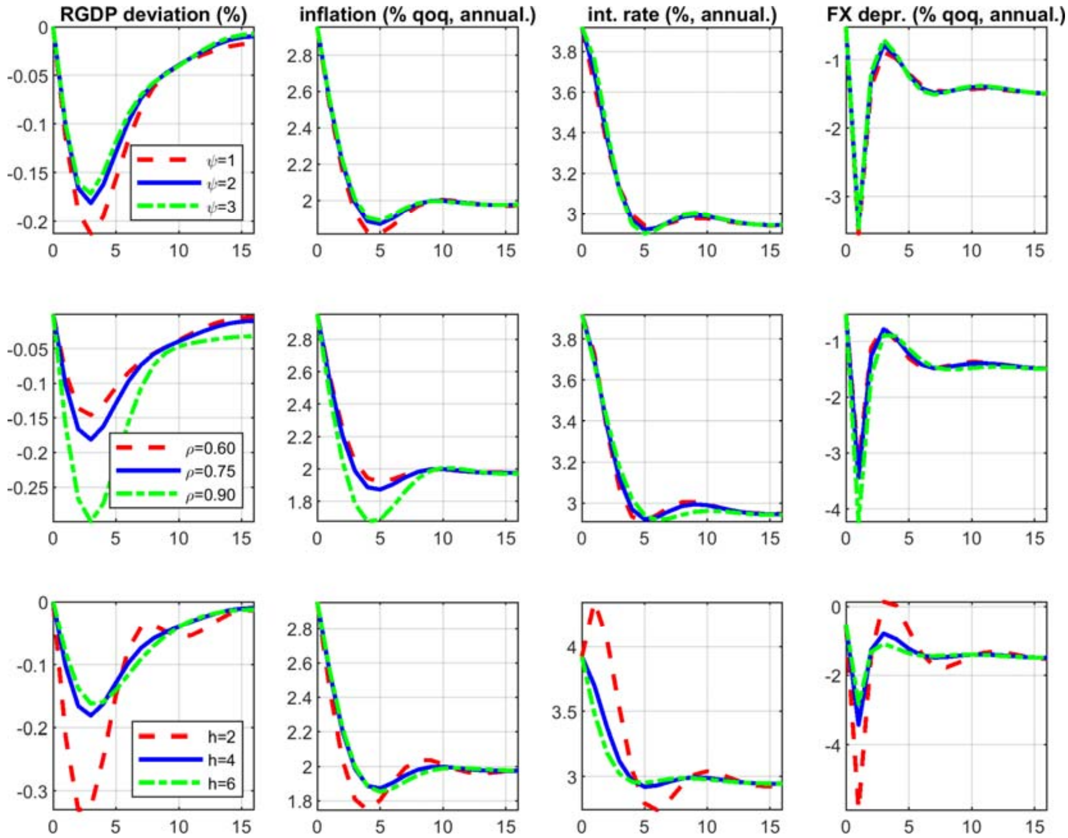
A similar evaluation applies to an increase in interest rate smoothing, which also leads to greater volatility of inflation and the exchange rate and more stable interest rates, while having little impact on output volatility. Finally, a longer horizon in the reaction function implies more volatile inflation and surprisingly also more volatile interest rates, but its impact on the exchange rate suggests a non-monotonic relationship. The effect of the horizon on output volatility is negative but again quite small.

In Appendix 2, we show additional results on the first-order autocorrelation showing that lower aggressivity, greater smoothing or a longer horizon result in higher persistence of inflation.

The unconditional volatilities reflect all shocks entering the model. In order to study the relationship between flexibility and monetary policy tradeoffs in more depth, we analyse how the economy responds to particular shocks. First, we look at the effects of disinflation, i.e. a permanent decrease in the inflation target, in terms of the paths of selected model variables and the cumulative output loss during the transition. The latter measure is often called the sacrifice ratio and is one of commonly presented characteristics used to describe stabilization tradeoffs. The sacrifice ratios implied by different calibrations can be helpful for choosing optimal parameter values. In our simulations, the economy starts in a steady state corresponding to a higher inflation target (specifically 3%). The inflation target is unexpectedly and immediately lowered by 1 percentage point, after which the economy converges to a new steady state, with no other shocks affecting it. We compute the deviations in the level of output by accumulating the deviations of the output growth rates from their long-run average (which is not affected by monetary policy) and we then sum these deviations to get the cumulative output loss over 16 quarters.

Figure 5 presents the responses of the output level, inflation and interest rates after the inflation target is lowered for different parameters in the reaction function. Inflation achieves its new, lower, level after about 10 quarters and a mild undershoot in all cases. Output responds by falling relatively persistently and returns to a balanced growth path only at the end of the period analysed. Here, the alternative calibrations have a more noticeable effect, with the fall being more pronounced in the case of higher smoothing or a shorter horizon. The second-to-last column of Table 2 shows numerical values of the sacrifice ratio for different parametrizations. Consistently with the previous discussion, the sacrifice ratio is substantially higher in the case of higher interest rate smoothing or a shorter horizon. More aggressive monetary policy leads to a lower value, although not much lower. Interestingly, the effect of horizon is asymmetric, with a longer horizon not yielding any additional effect compared to the baseline calibration.

Figure 5: Responses to Disinflation



Note: Paths of selected variables implied by the g3 model after the inflation target is unexpectedly lowered from 3% to 2% (and all other shocks are turned off) for different reaction function calibrations. The first column shows the deviation of real GDP from the original pre-disinflation balanced growth path.

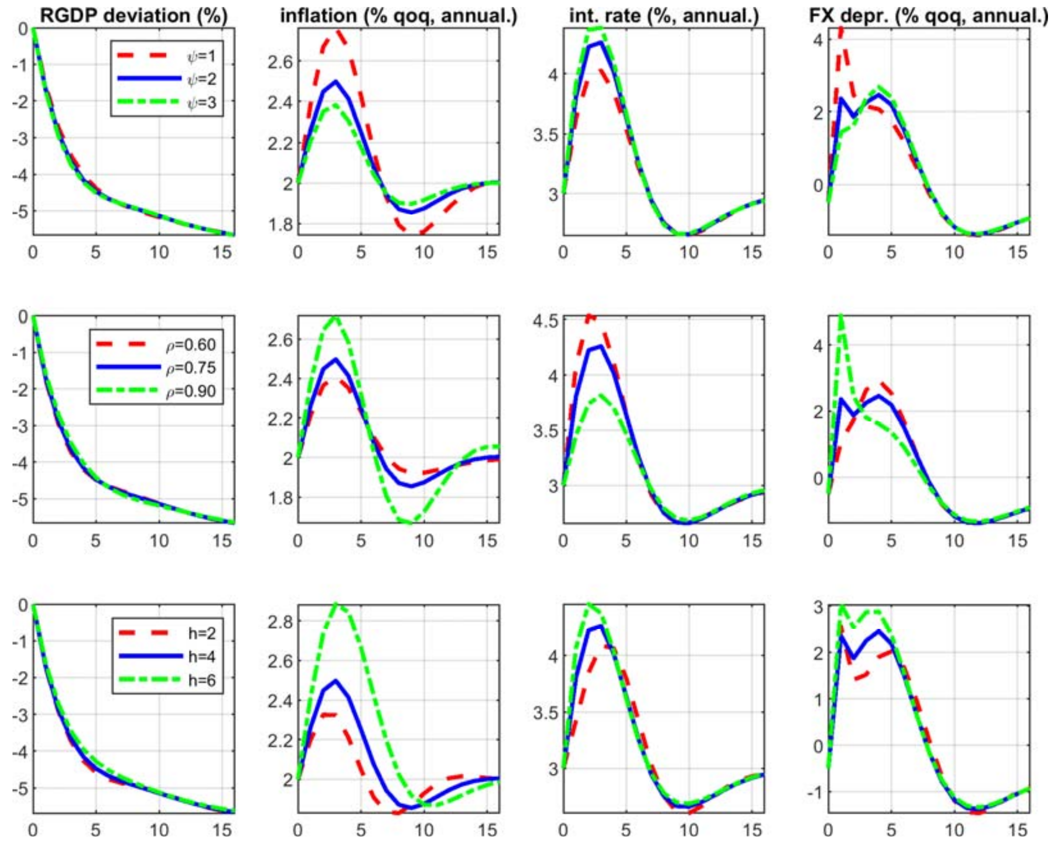
Table 2: Monetary Policy Tradeoffs after Disinflation and Technology Shock

calibration	ψ	ρ_i	h	sacrifice ratio – disinflation	long-run price change – technology shock
baseline	2	0.75	4	0.29	0.33
less aggressive	1			0.34	0.48
more aggressive	3			0.28	0.26
less smoothing		0.6		0.24	0.32
more smoothing		0.9		0.47	0.36
shorter horizon			2	0.42	0.12
longer horizon			6	0.29	0.89

Note: The sacrifice ratio is defined as the cumulative loss, compared to the pre-disinflation balanced path, in log of real GDP over 16 quarters (here multiplied by 100 and then divided by 4 due to quarterly frequency) after the inflation target is lowered (see Figure 5). The long-run price change captures the cumulative response of inflation (in qoq percentage points) over 16 quarters, i.e. approximately the change in the price level (in percentage points), after a technology growth shock (see Figure 6). Except for the initial impulse, in both cases all other shocks are turned off.

Next, we turn our attention to the case of supply shocks, which are an example of a situation in which stabilizing output and inflation could be in conflict, as they have opposite effects on inflation and real activity. Specifically, we study the response of the economy to a technology shock that temporarily slows the rate of technology growth. Figure 6 shows the impulse responses of output, inflation and interest rates to a negative shock to the growth rate of labour-augmenting productivity for various reaction function parameter values. The shock has a permanent negative impact on the level of output, but also increases inflation, which causes the central bank to raise interest rates. The increase in interest rates is quicker (and the increase in inflation thus weaker) when monetary policy is more sensitive to deviations of inflation from the target, when monetary policy smoothens less and with a shorter time horizon. Interestingly, the response of output to the technology shock is largely unaffected by different calibrations. The last column in Table 2 presents the long-run impact (after 16 quarters) of the technology shock on the price level (i.e. accumulated inflation) in percentage points. The largest difference in the behaviour of prices is due to monetary policy aggressiveness and horizon length. On the other hand, the effect of interest rate smoothing is small, since it seems to merely change the amplitude of the oscillatory inflation pattern, and the initial overshooting is compensated by later undershooting of the target.

Figure 6: Responses to Technology Shock



Note: Paths of selected variables implied by the g3 model after the economy is hit by a negative shock to technology growth (and all other shocks are turned off) for different reaction function calibrations. The first column shows the deviation of real GDP from the original pre-disinflation balanced growth path.

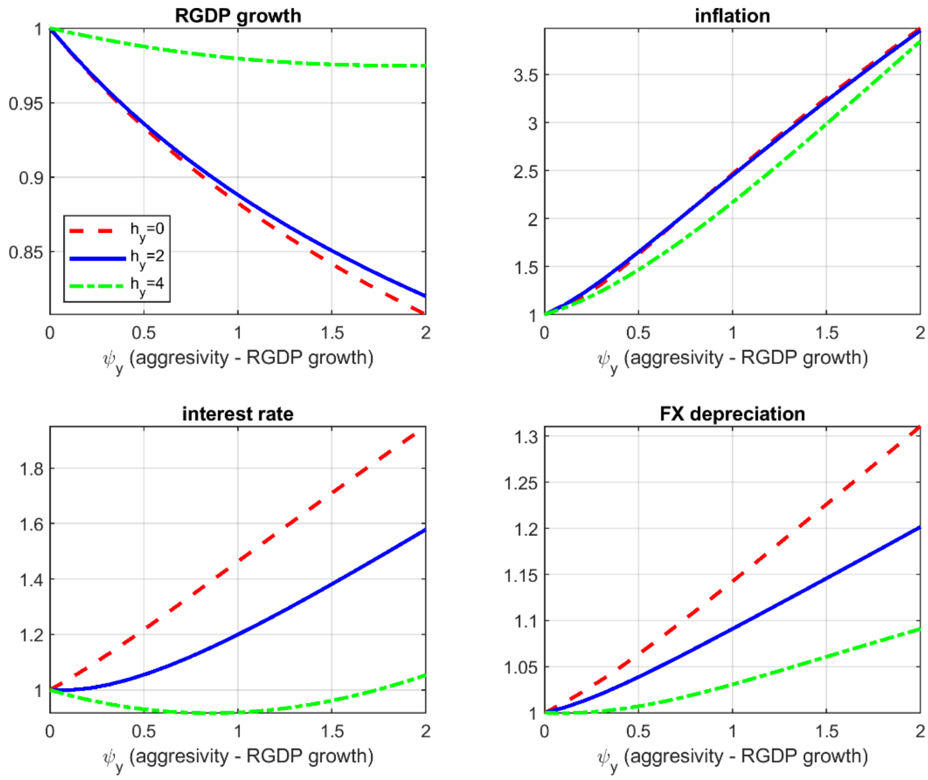
5.2 Reaction Function with an Output Term

Next, we modify the reaction function by incorporating a term responding to real economic activity. We add to equation (7) the expected deviation of real GDP growth from its steady-state value (currently calibrated as 3%) as a rough approximation of the cyclical position of the economy:[10]

$$\log(i_t) = \rho_i \log(i_{t-1}) + (1-\rho_i)\left(\log(\bar{\imath}) + \psi E_t\left[\log\left(\widehat{\Pi}^{4q}_{t+h}\right)\right] + \psi_y E_t\left[\log\left(\widehat{G}^{4q}_{t+h_y}\right)\right]\right) + \epsilon^{mp}_t. \quad (8)$$

We will consider values of aggressiveness with respect to output ψ_y of between 0 and 2, and an output forecast horizon h_y of 0, 2 or 4 (thus ranging from a backward-looking to a fully forward-looking response). Other parameters of the reaction function are kept at the baseline values, as in the first row of Table 2.

Figure 7: Volatility of Selected Variables (reaction function with output, relative to baseline)



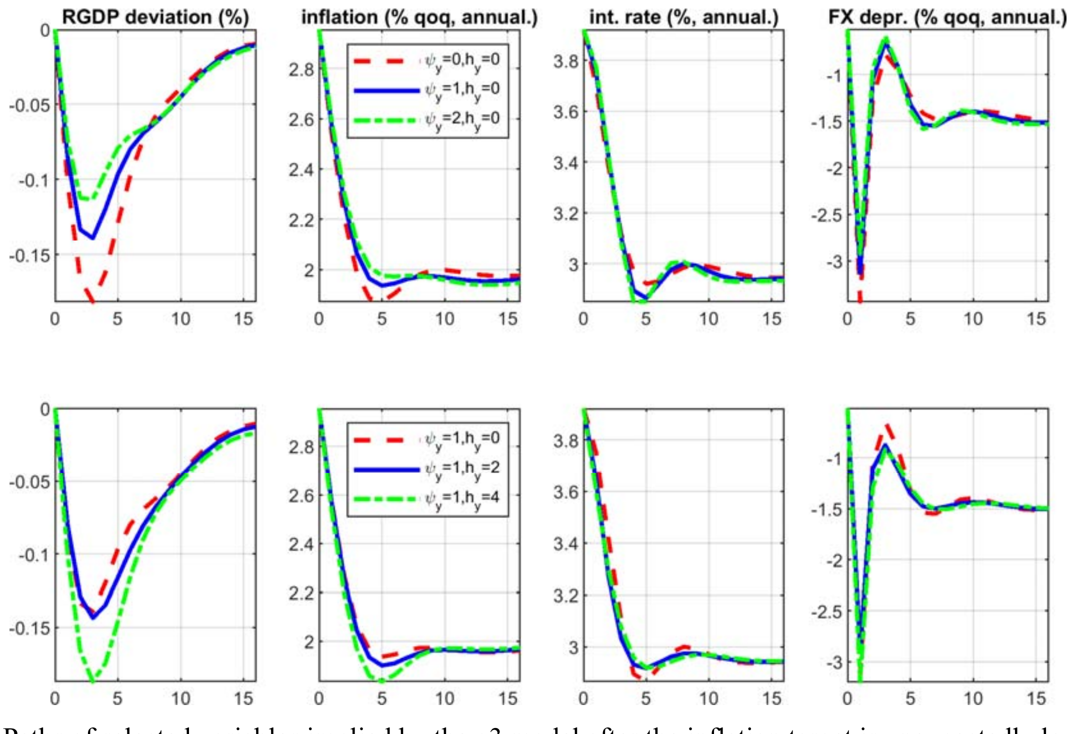
Note: Unconditional standard deviations from the g3 model (with all shocks turned on) for different horizons and for various output aggressivity and horizon parameters (other reaction function parameters are fixed at the baseline value). Values are normalized relative to the baseline calibration.

[10] The g3 model does not include the concept of the output gap, and adding it would require modifications to the model that are outside the scope of this paper. Although the concepts of the output gap and output growth are of course different (for example, during a recovery phase of the business cycle, growth may be high even if the gap is still negative), we feel that output growth still captures real economic activity in a tractable way.

Similar to Figure 4, in Figure 7 we plot the unconditional volatility of selected variables depending on the parameters considered (in addition, results for first-order autocorrelation are shown in Appendix 3). When the central bank responds more strongly to expected output growth, growth is more stable, but the effect is quantitatively not very large – if the response to output was the same as the response to inflation (ψ_y =2), output growth volatility would be reduced by about 20%. On the other hand, other variables become more volatile. This holds especially for inflation, which becomes substantially – up to four times – more volatile. We can also see that output stabilization is much weaker in the case of a fully forward-looking growth term, suggesting that expected future growth does not capture the cyclical position of the economy very well, perhaps due to its mean-reverting dynamics.

Figure 8 plots the responses to a permanent disinflation, defined in the same way as in the previous subsection, and the second-to-last column in Table 3 presents the associated sacrifice ratios. Responding more strongly to output growth limits the initial drop in output without having a large impact on inflation and thus correspondingly leads to smaller sacrifice ratios, although not dramatically so.

Figure 8: Responses to Disinflation (reaction function with output)



Note: Paths of selected variables implied by the g3 model after the inflation target is unexpectedly lowered from 3% to 2% (and all other shocks are turned off) for different calibrations of the reaction function containing the output term. The first column shows the deviation of real GDP from the original pre-disinflation balanced growth path.

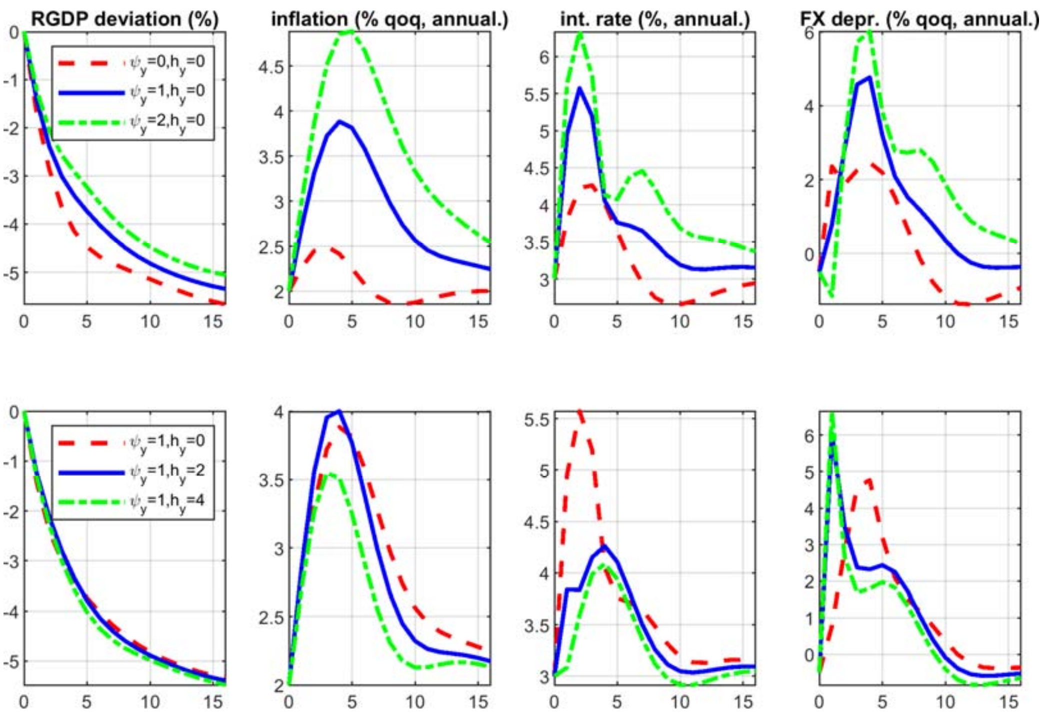
Table 3: Monetary Policy Tradeoffs for Reaction Function with Output Term

calibration	ψ_y	h_y	sacrifice ratio - disinflation	long-run price change - technology shock
no response to output	0	0	0.29	0.33
some response	1	0	0.25	3.65
stronger response	2	0	0.23	6.45
partly forward-looking	1	2	0.27	3.32
fully forward-looking	1	4	0.33	2.31

Note: For definitions, see Table 2. Other (non-output) reaction function parameters are fixed at their baseline levels.

In the case of the responses to the technology shock shown in Figure 9 (which parallels Figure 6), the reaction function containing the output term manages to dampen the fall in output to some extent. Due to the permanent character of the shock, however, monetary policy cannot prevent the eventual fall in output. At the same time, the stabilization policy comes at the cost of tolerating substantially higher inflation, which may climb to 5%. The implied long-run change in the price level, shown in the last column of Table 3, then also attains very high values. Somewhat paradoxically, such high inflation then causes responses of interest rates and exchange rate depreciation that are even stronger than if central bank had not responded to output, indicating the importance of anchoring of inflation expectations.

Figure 9: Responses to Technology Shock (reaction function with output)



Note: Paths of selected variables implied by the g3 model after the economy is hit by a negative shock to technology growth (and all other shocks are turned off) for different calibrations of the reaction function containing the output term. The first column shows the deviation of real GDP from the original pre-disinflation balanced growth path.

To sum up our results, adjusting the calibration of the reaction function towards higher flexibility would have only mildly positive effects on the stabilization of the real economy, provided that the remaining parts of the model stayed the same. At the same time, it would lead to relatively substantial costs in terms of less stable and less anchored inflation accompanied by higher volatility of all nominal variables, including interest rates, in the case of lower aggressivity, a longer time horizon or extending the reaction function to include real economic activity. In the case of a higher tendency to smooth interest rates, these would by definition be more stable, but at the same time other variables would fluctuate even more.

6. Conclusion

Flexible inflation targeting means that central banks must balance the main objective of achieving the inflation target with other considerations, such as stabilizing output. In theory, flexibility can be understood in terms of the central bank's loss function and the weight it gives to output volatility, which in turn determines the coefficients of its reaction function. In practice, central banks achieve flexibility by other measures as well, such as a dual legal mandate, escape clauses, interest rate smoothing, variation bands or policy horizons.

The CNB has always approached inflation targeting with a high degree of flexibility, both in terms of allowing for exceptions in cases of administrative and other one-off shocks, and in terms of smoothing interest rates and taking into consideration developments in the real economy. After reviewing the practices of several central banks, we found that comparatively, the CNB ranks among the more flexible ones, since it is grounded in a legal mandate with an explicit secondary objective, publicly communicates the variation band for accommodating short-term inflation volatility, is explicit about applying exceptions and uses a relatively long, one-year, horizon in its reaction function.

To evaluate the possible costs and benefits of putting more weight on output stabilization, we analysed how a change in the parameters of the CNB's reaction function would affect the economy according to the bank's core prediction model. The current form of the CNB's reaction function could be made more flexible by adjusting several of its features: targeting a narrower measure of inflation, prolonging the horizon, changing the aggressivity, smoothing, or incorporating other variables.

We found that lower aggressivity with respect to inflation, more emphasis on interest rate smoothing or a longer horizon would cause larger volatility of nominal variables but would not yield more stable output. Modifying the reaction function by including an output growth term would bring modest benefits in terms of output stabilization at the cost of significantly more volatile inflation. We showed that the monetary policy tradeoffs also depend on the specific shocks affecting the economy. In the case of disinflation, the reaction function parameters do not have a dramatic impact on the path of the economy, whereas in the case of a technology shock, attempting to stabilize output would result in large costs of excess inflation. Our results thus suggest that further attempts at greater flexibility by the CNB would lead to more volatile and less anchored inflation without achieving much additional output stabilization.

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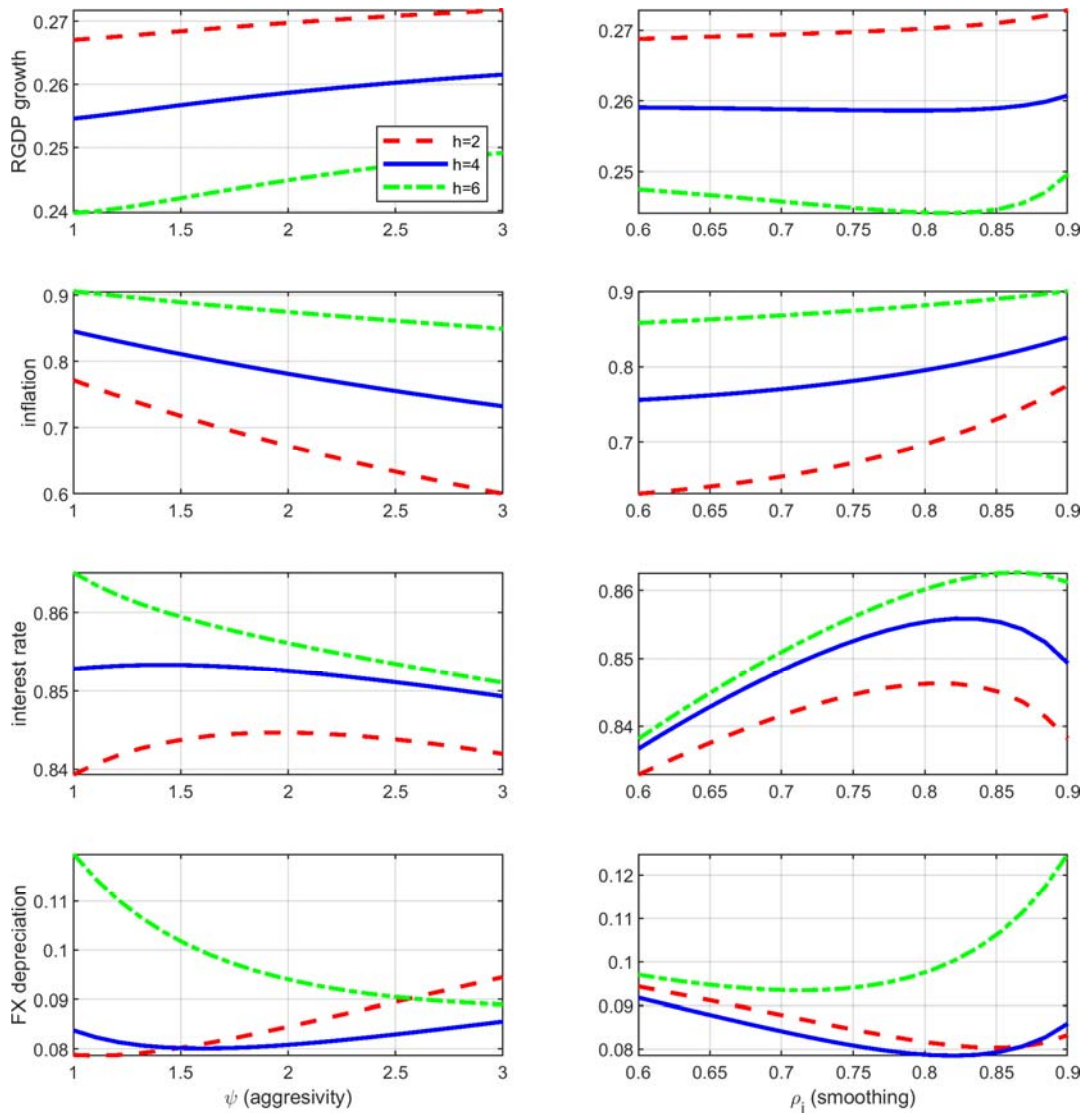
Appendix 1: Central Bank Flexibility – Selected Inflation-Targeting Central Banks

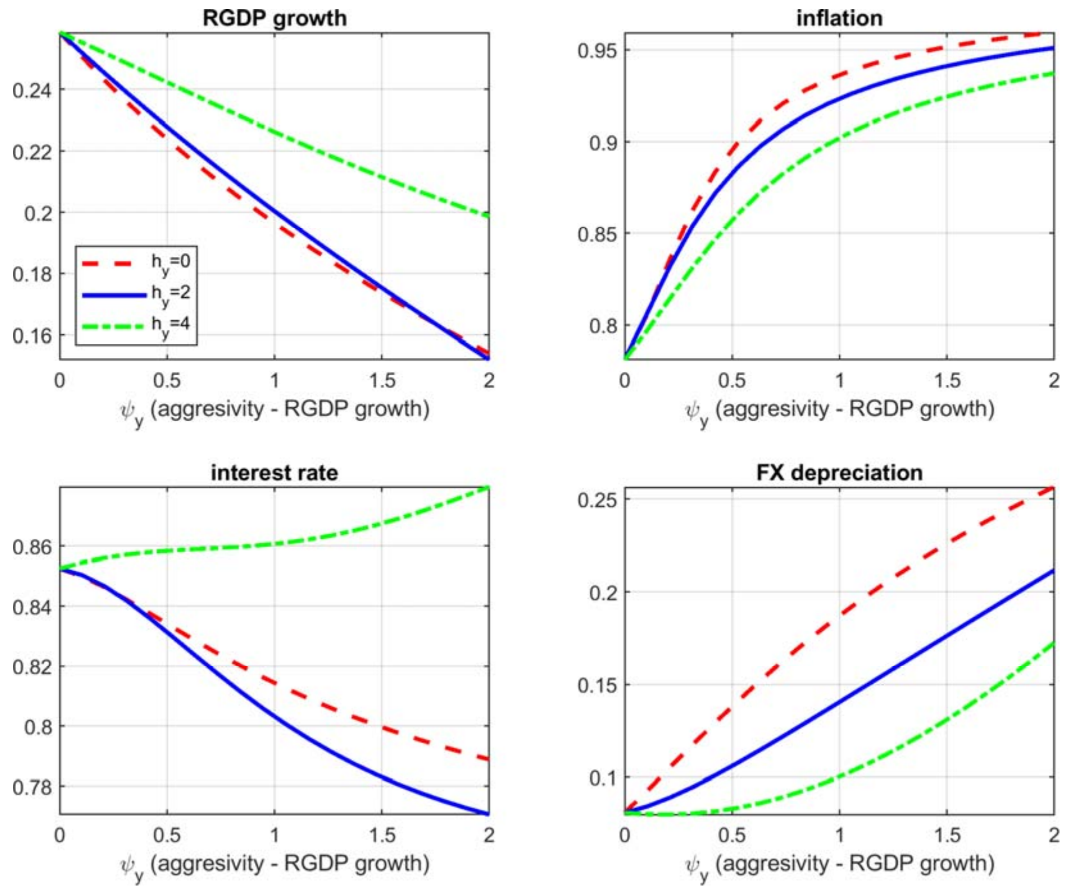
	Primary objective	Secondary objective	Inflation target	Variation band	Monetary policy horizon	Escape clauses	Output/employment in the reaction function	Monetary policy horizon in the model
ECB	price stability	support the general economic policies in the Union	<2%	none	none	yes, in the case of cost-push shocks only a gradual policy response	NAWM II (DSGE): output gap, change in output gap. NMCM (GMM model): output gap	0 quarters (NAWM II), +1 quarter (NMCM)
Fed	maximum employment, stable prices, and moderate long-term interest rates	none	2%	none	none	none	FRB/US model: output gap in the reaction function	0 quarters
Bank of England	price stability	support the economic policy of the government	2%	none, inflation letter when inflation deviates by more than 1 pp	none	none	COMPASS (DSGE): output gap	0 quarters
Sveriges Riksbank	price stability	none	2%	1-3% variation band	none	none	Ramses II (DSGE): gap in hours worked, level and difference	0 quarters
Magyar Nemzeti Bank	price stability	support the economic policy of the government	3%	± 1 percentage point	5-8 quarters	yes (significant one-off shocks)	MPM (gap model): output gap	+4 quarters
Narodowy Bank Polski	price stability	support the economic policy of the government	2.5%	± 1 percentage point	monetary policy transmission horizon of several quarters	none	NECMOD (hybrid): output gap	+1 quarter
Czech National Bank	price stability	support the economic policy of the government	2%	± 1 percentage point	4-6 quarters	yes (significant shocks in exogenous factors, namely changes in indirect taxes)	g3 (DSGE): none	+4 quarters
Norges Bank	price stability	none	2%	none	none	none	NEMO (DSGE): output gap	0 quarters
Schweizerische Nationalbank	price stability	takes account of economic developments	below 2%	none	none	yes (one-off shocks such as a sudden surge in oil prices or strong exchange rate fluctuations)	DSGE model: output gap, change in output gap	0 quarters
Reserve Bank of Australia	stability of the currency, full employment and economic prosperity	none	2-3% over the medium term	none	none	none	DSGE model: output gap and its change, change in the real exchange rate	0 quarters
Reserve Bank of New Zealand	to maintain price stability and to reduce undesirable fluctuations in employment and economic activity	none	2% over the medium term	1-3%	6-8 quarters	previously list in the PTA, now none	KITT (DSGE): none	+1 quarter
Bank of Canada	to protect the external value of the national monetary unit	none	2%	1-3%	6-8 quarters (may be shortened or extended when appropriate)	yes (one-off shocks, financial stability considerations, risk management in case of asymmetric risks)	Totem II (DSGE): output gap	+2 quarters

Appendix 2: Autocorrelation of Selected Variables



Note: First-order autocorrelations from the g3 model (with all shocks turned on) for different horizons and for various aggressivity and smoothing parameters (with the other parameters held fixed at the baseline value) – see also Figure 4.

Appendix 3: Autocorrelation of Selected Variables (reaction function with output term)



Note: First-order autocorrelations from the g3 model (with all shocks turned on) for various output aggressivity and horizon parameters (with the other parameters held fixed at the baseline value) – see also Figure 7.

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