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Monetary Policy and the Output Gap in DSGE Models for Small Open Economies: Insights from the Czech Republic

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Monetary Policy and the Output Gap in DSGE Models for Small Open Economies: Insights from the Czech Republic

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Abstract

This paper examines how alternative definitions of the output gap influence the dynamics and monetary policy prescriptions of New Keynesian DSGE models used in inflation-targeting regimes. Using the Czech economy as an example of a small open economy, we compare one exogenous and seven endogenous output-gap measures, including flexible equilibrium concepts, statistical filters, and structural approaches. The results show that endogenous identification is essential for ensuring internal consistency among business cycle fluctuations and other macroeconomic variables, while only structurally identified gaps fully exploit the advantages of the DSGE framework. Technology-augmented output emerges as the most operationally robust and conceptually coherent measure for real-side policy analysis. The findings further highlight that the policy implications of output-gap stabilization are determined by the chosen measure, which should align with the policymaker's preferences. Because these mechanisms are structural rather than country-specific, the conclusions extend to other small open economies with similar characteristics.

JEL Codes: D58, E32, F41.
Keywords: Business cycle, DSGE model, flexible equilibrium, HP filter, monetary policy, output gap, real marginal costs, technological growth.

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1. Introduction

Many central banks have not implemented inflation targeting in a strict sense but have instead adopted flexible inflation-targeting frameworks. This approach means that monetary authorities do not aim to achieve the inflation target at all costs but also take into account other objectives. Therefore, many central banks consider real economic developments, particularly real economic activity measured by GDP. A typical example is the Taylor rule (Taylor, 1993), which incorporates real economic activity, specifically the output gap.

The motivation for incorporating the output gap into a systematic policy response is twofold. First, it may reflect a dual mandate, as in the case of the Federal Reserve, where the central bank explicitly targets both price stability and full employment. Alternatively, monetary policy is based on the primary objective of price stability, and the policy rule has so far explicitly included only inflation. However, the broader policy framework might still allow the central bank to take into account real economic conditions—such as the output gap or GDP growth—once the price stability goal has been achieved. This creates a rationale for assigning some weight to real-side variables in monetary policy design. Second, the output gap in the policy rule serves as an indicator of future inflation, providing a forward-looking element for monetary policy decisions.

A key question for New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models is how the output gap should be defined within a policy rule. Estimating the output gap and the associated measure of potential growth within a DSGE framework is inherently complex and challenging. This arises from the fact that potential output, and consequently the output gap, is unobservable and can be defined in multiple ways. Despite the popularity of DSGE models in central banks, no consensus has yet emerged on the most appropriate method for defining and identifying the output gap.

The aim of this paper is to survey and compare alternative approaches to identifying output gaps in DSGE models and to assess how these approaches influence the model dynamics, structural interpretation, and monetary policy response. The analysis is conducted in the context of a small open economy operating under an inflation-targeting regime with an independent monetary policy, where the interest rate serves as the primary policy instrument and the exchange rate may act as a supplementary tool. Furthermore, we contribute to the literature by analyzing the trade-off between inflation variability and economic activity fluctuations, examining how this relationship depends on the chosen output gap measure and its weight in the policy rule.

Using the small open Czech economy as a case study, we assess the alternative approaches within the CNB's core projection framework. The g3+ model is a structural, microfounded DSGE model tailored to the main features of the Czech economy: a highly open economy that is a net energy importer but a net exporter of goods—primarily to the euro area, with Germany as its dominant trading partner. Consequently, the model gives particular weight to foreign trade and the exchange rate as channels of monetary transmission under inflation targeting (Andrle et al., 2009). Forward-looking expectations and an endogenous monetary policy rule are essential elements, reflecting the CNB's inflation-targeting regime in place since 1998, with a one-to-one-and-a-half-year policy horizon and a 2% inflation target.

The original g3 model has served as the CNB's main forecasting tool since 2008. Its 2019 upgrade to g3+ introduced an enhanced semi-structural foreign block and additional improvements (Brázdik et al., 2020), including a decomposition of foreign output into potential output and the output gap. By contrast, the domestic output gap—regularly published in the CNB's Monetary Policy Reports—continues to be identified outside the core model using satellite methods. This contrast naturally motivates a systematic evaluation of alternative approaches to identifying the domestic output gap within a DSGE framework explicitly designed for a small open economy.

This paper considers one exogenously and seven endogenously identified output gap measures, which are grouped into three categories. The first group comprises gaps derived from flexible equilibrium concepts, which aim to eliminate inefficiencies and imperfections arising from nominal and real rigidities. Specifically, we analyze the flexible price equilibrium, the flexible real equilibrium, and a combination of both approaches. The second group consists of statistical gap measures: the endogenous Hodrick–Prescott (HP) filter and deviations of GDP growth from its steady-state path. The third group comprises indicators that directly exploit the model's structural features, specifically a technology-augmented output gap and real marginal costs.

Based on our results, we argue that the output gap should be determined endogenously within the model to allow for systematic feedback between the business cycle position and other endogenous variables. Among the endogenous measures considered, technological growth is the most suitable for output gap identification in microfounded DSGE models, as it fully reflects real economic dynamics in a comprehensive and internally consistent manner. While the flexible equilibrium approach—which abstracts from both price and real rigidities, so that potential output is determined solely by technological growth—is conceptually appealing, it is operationally demanding due to model complexity. Consequently, a technology-augmented output gap emerges as the most practical method for measuring the business cycle within the DSGE framework, particularly when policymakers aim to systematically respond to real-side developments.

If the policymaker prefers to define the output gap primarily as an indicator of future inflationary pressure, then the business cycle position captured by real marginal costs is appropriate. However, in this case, the gap reflects a combination of both demand and supply pressures, rather than isolating conventional demand-side effects. This approach may amplify the policy tightening response to any future price pressures identified through marginal costs. If this is the policymaker's preference, it raises the question of whether the policy rule should instead target future deviations from the inflation target directly, potentially with a higher weight on the inflation term, rather than extending the rule with an explicit output gap term.

From a policy perspective, we find that increasing the weight of the output gap in the policy rule generally raises inflation variability, potentially undermining price stability, which is the primary objective of most central banks, including the Czech National Bank. The exception is when the output gap is proxied by real marginal costs: in this case, a higher weight in the policy rule reduces inflation variability, consistent with the definition of the gap. These findings underscore that the choice of output gap measure should reflect policymakers' preferences, as different approaches generate distinct economic narratives and have implications for policy design.

Our results may also be informative for the modeling of other small open economies with similar structural characteristics, thereby extending the relevance of our analysis beyond the Czech case.

Related Literature

There is no unified theoretical concept of the output gap specifically tailored to DSGE models. For example, Vetlov et al. (2011) distinguish three types of potential output within the DSGE framework. First, efficient output is derived under assumptions of perfectly competitive markets with flexible prices and wages, implying zero markups and the absence of markup shocks. Second, natural output allows for imperfect competition and therefore admits markup shocks, while still assuming flexible prices and wages. Finally, trend output captures the effects of permanent technology shocks that affect the economy's steady-state path.

The workhorse DSGE model of Smets and Wouters (2003) incorporates the output gap directly into the monetary policy rule. In this context, the output gap is defined as the percentage deviation of actual output from potential output, where potential output corresponds to the level that would prevail under flexible prices and wages in the absence of cost-push shocks. According to the typology of Vetlov et al. (2011), this definition corresponds to the natural output concept.

As a result, the definition and treatment of the output gap differ across central bank DSGE models. In many cases, the output gap is identified exogenously, that is, outside the DSGE framework. This approach contrasts with the endogenous output gap definitions used in semi-structural gap models.

For instance, the Riksbank's core forecasting model described in Adolfson et al. (2013) uses hours worked rather than output as a measure of resource utilization. These hours are observed and detrended using a Hodrick–Prescott (HP) filter outside the model, and the resulting series is incorporated into the policy rule.

In contrast, Norges Bank's core model (NEMO), as outlined by Kravik and Nimir (2019), uses a loss function instead of a Taylor-type interest rate rule to determine optimal policy. The loss function incorporates output variability, measured as GDP excluding oil and gas production. While the use of a loss function provides greater flexibility in policy design, it is less commonly adopted due to its sensitivity to model calibration and the structure of underlying shocks.

The New York Fed DSGE model, as described by Dotsey et al. (2011), assumes that monetary policy responds to inflation deviations from target and to some measure of real economic activity. However, the specific nature of this real activity measure is not made explicit. Given the Federal Reserve's dual mandate, it is likely that the measure corresponds to deviations of unemployment from its natural rate.

The Bank of Canada's core forecasting model, TOTEM III, includes a Taylor-type interest rate rule with an output gap term (Corrigan et al., 2021). In this case, however, the output gap is treated as exogenously identified and enters the model as an observed variable. Corrigan et al. (2021) note that prior to 2006, output gap estimates reflected internal staff assessments, whereas post-2006 values reflect real-time judgments by the Governing Council. The methodology used to forecast the exogenous output gap is not disclosed.

In the case of the United Kingdom, Harrison and Özlem (2010) estimate a DSGE model using detrended data and derive an output gap proxy based on a production function incorporating labor hours, capital, and total factor productivity. The policy rule in this model adjusts total output for productivity, effectively controlling for long-term trends.

For Chile, García-Schmidt and García-Cicco (2020) include GDP growth—rather than an explicit output gap—in the interest rate rule, alongside inflation deviations from target. Similarly, the euro area model developed by Christoffel et al. (2010) incorporates a measure of real economic activity in the form of real GDP growth adjusted for productivity growth. In both cases, trend output is used to define potential output and thus the implied output gap.

The Czech National Bank's DSGE model, as used by Andrle et al. (2009) and Brázdik et al. (2020), reflects the CNB's primary objective of price stability by specifying a monetary policy rule that responds exclusively to expected inflation, with no direct role for measures of real economic activity.

Vetlov et al. (2011) also evaluate whether DSGE model-based output gaps serve as valid indicators of inflationary pressures. This is done by assessing the inflation forecast performance of these gaps within a reduced-form Phillips curve framework and by analyzing conditional correlations between inflation and various model-derived indicators. Their findings suggest that potential output based on flexible price assumptions tends to be more volatile, resulting in smaller and less persistent output gaps than those obtained from statistical methods. From a policy perspective, explicitly accounting for market imperfections and nominal rigidities increases the relevance of model-consistent potential output for designing optimal monetary policy aimed at improving welfare and macroeconomic stabilization. Nevertheless, Vetlov et al. (2011) conclude that there is no robust empirical evidence that model-consistent output gaps consistently outperform traditional statistical indicators of inflationary pressures. Similarly, Armenter and Bodenstein (2009) argue that statistical output gap measures may lack a firm theoretical link to inflation, potentially rendering them misleading, while DSGE-based output gaps are highly sensitive to underlying model assumptions and calibration choices.

Organization of the Paper

The remainder of the paper is structured as follows. Section 2 introduces the g3+ model, while Section 3 outlines the different approaches to measuring the output gap within this model. Section 4 presents the identified output gaps and their properties, highlighting how they vary across the different approaches. Section 5 discusses which output gap measure should be preferred, based on the findings from the previous section and policymakers' preferences. It also evaluates optimal policy design through a loss function analysis. Finally, the last section provides brief concluding remarks.

2. Description of the Model

The g3+ model is a structural two-agent New Keynesian (TANK) DSGE framework developed for regular forecasting of the Czech economy, which is a small open economy with an independent monetary policy. The model incorporates a range of nominal rigidities and real frictions, allowing it to capture empirically relevant transmission channels observed in data. This section summarizes the key building blocks and mechanisms of the model, with a more detailed description provided in Andrle et al. (2009) and Brázdik et al. (2020, 2025).

2.1 Foreign Block

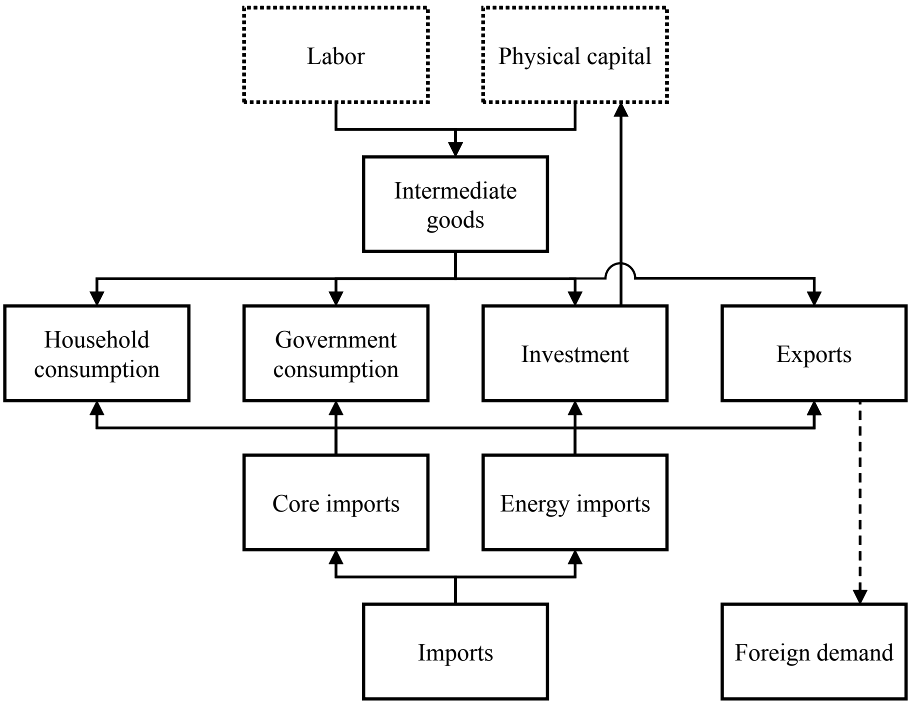
The gap-based foreign block comprises a set of behavioral equations describing the business cycle in the external environment, capturing the main export destinations of domestic firms within the euro area.

Output growth is decomposed into the output gap, the fundamental trend, and a trend shifter. The business cycle is captured through an IS curve that links the output gap (as a measure of demand) to the real interest rate and the real exchange rate gap. The fundamental trend reflects the persistent component of the supply side, whereas the trend shifter captures sudden distortions in potential GDP growth.

Producer price inflation is decomposed into two components—core and energy—with time-varying weights. The core component is modeled using an open-economy Phillips curve and is driven by inflation expectations, demand-driven inflationary pressures arising from real economic activity, and the real exchange rate gap. Core PPI, rather than HICP inflation, is modeled because it reflects the inflation dynamics relevant for a highly export-oriented domestic industrial economy, in which foreign producer prices are key for assessing price competitiveness relative to the euro area. The energy component follows a simple autoregressive process. Consumer price inflation is linked to producer price inflation.

The monetary authority follows a Taylor-type reaction function aimed at achieving the inflation target over the medium term. The rule incorporates expected deviations of consumer price inflation from the inflation target and the output gap, together with interest rate smoothing. The model explicitly incorporates foreign unconventional monetary policy by including a shadow interest rate alongside the conventional policy rate. The shadow rate enables assessment of the true stance of foreign monetary policy when conventional rates are constrained by the zero lower bound. The rest of the world is represented through an exchange rate link to the United States economy.

Figure 1: Domestic Production Sectors and Price Rigidities in the g3+ Model



Note: Dotted boxes represent production inputs for intermediate goods. Solid arrows depict rigidities in domestic currency, while dashed ones indicate rigidities in foreign currency

2.2 Domestic Economy

The main domestic components of the g3+ model comprise the following sectors: households, firms producing intermediate and final goods, and the monetary and fiscal authorities. The structure of the goods-producing sectors and the corresponding price rigidities is illustrated in Figure 1.

Households consist of two types, reflecting the model's two-agent framework. The first type, referred to as Ricardian households, consume final goods under an internal habit formation mechanism. They rent capital, supply labor to intermediate goods producers, and receive wages determined by Calvo-type contracts. Ricardian households participate in the domestic bond market but lack access to international financial markets. The second type, known as hand-to-mouth, rule-of-thumb, or non-Ricardian households, consume their entire labor income in each period and do not participate in financial markets. Consequently, they are unable to smooth consumption intertemporally.

The intermediate production sector comprises three categories of firms. The first produces domestic intermediate goods using capital and labor inputs under a Cobb–Douglas production technology. The second and third categories are importing firms—energy and non-energy (core) importers. Imported intermediate goods are produced exclusively from foreign inputs and do not rely on domestic factors. Importing firms operate under local-currency pricing, which implies that the prices of imported goods are sticky in domestic currency terms. All firms follow Calvo pricing when setting their prices, giving rise to New Keynesian Phillips curves for each type of intermediate good.

Final goods producers assemble consumption, public spending, investment, and export goods by combining domestically produced and imported intermediate inputs, using sector-specific production technologies. Analogously to the intermediate goods sector, each final goods sector employs Calvo price setting, resulting in a New Keynesian Phillips curve for each final good. Price stickiness in export goods is modeled under the assumption of foreign-currency pricing.

GDP growth is defined as the sum of its components, weighted by the nominal shares of these components in nominal output. Furthermore, the growth rate of each GDP component is calculated as the ratio of its current to previous level, stationarized by technological growth. Each GDP component is detrended by the aggregate technological trend as well as by sector-specific technologies that capture their heterogeneous dynamics and volatility. Aggregate technology is driven by three factors: labor-augmenting technology (A), investment-specific technology (a^J), and willingness to work (a^L):

$$\Delta Z_t = \Delta A_t + \Delta a_t^J + \Delta a_t^L. \tag{1}$$

The steady-state growth rate of labor-augmenting technology is set at 2.5%, while both investment-specific technology and willingness to work are assumed to have zero steady-state growth rates. All variables in the equations are expressed in logarithmic transformations. In addition, the domestic components of GDP are also stationarized by a convergence technology. The convergence term, Δa_t^C, captures the historical tendency of the Czech economy to grow above its steady-state rate, reflecting its gradual convergence toward more advanced economies. While this component was persistently positive in the past, it has gradually declined over time, reaching zero by the end of 2019.

The central bank follows a monetary policy rule featuring interest rate smoothing. This rule links the nominal interest rate to deviations of expected year-on-year policy-relevant inflation from the inflation target. The government sector is characterized by a period-by-period budget constraint and consumes non-productive public goods. Finally, the profit-maximizing behavior of foreign exchange dealers, who have access to international financial markets, implies the uncovered interest rate parity (UIP) condition.

3. Approaches to Measuring the Output Gap

Several definitions of the output gap, which are later applied and estimated for the Czech economy within the g3+ model, are presented below. These include the exogenously identified gap, various flexible equilibrium gaps, the gap measured as the deviation from steady-state growth, the endogenous gap calculated using the HP filter, and gaps defined using aggregate technology and real marginal costs.

3.1 Exogenous Identification of the Output Gap

In the first method, the output gap is treated as an exogenously identified variable determined outside the model. For this purpose, it is estimated using the CNB's Quarterly Projection Model (QPM) and is taken as given in the g3+ model.[1]

Within the g3+ model, the output gap $\hat{y}_t$ is assumed to follow a simple AR(1) process:

$$\hat{y}_t = \rho^{\hat{y}}\hat{y}_{t-1} + \varepsilon_t^{\hat{y}}, \tag{2}$$

where $\rho^{\hat{y}} = 0.7$ captures the persistence of the output gap, and $\varepsilon_t^{\hat{y}}$ is the shock to the gap. The dynamic of output growth Δy_t is defined as the sum of potential output growth, Δy_t^*, and the change in the output gap, $\Delta\hat{y}_t$:

$$\Delta y_t = \Delta y_t^* + \Delta\hat{y}_t. \tag{3}$$

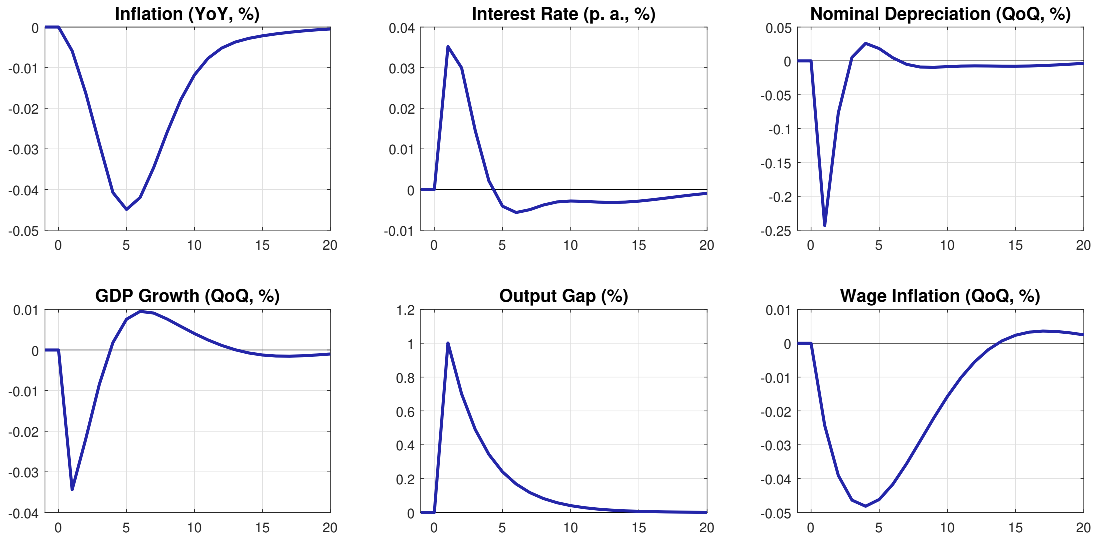
This approach provides a simple way to incorporate economic activity into policy analysis within the g3+ framework. However, it has an important limitation. The output gap is not identified endogenously and may therefore be inconsistent with other model variables. For example, a higher output gap combined with unchanged output growth implies a lower rate of potential output growth. This lack of internal consistency represents a significant drawback for practical use. In particular, it implies that changes in monetary conditions cannot affect the cyclical position of the economy.

Despite this limitation, the approach can still offer useful insights for broader policy discussions and may complement forecast-based recommendations. For instance, if the economy is assessed to be operating above potential, implying a positive output gap, monetary policy may respond with a stronger increase in the policy rate than suggested by the baseline forecast in order to restrain excessive and potentially inflationary demand pressures.

This mechanism is illustrated in Figure 2, which shows the impulse response to a positive shock to the exogenous output gap. Since the output gap enters the model only through the policy rule, the resulting responses resemble those following a contractionary monetary policy shock. The policy rate increases, leading to a higher real interest rate relative to the external environment. This induces a temporary appreciation of the exchange rate, followed by lower inflation and weaker output growth. However, because the output gap is modeled exogenously and affects the economy solely through the policy rule, its overall impact on the policy rate remains limited.

[1] The QPM is a small semi-structural model that served as the core forecasting model at the Czech National Bank from 2002 to 2008, when it was replaced by the microfounded DSGE model g3. The QPM is currently used as a satellite model to regularly assess the cyclical position of the domestic economy. Further details are provided in Beneš et al. (2002).

Figure 2: Responses of Major Domestic Variables to an Output Gap Shock



Note: The responses correspond to an annualized unit shock and cover the 20 quarters following the initial shock. Deviations from the steady state are expressed in percentage points. Quarter-on-quarter dynamics are annualized, and the output gap is measured as the deviation from potential output.

3.2 Flexible Equilibrium Measures

A flexible price equilibrium provides a widely used theoretical benchmark for assessing the cyclical position of the economy in a DSGE framework. To better understand and illustrate the effects of different economic rigidities, three alternative specifications of flexible equilibria are considered:

- **Flexible price equilibria:** This assumes the absence of nominal rigidities in price and wage setting, along with the absence of all nominal shocks (both domestic and foreign).
- **Flexible real equilibria:** The specification excludes real rigidities in household consumption (such as habit formation) and assumes the absence of real shocks in both the domestic and foreign economies.
- **Flexible price and real equilibria:** This combines both the flexible price and flexible real equilibria above. In this case, economic fluctuations stem solely from technological shocks, with no rigidities present.

The chosen equilibrium specification determines which type of rigidity and, consequently, inefficiency, is addressed by monetary policy. Each version provides a distinct interpretation of the output gap and the sources of inefficiency in the economy.

To analyze the policy implications of the three different flexible equilibrium concepts for identifying the business cycle position of the economy within the g3+ model, a three-step procedure is applied:

1. **Identification of Counterfactual Flexible Equilibria**

   Each flexible equilibrium is first identified within the g3+ model as a counterfactual scenario, characterized by the absence of the relevant rigidities and shocks (nominal, real, or both). The resulting counterfactual output defines the natural output for the corresponding specification.

The output gap is then calculated as the deviation of actual output from its counterfactual natural level.

The interpretation of the output gap differs depending on the equilibrium specification. Under the flexible price equilibrium, the gap reflects inefficiencies arising from nominal rigidities. For instance, a positive output gap implies that price and wage stickiness, combined with nominal shocks, are contributing to an overheating economy. In contrast, under the flexible real equilibrium, the gap captures the impact of real rigidities and shocks. In the combined flexible price and real equilibrium, the output gap reflects deviations from a fully efficient, frictionless economy.

2. **Model Integration of Natural Output**

   Next, the natural output is introduced into the g3+ model as an exogenous variable. To accommodate this, two additional equations are appended to the model structure. Specifically, output growth Δy_t is decomposed into natural (flexible) output growth Δy_t^* and changes in the output gap $\Delta \hat{y}_t$, as shown in equation (3). Natural output growth follows an AR(1) process:

$$\Delta y_t^* = a^{y^*} \Delta y_{t-1}^* + (1 - a^{y^*}) \Delta y^* + \varepsilon_t^{y^*}, \tag{4}$$

   where $a^{y^*} = 0.7$ is the autoregressive parameter, Δy^* represents the steady-state growth rate of the economy, and $\varepsilon_t^{y^*}$ denotes the innovation to natural output growth.

3. **Evaluation through Conditional Forecasting**

   Finally, impulse response functions are generated by computing the difference between forecasts from baseline and conditional simulations. The baseline simulation is based solely on observed data and the natural output path derived in the first step. The conditional simulation includes the shock of interest.

   If the shock is relevant to the flexible equilibrium concept, the natural output path is also recalculated in the conditional simulation to maintain internal consistency. For example, a technological growth innovation affects the flexible price equilibrium, which determines potential output, and the full model with nominal rigidities, which determines actual output. However, the magnitude and timing of the responses differ between the two models, and these differences are reflected in the output gap. Conversely, if a shock does not affect output in the flexible price equilibrium, it influences output in the model with rigidities only through the output gap. A typical case is a monetary policy shock: it has no direct effect on potential output under the flexible price equilibrium, but in the full model it reduces actual output growth via a negative output gap.

3.3 Deviation from Steady-State Output Growth

Approximating potential output based on the steady-state growth offers a simple method for identifying the output gap. In this framework, economic growth can be expressed as the combination of the change in the output gap and trend growth. Formally, the trend growth is expressed as the sum of the current steady-state growth rate of the economy, α^A (set at 2.5%), and the convergence adjustment capturing deviations from the long-term growth path due to transitional dynamics, ΔaC_t:

$$\Delta y_t = \Delta \hat{y}_t + \alpha^A + \Delta aC_t. \tag{5}$$

The output gap at time t is then constructed recursively by summing its lagged value and the current-period change.

This method provides a tractable and transparent way of estimating the cyclical component of output. However, it abstracts from many structural features of the economy and may not properly capture complex dynamics, particularly during periods of large shocks or structural changes.

3.4 Endogenous Hodrick–Prescott Filter

Incorporating the Hodrick–Prescott (HP) filter directly into the model provides an alternative way to integrate output gap considerations within a DSGE framework. To implement this approach, the g3+ model is extended with several additional equations.

First, the level of output, y_t, is defined as its lagged value adjusted for output growth, Δy_t:

$$y_t = y_{t-1} + \Delta y_t. \tag{6}$$

Next, output is decomposed into natural output and the output gap:

$$y_t = y_t^* + \hat{y}_t. \tag{7}$$

Finally, the relationship between actual and potential output is specified using a two-sided HP filter, expressed as a centered moving average:

$$y_t = \lambda y_{t-2}^* - 4\lambda y_{t-1}^* + 6\lambda y_t^* - 4\lambda y_{t+1}^* + \lambda y_{t+2}^*, \tag{8}$$

where the smoothing parameter λ is set to 1600, a conventional value for quarterly data.[2]

This HP filter-based approach is purely statistical and therefore lacks any structural economic interpretation. However, despite this limitation, the HP filter remains one of the most widely used non-structural techniques for estimating the output gap, making it a relevant concept within the broader DSGE analysis.

3.5 Technology Growth as a Proxy for Potential Output

As an alternative, structurally grounded approach, the output gap is identified endogenously, based on the internal dynamics of the g3+ model. The key novelty lies in linking the trend in economic activity directly to technological progress.

The g3+ model, as a DSGE model, follows the New Keynesian paradigm, which integrates elements from both the Real Business Cycle (RBC) theory and Keynesian economics. In the RBC framework, real variables (including output) are entirely driven by technological progress due to money neutrality. In contrast, the New Keynesian framework recognizes that monetary policy can influence short-term activity due to the presence of nominal rigidities. However, in the long run,

[2] A two-sided filter is preferred over its one-sided counterpart because the objective of the analysis is to compare the business cycle positions implied by different models rather than to construct real-time assessments. Although the one-sided filter may be advantageous in real-time applications (Mise et al., 2005), it suffers from important shortcomings. In particular, recent evidence shows that it does not adequately remove low-frequency fluctuations, thereby distorting the estimated cyclical component (Wolf et al., 2024).

monetary policy does not affect output, making technology-driven growth a suitable proxy for natural output.

Specifically, in this approach, aggregate technology growth, ΔZ_t, defined in equation (1), is used as the primary driver of potential economic growth. This variable captures the key structural forces shaping long-run economic dynamics within the g3+ model, as described in Section 2. However, to take into account real convergence, which is especially relevant in the context of the Czech economy, a convergence technology, aC, is added to reflect temporarily elevated growth rates during the catch-up process. This results in the following specification for potential output dynamics:

$$\Delta y_t^* = \Delta Z_t + \Delta aC_t. \tag{9}$$

This structural identification of the output gap has the advantage of internal consistency with the model's other variables, allowing for meaningful policy analysis. Because the output gap is derived endogenously through dynamic interactions—rather than imposed as an exogenous input—it captures the interplay of technology, preferences, and policy in shaping economic fluctuations.

3.6 Real Marginal Costs as a Proxy for the Output Gap

For monetary policy purposes, it is useful to define the output gap in a way that directly links to inflation dynamics. As a key driver of future inflationary pressures, the output gap can be approximated using the structural price-setting relationships embedded in the g3+ model, specifically the Phillips curve for the final goods and services sector.

In this context, real marginal costs in the consumer sector are the preferred measure for identifying the output gap. This choice reflects the fact that marginal costs in the consumer sector capture not only domestic determinants through intermediate input prices but also foreign influences transmitted via import prices—an aspect of particular importance for a small open economy.[3]

The output gap is then identified using the relationship between real marginal costs in the consumer sector, rmc_t^c, and the steady-state markup of firms selling consumption goods and services, μ^c:

$$\hat{y}_t = \eta(rmc_t^c + \mu^c). \tag{10}$$

where parameter $\eta = 4$ measures the elasticity of the output gap with respect to marginal costs.

The calibration of η serves two purposes. First, it ensures that the variability of the marginal cost-based output gap is appropriately aligned by allowing the adjustment of less volatile marginal costs to match the observed variability of the output gap. Second, it enables the model to capture a realistic magnitude of inflationary pressures arising from fluctuations in marginal costs. Specifically, an increase in real marginal costs—reflecting heightened production pressure and resource utilization—signals stronger inflationary pressures and contributes to a positive output gap.

This approach maintains internal consistency with the model's inflation dynamics and provides a direct link between the output gap and the monetary policy objective.

[3] Furthermore, the consumption sector has the largest weight in domestic demand and therefore appears to be an appropriate choice for approximating the output gap.

3.7 Extended Policy Rule

The policy rule in the CNB's core forecasting model g3+ is extended to enable the central bank to respond not only to expected inflation deviations but also to the real business cycle position, as captured by the output gap. In the rule, the current output gap is preferred over the expected output gap. Although the current output gap is unobservable and subject to revisions in GDP data, it remains more reliable. In contrast, the expected output gap can differ significantly from the ex-post estimated gap, potentially resulting in significant policy errors. The extension allows monetary policy to be better aligned with the broader macroeconomic environment. The extended policy rule is specified as follows:

$$i_t = \rho^i i_{t-1} + (1-\rho^i)(i^* + \psi^\pi \hat{\pi}_{t+4} + \psi^{\hat{y}} \hat{y}_t) + \varepsilon_t^i, \tag{11}$$

where i_t represents the nominal interest rate (3M PRIBOR) in period t and ρ^i is the interest rate smoothing parameter.[4] The neutral policy rate, denoted as i^*, is defined as the equilibrium real interest rate adjusted for the inflation target. The parameter ψ^π measures the central bank's responsiveness to expected deviations of inflation from its target one year ahead, denoted as $\hat{\pi}_{t+4}$, while the weight assigned to the output gap $\hat{y}_t$ is given by the parameter $\psi^{\hat{y}}$ and governs the policy response to the output gap.

The calibrated values of $\psi^\pi = 2$ and $\psi^{\hat{y}} = 0.125$ ensure an appropriately strong monetary policy response to inflation, consistent with conventional monetary policy practice. To prevent abrupt changes and excess volatility in the policy interest rate, the smoothing parameter ρ^i is set at 0.75. The neutral policy rate is set at 3%, assuming a 1% natural real rate and an inflation target of 2%. Section 5 of the paper evaluates alternative calibrations of the parameter $\psi^{\hat{y}}$ using a welfare-based analysis, illustrating the trade-offs involved, particularly between inflation variability and output gap fluctuations.

Importantly, this extended policy rule is applied consistently across all output gap measures discussed above and explored in the paper. This allows for a systematic comparison of how different output gap concepts influence monetary policy dynamics and outcomes.

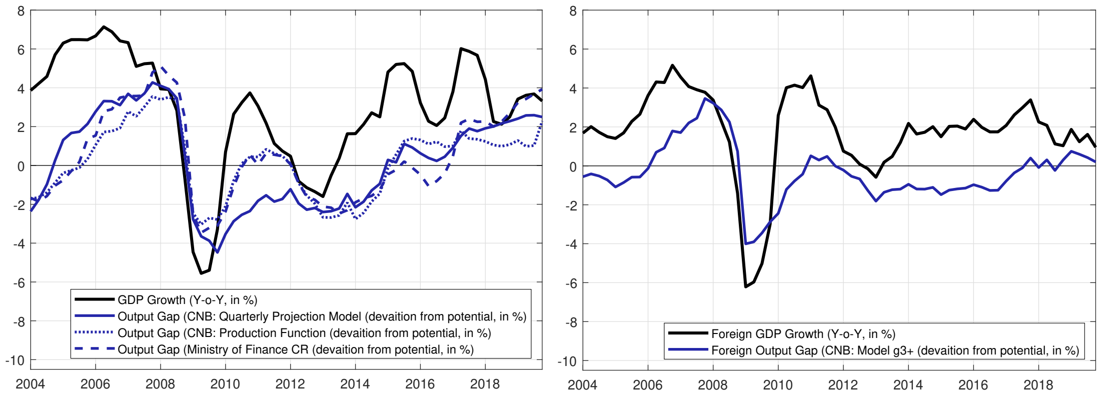
4. Results

All output gap estimates presented in this section are derived from model-based identification without the use of expert judgments, with the sole exception of the exogenous QPM-based measure. In this case, expert judgments are incorporated, as they reflect the CNB's official assessments of the business cycle position published in its Monetary Report. This QPM-based output gap therefore serves as the benchmark against which the performance of alternative identification approaches is evaluated. Figure 3 presents not only our benchmark output gap measure but also alternative estimates used by the CNB, derived from the production function approach, and by the Ministry of Finance. These assessments are broadly consistent, indicating that the choice of benchmark does not materially affect the evaluation of the approaches investigated in this paper. Moreover, Panel B shows the output gap of the Czech Republic's main euro area trading partners, highlighting that the domestic business cycle was largely synchronized with foreign developments, particularly up to 2015.

[4] The three-month Prague Interbank Offered Rate (3M PRIBOR) serves as the data input for the short-term interest rate in the model, as it is the closest market counterpart to the two-week repo rate set by the Czech National Bank.

Figure 3: Business Cycle of the Czech Economy and Its Trading Partners

Panel A: Czech Republic | Panel B: Trading Partners in the Euro Area



Note: Estimates of the output gap are taken from *Monetary Policy Report – Summer 2024* for the CNB, and from *Macroeconomic Forecast – August 2024* for the Ministry of Finance of the Czech Republic.

The presented simulation range covers the period 2004 Q1–2019 Q4. The pandemic and the subsequent energy crisis are excluded, since these events require substantial expert inputs for proper interpretation. These judgments are commonly embedded in CNB forecasts. Moreover, the aim of this paper is to provide insight into how these alternative approaches perform under a standard business cycle in a small open economy, rather than during extreme events.

4.1 Identified Business Cycle Position of the Economy

Figure 4 presents the identified business cycle position of the Czech economy across all output gap approaches considered. For additional context, year-on-year GDP growth is also shown, providing a broader perspective on the country's economic developments. A detailed description of each measure is provided in Appendix A2.

The benchmark measure, obtained using the QPM framework with expert judgments incorporated, indicates that the output gap turned positive in 2005. For a small open economy, this assessment of the business cycle aligns intuitively with the foreign output gap (Figure 3). The subsequent economic expansion, with output exceeding potential, persisted until the onset of the Great Recession. The global downturn introduced significant economic slack, pushing the output gap into negative territory for several years. In response to prolonged disinflationary pressures and a negative output gap, the CNB reached the technical zero lower bound in November 2012. To ease monetary conditions further, an exchange rate floor was introduced in November 2013. This policy is reflected in a gradual closing of the negative gap, which turned positive again in 2015 as demand recovered and the koruna's depreciation supported the competitiveness of Czech exporters in foreign markets. Fiscal expansion in 2018–2019 further reinforced above-potential output.

The flexible equilibrium measures broadly reproduce this narrative but differ in the magnitude and timing of key turning points (Figure 4: Panel A). These approaches generally imply a higher output gap prior to the crisis and display notable post-crisis divergence. The real and combined real-price equilibrium measures point to a rapid transition into negative territory, whereas the flexible price equilibrium suggests a more gradual adjustment, maintaining a positive gap until 2009. These differences highlight the sensitivity of estimated cyclical positions to assumptions regarding rigidities, shocks, and the behavior of potential output.

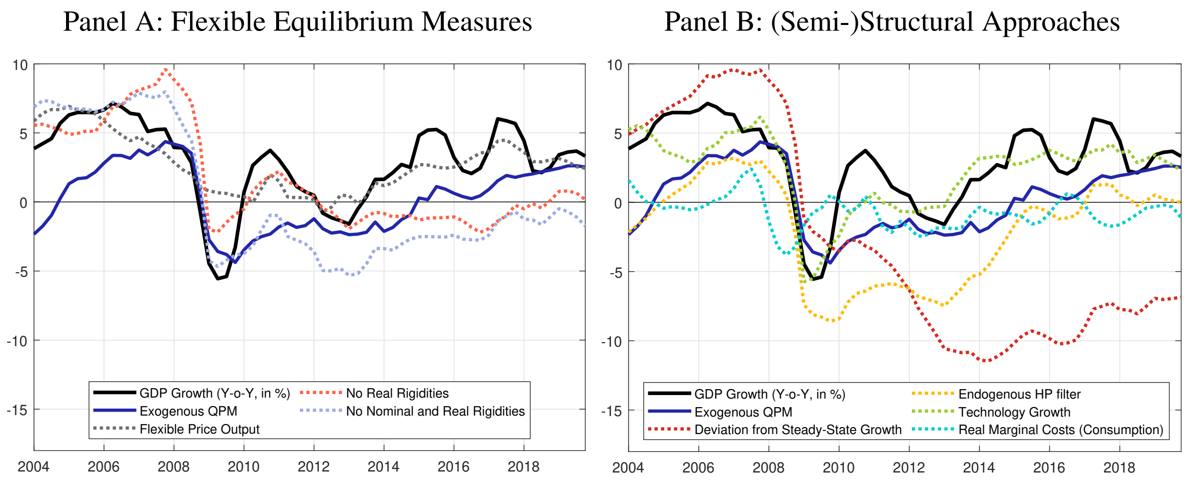
Among the (semi-)structural approaches, the output gap identified through technological growth and that derived from the endogenous HP filter track the benchmark measure reasonably well, though with differences in amplitudes around the Great Recession (Figure 4: Panel B). In contrast, the methods based on deviations from steady-state GDP growth and on real marginal costs provide markedly different assessments. The growth-deviation approach overstates the pre-crisis overheating and implies a persistently negative gap thereafter. The marginal cost-based measure leads the benchmark gap, consistent with the timing of cost-pressure transmission in the Phillips curve. It captures rising domestic and external cost pressures before the global financial crisis, the dampening effect of a strong koruna, and the substantial influence of subdued foreign conditions after 2011. Overall, it yields a predominantly negative output gap throughout most of the post-Great Recession period.

Taken together, the comparison across the benchmark, flexible equilibrium, and (semi-)structural methods illustrates how alternative modeling assumptions shape the estimated business cycle position of a small open economy. The remainder of this section further examines the properties of the estimated output gaps and compares them with the benchmark measure.

4.2 Summary Statistics

Summary statistics for the estimated output gap are presented in Table 1. In the benchmark case (QPM-based identification with expert judgments), the mean of the output gap is close to zero, consistent with the steady-state value assumption. The estimation without nominal and real rigidities also yields a mean close to zero, but with substantially higher variability. Furthermore, this approach exhibits a significantly larger range between its minimum and maximum values. Other flexible equilibrium-based approaches tend to produce a more positive average output gap. However, excluding real rigidities from potential output amplifies the business cycle volatility in the Czech economy, resulting in larger fluctuations compared to the flexible price approach.

Figure 4: Estimated Output Gaps

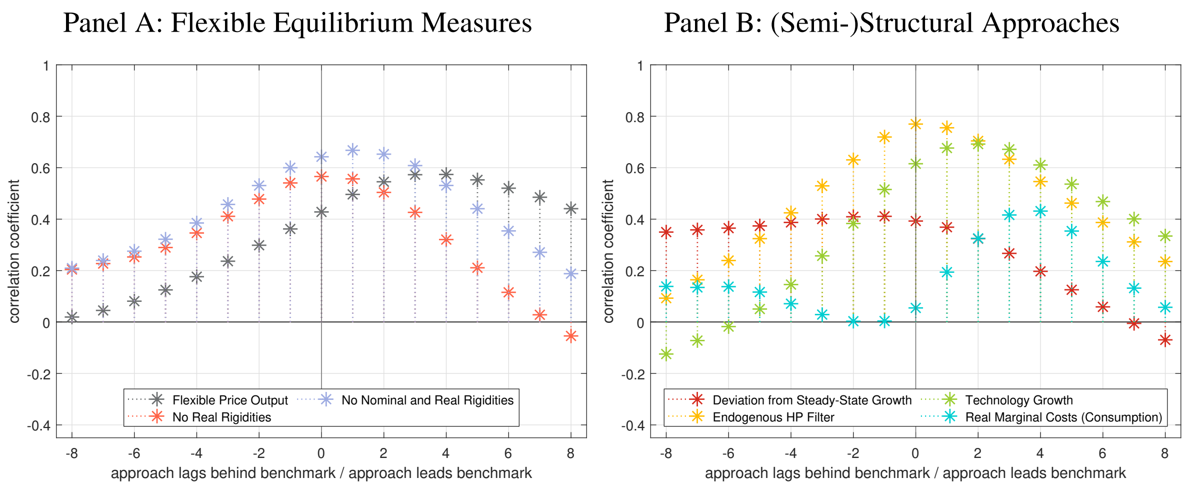


Note: Deviation from potential output, in percentages.

Table 1: Summary Statistics of Estimated Output Gaps

Approach	Mean	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis
Exogenous QPM	0.23	-4.48	4.28	2.39	-0.05	1.76
Flexible Price Output	2.75	-0.74	6.92	2.09	0.41	2.24
No Real Rigidities	1.71	-2.19	9.62	3.58	0.80	2.16
No Nominal and Real Rigidities	0.19	-5.32	7.99	4.60	0.69	1.80
Deviation from Steady-State Growth	-2.74	-11.47	9.60	7.52	0.54	1.68
Endogenous HP Filter	-2.09	-8.59	3.19	3.70	-0.34	1.69
Technology Growth	2.23	-5.74	6.18	2.65	-1.17	4.03
Real Marginal Costs (Consumption)	-0.72	-3.80	2.43	1.18	0.04	3.52

Figure 5: Cross-Correlation of Estimated Output Gaps with the Output Gap Obtained Exogenously by the QPM



Note: Positive (negative) values indicate the correlation of a particular output gap identification with a lagged (leading) benchmark output gap, specifically the exogenous QPM-based identification incorporating expert judgments. The x-axis represents quarters.

Among all the methods considered, the approach based on deviations from the steady-state growth rate is the most volatile. Its mean value is considerably negative, similar to that of the endogenous HP filter approach. When potential output is defined by technology growth, the average output gap is significantly positive, although its standard deviation is comparable to the benchmark estimate. Additionally, its minimum and maximum values fall within the range implied by other approaches.

The output gap defined by real marginal costs in the consumer sector is, on average, slightly negative and exhibits the lowest standard deviation—although its variability was adjusted using a scaling parameter (see Equation 10).

Most output gap measures display skewness values relatively close to zero, indicating symmetric distributions characteristic of the normal distribution. The technology growth-based output gap exhibits negative skewness, implying deeper troughs during downturns. However, this pattern is consistent with observed characteristics of the business cycle (Morley and Piger, 2012). It is also the only approach showing leptokurtosis (kurtosis above 3), indicating heavier tails and a higher frequency of extreme values compared to the normal distribution. In contrast, the other output gap filtering methods exhibit platykurtic behavior (kurtosis below 3), characterized by lighter tails and fewer extreme outliers.

4.3 Cross-Correlations

Figure 5 presents the cross-correlations between the various output gap measures and the benchmark, defined by the exogenous QPM estimate incorporating expert judgments. The output gaps defined as the difference between actual output and various flexible equilibrium outputs exhibit positive contemporaneous cross-correlations with the benchmark, ranging from 0.4 to 0.6 (Figure 5: Panel A). Moreover, these output gaps—most notably the output gap based on the flexible price equilibrium—tend to lead the benchmark, suggesting their potential usefulness as leading indicators of the economy's business cycle position.

A broader variety of cross-correlation patterns is observed among the (semi-)structural approaches (Figure 5: Panel B). The endogenous HP filter displays the strongest contemporaneous correlation with the benchmark, approaching 0.8. Similarly, the technology growth-based measure shows strong co-movement with the benchmark output gap and also exhibits some leading behavior. In contrast, the remaining two approaches—the deviation of GDP growth from its steady state and real marginal costs in the consumer sector—display weaker synchronization, with peak correlation values around 0.4.

Notably, real marginal costs exhibit behavior consistent with that of a leading indicator of the business cycle. Increases in real marginal costs—interpreted here as a proxy for the output gap—tend to precede periods of economic expansion, as captured by other output gap measures. According to the maximum cross-correlation, real marginal costs lead the business cycle most strongly at a one-year horizon, reinforcing the forward-looking nature of monetary policy.

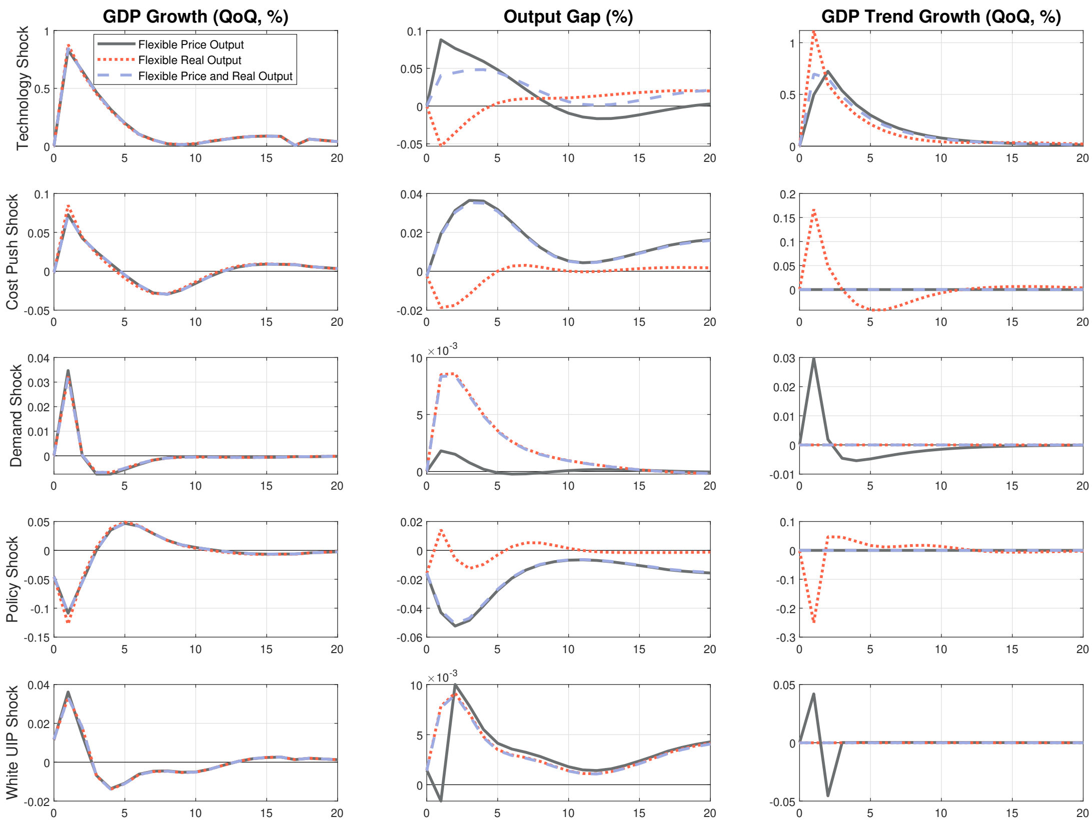
If policymakers are seeking an early-warning indicator of the business cycle, the flexible price equilibrium and the endogenous approach based on real marginal costs serve this purpose best. In contrast, the remaining types of flexible equilibrium, along with the HP filter and the approach based on technology growth, are better suited to closely mimic the current QPM-type methodology. Finally, the output gap measured as the deviation from steady-state growth tends to lag behind the benchmark and therefore appears inferior to the other alternatives.

4.4 Impulse Response Analysis

The dynamic responses of the domestic economy to selected structural shocks are examined in this section, with particular emphasis on key domestic shocks. These include innovations in labor-augmented technological growth, a household demand shock, a consumption cost-push shock, a monetary policy shock, and a white-noise uncovered interest parity (UIP) shock. The analysis also evaluates how augmenting the policy rule with the output gap influences these responses.

The impulse response functions (IRFs) display broadly similar dynamics to those of the baseline g3+ model, reflecting the fact that achieving the inflation target remains the primary objective of monetary policy. From a quantitative standpoint, incorporating the output gap both as a model variable and as an element of the policy rule has only limited effects on the overall model dynamics. Therefore, the discussion focuses on the responses of GDP growth and two newly introduced variables—the output gap and potential output growth. These are presented in Figure 6 for flexible equilibrium-based measures and in Figure 7 for (semi-)structural gap measures. IRFs for other key macroeconomic variables, including CPI inflation, the nominal interest rate, the nominal exchange rate, and wage inflation, are provided in Appendix A3.

Figure 6: Responses of Output Growth, the Output Gap, and Potential Output to Major Domestic Shocks Under Flexible Equilibrium Identifications of Potential Output

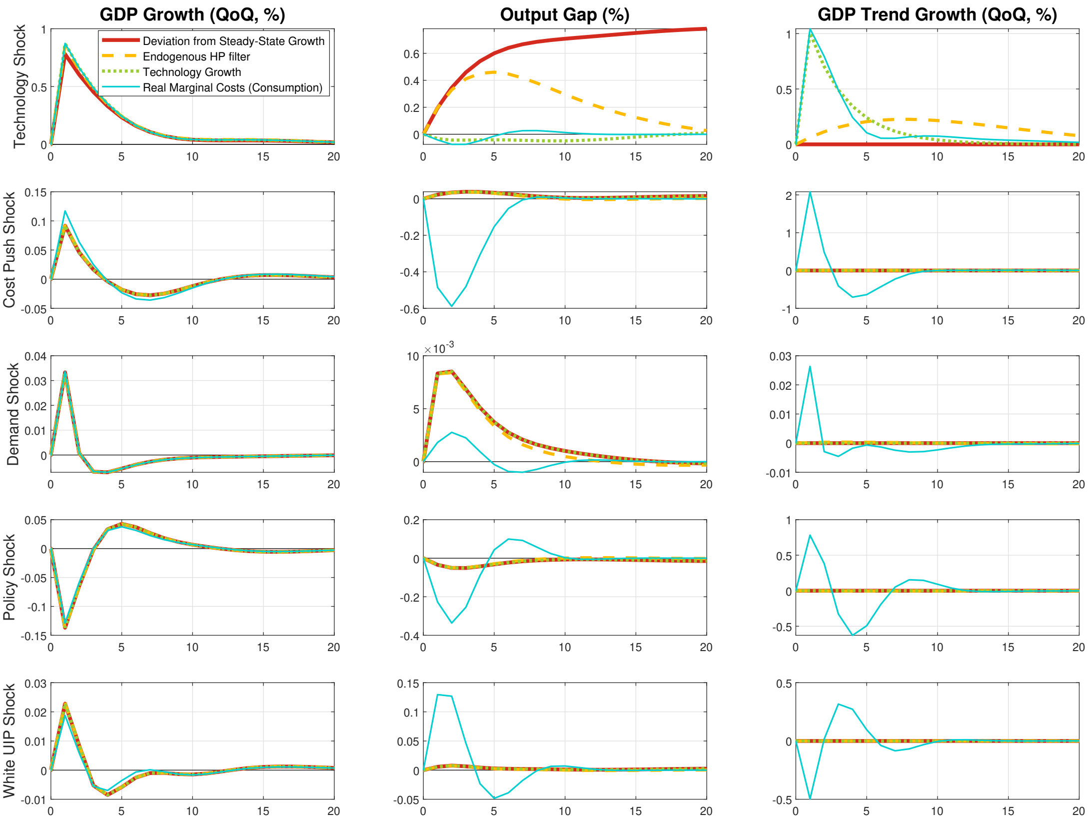


Note: The responses correspond to an annualized unit shock and cover the 20 quarters following the initial shock. Deviations from the steady state are expressed in percentage points. Quarter-on-quarter dynamics are annualized, and the output gap is measured as the deviation from potential output.

Flexible Equilibrium Measures

Both the flexible price equilibrium and the flexible real equilibrium have their strengths and weaknesses. The flexible price equilibrium generally provides an intuitive response to most shocks. However, its implication of a positive output gap following favorable technological shocks is counterintuitive. In reality, due to real rigidities, the economy adjusts only gradually to such improvements, implying that the output gap should initially be negative. In this sense, the flexible real equilibrium yields a more desirable response of the output gap to positive innovations in labor-augmenting technology. However, it also exhibits certain weaknesses—for instance, an increase in potential output in response to a cost-push shock. When the two flexible equilibrium measures are combined, potential output responds only in the case of technological shocks.

Figure 7: Responses of Output Growth, the Output Gap, and Potential Output to Major Domestic Shocks Under (Semi-)Structural Identifications of Potential Output



Note: The responses correspond to an annualized unit shock and cover the 20 quarters following the initial shock. Deviations from the steady state are expressed in percentage points. Quarter-on-quarter dynamics are annualized, and the output gap is measured as the deviation from potential output.

Nonetheless, this approach still produces a positive output gap following an improvement in labor-augmenting technology, which remains counterintuitive.

A positive *innovation in labor-augmented technological growth*—representing an unanticipated improvement in domestic supply—leads to an increase in output growth (Figure 6). Under the flexible price equilibrium—used as a proxy for potential output—prevailing real rigidities constrain the increase in potential growth, resulting in a positive output gap. However, when potential output is defined by the flexible real equilibrium, technological progress raises potential output more than actual GDP, implying a negative output gap. If potential output is approximated by the level of output that would prevail in the absence of both nominal and real rigidities, then a positive technological shock results in a positive output gap.

A positive *consumption cost-push shock* does not affect potential output when measured by the flexible price equilibrium, as this concept excludes nominal shocks. Therefore, the entire increase in actual output is reflected in a widening positive output gap. This result also holds under a specification with neither nominal nor real rigidities. By contrast, the absence of real rigidities alone enables the shock to propagate more swiftly, resulting in a stronger response of potential output. Consequently, potential output increases more than actual output, yielding a negative output gap.

A positive *shock to household demand* intuitively generates a positive output gap across all flexible equilibrium measures. Potential output is marginally affected only under the flexible price equilibrium. Other flexible concepts leave potential output unchanged and are therefore fully reflected in a positive output gap, as they abstract from real shocks and rigidities.

A restrictive *monetary policy shock* leads to a decline in GDP growth. When potential output remains unaffected, the output gap turns negative. However, under the flexible real equilibrium—which assumes the absence of real rigidities—potential output also responds to the policy shock. In this case, the decline in potential output outpaces the fall in actual output, temporarily resulting in a counterintuitive positive output gap.

A one-off *exchange rate depreciation shock* affects potential output only temporarily under the flexible price equilibrium, since the shock is treated as a real disturbance reflecting sentiment in financial markets. In this case, the initial, short-lived increase in potential output generates a negative output gap, which subsequently turns positive, aligning with the responses under other flexible equilibrium definitions.

(Semi-)Structural Approaches

When potential output is identified solely through technological growth, it responds exclusively to labor-augmenting technology shocks (Figure 7). Other shocks affect only the cyclical output gap. In contrast, the endogenous HP filter distributes the impact of shocks between the trend and the gap, reflecting its purely statistical nature and lack of economic interpretation, and typically assigns a larger share to the gap. Under the real marginal cost-based identification, potential output growth responds more strongly than the cyclical component. As a result, for most shocks—except the household demand and white-noise UIP shocks—the output gap adjusts in the opposite direction to offset the exaggerated movements in potential output. Furthermore, both the output gap and potential output, as measured by real marginal costs, exhibit a stronger response than when measured by alternative methods. Finally, when the output gap is measured as the deviation from steady-state output growth, innovations in labor-augmenting technology generate a counterintuitive permanent effect on the gap due to the assumption of unchanged steady-state GDP growth.

A positive *labor-augmenting technology shock* implies a negative output gap when measured using the technology-based and real marginal cost approaches. This outcome is intuitive: unexpected technological progress raises potential output, but due to frictions, potential output increases more than actual output, resulting in a negative output gap. In contrast, the endogenous HP filter and the gap measured as deviations from steady-state growth interpret faster GDP growth as a positive output gap. Furthermore, in the case of the deviations-from-steady-state growth measure, the impact on the output gap is persistent, as potential output does not respond to the technological improvement at all—even though the shock leads to a permanent increase in GDP.

Under all measures except the real marginal cost framework, *a consumption cost-push shock* leads to a positive output gap. However, in the real marginal cost framework, the increased markup lowers real marginal costs for firms, resulting in a negative output gap.

For a *household demand shock*, the output gap becomes positive across all approaches, consistent with rising inflationary pressures stemming from excess demand.

A *monetary policy tightening* implies a negative output gap across all methods. Under the real marginal cost approach, a monetary policy tightening leads to a decrease in real marginal costs, which results in a markedly negative output gap. At the same time, potential output growth increases, reinforcing the countercyclical nature of the gap.

An unexpected *depreciation of the Czech koruna* leads to economic overheating across all specifications of the output gap. This aligns with the conventional view that nominal depreciation stimulates short-term economic growth in an export-oriented small open economy.

5. Policy Implications

5.1 Assessing Alternative Output Gap Measures

The inclusion of the output gap in the g3+ model does not qualitatively alter the model's dynamic properties in terms of economic plausibility. However, each approach to identifying the gap yields a different outcome and carries distinct implications. Hence, the estimates obtained confirm the findings of Armenter and Bodenstein (2009), which show that DSGE-based output gap estimates are highly sensitive to the underlying model assumptions.

First of all, based on our results, we propose that the output gap should be endogenously determined within the model. Without endogeneity, alternative scenarios cannot be properly constructed, as the output gap remains fixed. Therefore, model-consistent and endogenously identified output gap measures are preferred.

The choice of endogenous output gap should reflect the specific policy objective. If monetary policy aims to respond to real economic activity, a technology-augmented output gap provides an effective proxy. It fully exploits the structural advantages of the DSGE model, while preserving all the investigated properties, aligning with economic intuition, and corresponding closely to the benchmark measure.

The endogenous HP filter remains a feasible method for assessing the business cycle at first glance; however, it lacks a clear structural foundation within the model. By contrast, defining the gap as deviations from a steady-state output growth path is less suitable, as it either implies a persistent negative output gap following a downturn—because actual output does not return to the initial path—or requires frequent and precise estimation of the evolving steady-state path to produce a realistic measure. This latter approach often necessitates an auxiliary model to estimate quarterly steady-state values, thereby diminishing the advantage of endogenous output gap identification.

If the objective is to offset inefficiencies arising from rigidities and frictions, flexible equilibrium-based measures may be appropriate. The flexible price equilibrium represents a world without nominal frictions or monopolistic competition inefficiencies, while the real equilibrium addresses only real rigidities. The combined nominal and real flexible equilibrium incorporates both assumptions, providing a comprehensive frictionless framework. Since distinguishing between the nominal and real components of shocks is often challenging, adopting the combined flexible equilibrium resolves this issue. Furthermore, this approach implies that potential output is driven solely by frictionless mechanisms and technological progress, highlighting technological growth as the most appropriate basis for identifying potential output—and, consequently, the output gap—in DSGE models. However, the combined nominal and real flexible equilibrium is operationally challenging due to model complexity, particularly if it is intended for regular use.

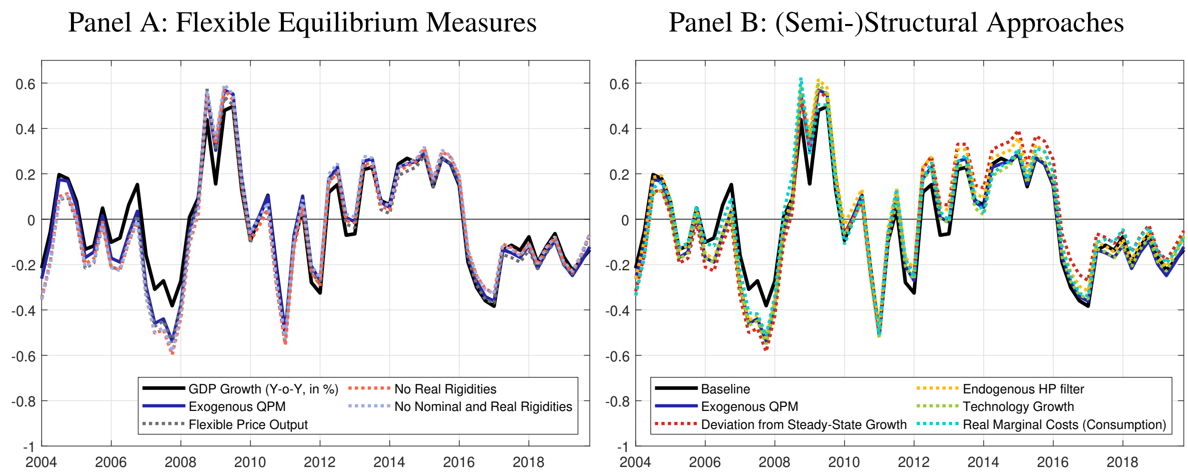
If the policymaker prefers to define the output gap primarily as an indicator of future inflationary pressures, an output gap identified on the basis of real marginal costs is appropriate. However, this implies that monetary policy responds to both demand- and supply-driven price pressures. If this is the policymaker's intention, it raises the question of whether the policy rule should instead be adjusted to place greater emphasis on expected deviations of inflation from the target. Modifying the interest rate smoothing parameter or assigning a higher weight to the inflation term in the rule are more straightforward options than introducing an output gap of this type into the policy rule. However, based on cross-correlation analysis, this approach might be useful as an early-warning indicator of the business cycle.

5.2 Impact of the Output Gap on Monetary Policy

From a policy perspective, incorporating the output gap into the policy rule influences the interest rate path. The strength of this effect depends on the calibration of the rule. However, the impulse response analysis indicates that the output gap has only a limited effect on the dynamics of key macroeconomic variables. This is particularly true for responses to demand-side shocks. To materially influence these dynamics, the weight of the output gap in the policy rule would need to be substantially higher, approaching the weight assigned to inflation.

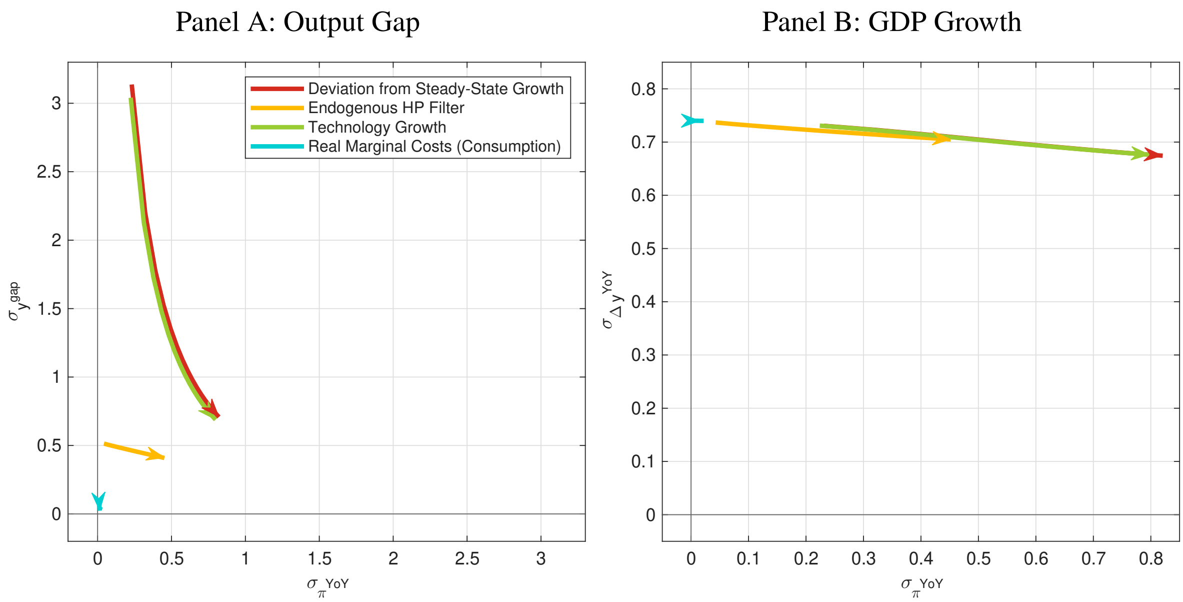
Furthermore, adding the output gap to the policy rule does not significantly alter the interpretation of historical data through the lens of the g3+ model. The filtered historical policy shocks, depicted in Figure 8, are similar across all considered approaches, despite substantial differences in the identification of the output gap. However, these results are conditional on the weight assigned to the output gap in the policy rule. Therefore, it is essential to discuss both the choice of this weight and its implications.

Figure 8: Policy Shocks Under Different Identifications of the Output Gap



Note: Measured in percentage points. Shocks are identified by means of historical filtering, conditional on the observed data.

Figure 9: Trade-off in the Variability of Inflation and Measures of Economic Activity



Note: The x-axis shows the standard deviation of inflation; the y-axis depicts the standard deviation of the output gap and GDP growth, respectively. All measured in percentage points.

The weight assigned to the output gap in a monetary policy rule should reflect policymakers' preferences regarding the degree to which the position of the business cycle is taken into account, while ensuring that the central bank remains firmly committed to its primary objective of price stability. In the presence of supply shocks, responding to fluctuations in the output gap entails a policy trade-off, as maintaining inflation close to the target may necessitate a temporary deceleration in real economic activity. To evaluate the implications of output gap stabilization within the g3+ model framework, a Taylor curve was constructed (Taylor, 1993). This welfare-based analysis captures the trade-off between the variability of consumer price inflation and that of the output gap. Specifically, the policy parameter $\psi^{\hat{y}}$, which governs the response to the output gap, was varied from 0.125 to 2 in increments of 0.125. Figure 9 depicts the resulting trade-offs in the variability of inflation, the output gap, and real GDP growth. This part of the analysis focuses solely on (semi-)structural approaches.

The results indicate that monetary policy is only marginally effective in reducing output gap variability when the gap is estimated using an endogenous HP filter (Figure 9: Panel A). Specifically, the standard deviation of inflation increases by more than a factor of ten as the parameter $\psi^{\hat{y}}$ rises from 0.125 to 2, while the corresponding reduction in output gap volatility remains negligible. In contrast, a more favorable trade-off emerges when the output gap is defined in terms of technology growth or the deviation of GDP growth from its steady state. From this perspective, the inflation costs associated with stabilizing the output gap are relatively moderate—particularly when the policy objective function assigns equal or near-equal weight to both inflation and output gap stabilization. When the output gap is identified using real marginal costs, the variability of both inflation and the output gap declines as $\psi^{\hat{y}}$ increases. This occurs because placing greater emphasis on the output gap effectively strengthens the policy response to expected future inflation, thereby contributing to more effective inflation stabilization.

When comparing the variability of inflation and output growth, the trade-off associated with the endogenous HP filter becomes more comparable to that of other (semi-)structural approaches, such as those based on technology growth or deviations of GDP from its steady state (Figure 9: Panel B). Although the output growth variability decreases, this improvement comes at the cost of higher inflation variability. In fact, the increase in inflation volatility outweighs the reduction in output variability, especially compared to the baseline scenario, where the output gap played a minor role in the policy rule. Reacting to an output gap defined in terms of real marginal costs helps reduce the variability of both inflation and output, but the overall gain is negligible.

These findings indicate that the weight on the parameter $\psi^{\hat{y}}$ should be set with care, given its influence on inflation variability and, consequently, the monetary authority's ability to meet the inflation target consistently over time.

6. Conclusion

This paper has examined how alternative definitions of the output gap in a New Keynesian DSGE framework affect model dynamics, structural interpretation, and the design of monetary policy in a small open economy operating under inflation targeting. The analysis highlights not only the conceptual diversity underlying output gap measures but also the material policy consequences arising from these differences. Building on the example of the Czech economy, we have assessed one exogenous and seven endogenous measures, spanning flexible equilibrium concepts, statistical filters, and structurally grounded indicators such as technology-augmented output and real marginal costs.

Three main conclusions emerge. First, the output gap should, whenever feasible, be identified endogenously within the model. Endogenous identification ensures consistency among potential output, the business cycle position, and other structural relationships, allowing the gap to respond consistently to model-based shocks and endogenous adjustment mechanisms. In this respect, technology-augmented output provides the most coherent and operationally robust measure, embedding the underlying drivers of real economic activity and supporting a microfounded monetary policy analysis. While flexible equilibrium concepts remain theoretically appealing—especially in the tradition of the efficient or natural level of output in New Keynesian models—their practical implementation is impeded by model complexity and demanding calibration requirements.

Second, real marginal costs provide a viable alternative when the policymaker's primary concern is the identification of future inflationary pressures. In line with New Keynesian price-setting theory, real marginal costs capture both demand and supply forces that influence inflation dynamics. They are therefore well suited to rules that place greater emphasis on stabilizing expected deviations of inflation from target. Nevertheless, this potentially amplifies reactions to supply-driven movements in marginal costs.

Third, from a policy design perspective, the weight assigned to the output gap interacts critically with the choice of the gap measure itself. Increasing the weight on the output gap generally amplifies inflation variability, thereby potentially complicating the attainment of price stability—the primary mandate of inflation-targeting central banks. A notable exception arises when the gap is defined in terms of real marginal costs: in this case, higher weights may reduce inflation variability due to the structural link between marginal costs and inflation embedded in the New Keynesian Phillips curve. Consequently, the choice of output gap measure should be aligned with the policymaker's institutional preferences.

Overall, the findings suggest that technology-augmented output is the most practical and conceptually coherent choice for DSGE-based policy analysis in small open economies such as the Czech Republic. However, the broader implications extend to other economies with similar structural characteristics. By clarifying the consequences of alternative output gap definitions, this study contributes to more transparent and consistent application of DSGE models in the formulation and evaluation of monetary policy.

References

ADOLFSON, M., S. LASÉEN, L. CHRISTIANO, M. TRABANDT, AND K. WALENTIN (2013): "Ramses II - Model Description." Occasional Paper Series 12, Sveriges Riksbank.

ANDRLE, M., T. HLÉDIK, O. KAMENÍK, AND J. VLČEK (2009): "Implementing the New Structural Model of the Czech National Bank." CNB Working Paper No. 2/2009, Czech National Bank.

ARMENTER, R. AND M. BODENSTEIN (2009): "Of Nutters and Doves." *The B.E. Journal of Macroeconomics,* 9(1):1–22.

BENEŠ, J., D. VÁVRA, AND J. VLČEK (2002): "Střednědobá makroekonomická predikce: makroekonomické modely v analytickém systému CNB." *Czech Journal of Economics and Finance,* 52(4):197–231.

BRÁZDIK, F., T. HLÉDIK, Z. HUMPLOVÁ, I. MARTONOSI, K. MUSIL, J. RYŠÁNEK, T. ŠESTOŘÁD, J. TONNER, S. TVRZ, AND J. ŽÁČEK (2020): "The g3+ Model: An Upgrade of the Czech National Bank's Core Forecasting Framework." CNB Working Paper No. 7/2020, Czech National Bank.

BRÁZDIK, F., K. MUSIL, T. POKORNÝ, T. ŠESTOŘÁD, J. TONNER, AND J. ŽÁČEK (2025): "Upgrading the Czech National Bank's Core Forecasting Model g3+." CNB Working Paper No. 7/2025, Czech National Bank.

CHRISTOFFEL, K., W. ANDERS, AND G. COENEN (2010): "Forecasting with DSGE Models." Working Paper Series 1185, European Central Bank.

CORRIGAN, P., H. DESGAGNÉS, J. DORICH, V. LEPETYUK, W. MIYAMOTO, AND Y. ZHANG (2021): "ToTEM III: The Bank of Canada's Main DSGE Model for Projection and Policy Analysis." Technical Report 119, Bank of Canada.

DOTSEY, M., M. DEL NEGRO, A. SBORDONE, AND K. SILL (2011): "System DSGE Project Documentation." FOMC background memo, Federal Reserve.

GARCÍA-SCHMIDT, M. AND J. GARCÍA-CICCO (2020): "A TNT DSGE Model for Chile: Explaining the ERPT." Working Papers 868, Central Bank of Chile.

HARRISON, R. AND O. ÖZLEM (2010): "Evaluating and Estimating a DSGE Model for the United Kingdom." Working Papers 380, Bank of England.

KRAVIK, M. AND Y. NIMIR (2019): "Navigating with NEMO." Staff Memo 5, Norges Bank.

MISE, E., T.-H. KIM, AND P. NEWBOLD (2005): "On Suboptimality of the Hodrick–Prescott Filter at Time Series Endpoints." *Journal of Econometrics,* 128(2):269–293.

MORLEY, J. AND J. PIGER (2012): "The Asymmetric Business Cycle." *The Review of Economics and Statistics,* 94(1):208–221.

SMETS, F. AND R. WOUTERS (2003): "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association,* 1(5):1123–1175.

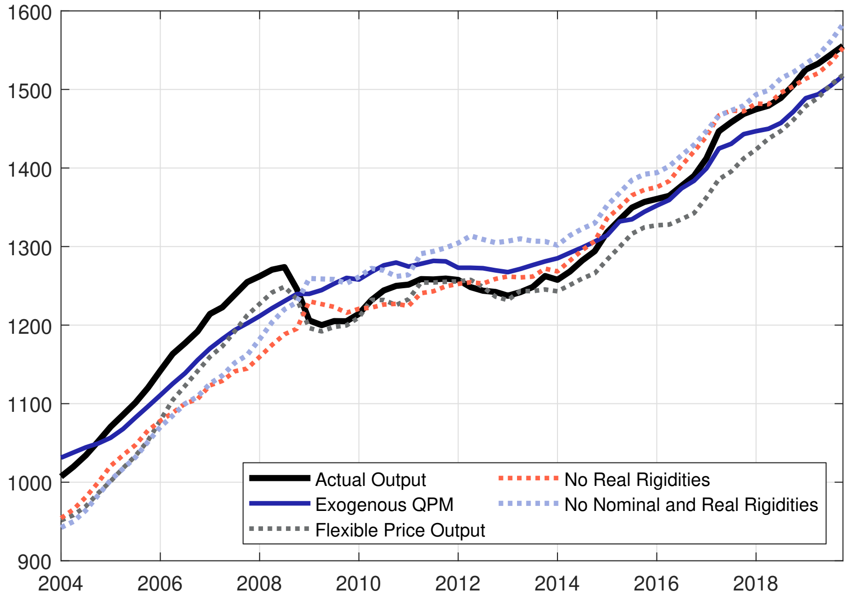
TAYLOR, J. B. (1993): "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy,* 39:195–214.

VETLOV, I., T. HLÉDIK, M. JONSSON, H. KUCSERA, AND M. PISANI (2011): "Potential Output in DSGE Models." Working Paper Series 1351, European Central Bank.

WOLF, E., F. MOKINSKI, AND Y. S. SCHÜLER (2024): "On Adjusting the One-Sided Hodrick–Prescott Filter." *Journal of Money, Credit and Banking,* 56(8):2075–2100.

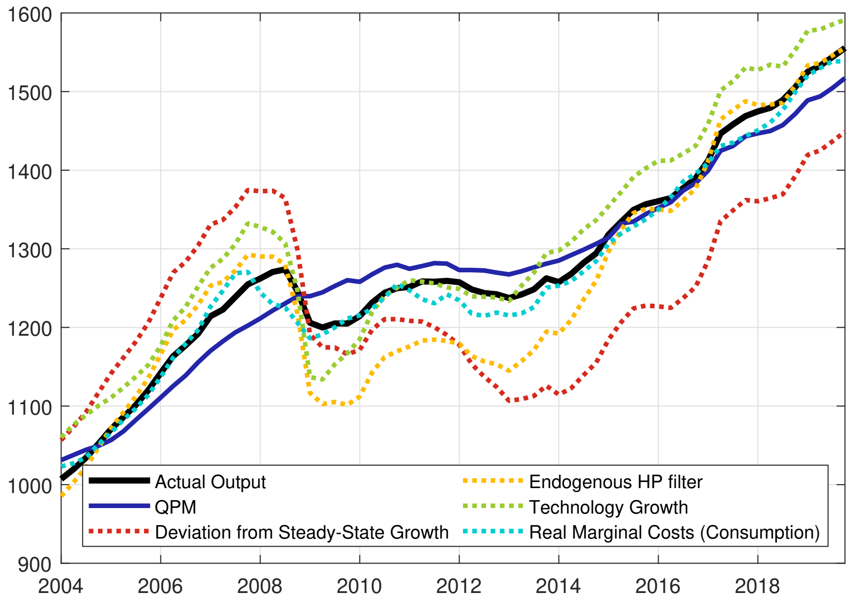
Appendix A1: Potential Output

Figure A1: Actual and Flexible Equilibrium Output



Note: Measured at constant prices of 2020, in billions of CZK.

Figure A2: Actual and Potential Output Obtained by Different (Semi-)Structural Identification Strategies



Note: Measured at constant prices of 2020, in billions of CZK.

Appendix A2: Details on the Identified Business Cycle Position of the Economy

A2.1 Flexible Equilibrium Measures

Qualitatively, flexible equilibrium measures offer a similar narrative of the Czech economy's cyclical position as the benchmark QPM-based output gap (Figure 4: Panel A). However, notable differences emerge in the magnitude and timing of cyclical peaks and troughs. In particular, the flexible price equilibrium approach generally produces higher output gap estimates across most of the sample period. This suggests that, in the absence of nominal rigidities and shocks, potential output would have been lower than that implied by alternative identification methods.

All flexible equilibrium measures point to a positive output gap before the Great Recession, consistent with declining inflationary pressures in the wake of the global financial crisis. However, in the post-crisis period, the estimated output gap trajectories diverge depending on the specific equilibrium framework employed. The flexible real equilibrium and the combined flexible price and real equilibrium approaches show a rapid shift from a positive to a negative gap, reflecting a sharp downturn. In contrast, the flexible price equilibrium measure implies a more gradual closing of the positive output gap, starting even before the onset of the Great Recession. According to this perspective, the output gap remained positive into 2009 and only converged to zero in 2010. This implies that, without nominal frictions and associated shocks, the GDP decline would have appeared more pronounced relative to observed GDP.

The temporary uptick in inflationary pressures during the 2010 recovery is reflected in a corresponding increase in the estimated business cycle position. However, this upward trend was short-lived, as the euro area sovereign debt crisis of 2011–2012 induced a renewed economic slowdown. Under the flexible real equilibrium and the combined equilibrium measures, the output gap was significantly affected by the crisis, whereas potential output growth remained relatively resilient to the adverse foreign demand shock—unlike actual GDP, which experienced a more pronounced decline.

During the exchange rate commitment period (2013–2017), both the flexible price and the combined equilibrium measures indicate rising inflationary pressures, consistent with above-potential output. By contrast, the real equilibrium-based output gap remained relatively stable. Notably, all three approaches also detect a modest decline in the output gap in the quarters preceding the COVID-19 pandemic.

A2.2 (Semi-)Structural Approaches

Among the (semi-)structural approaches, the output gap identified based on technological growth closely mimics the trajectory of the benchmark QPM-based measure (Figure 4: Panel B). Similarly, the endogenous HP filter provides a broadly consistent narrative. In contrast, output gap estimates based on real marginal costs and deviations from steady-state GDP growth differ significantly, offering an alternative perspective on the business cycle in the Czech Republic.

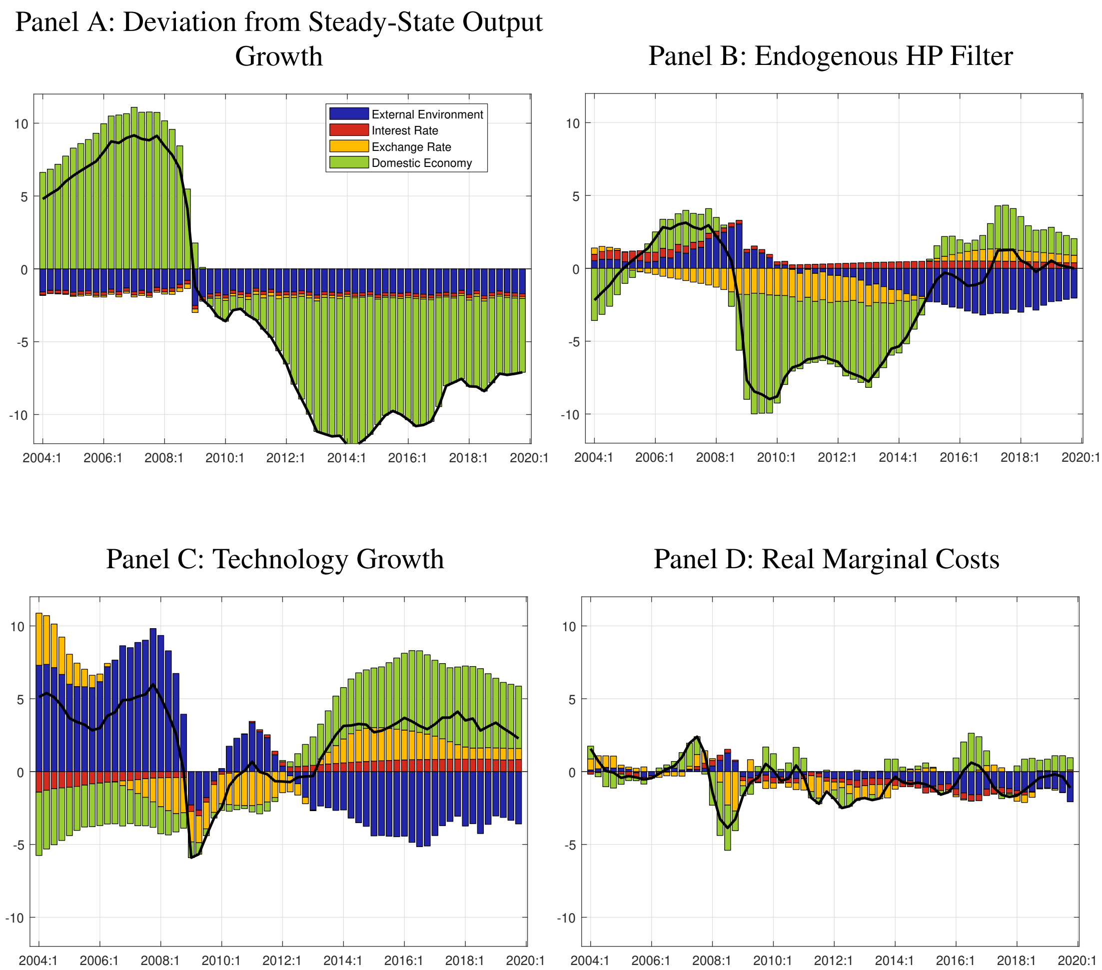
The output gap measure derived from deviations in output growth from its steady state appears overly simplistic and less reliable for capturing business cycle dynamics. It tends to overestimate the extent of economic overheating prior to the Great Recession. Following the subsequent downturn, this method implies a substantial and persistent negative output gap extending until the end of the sample period. These limitations are further illustrated by the historical decomposition into observable variables in Figure A3: Panel A, which suggests that the cycle is driven almost exclusively by domestic factors, while the external environment consistently contributes negatively. Moreover, this identification assigns negligible—or no—role to domestic monetary policy.

The endogenous HP filter embedded within the g3+ model provides a broadly similar depiction of the business cycle to the benchmark QPM. However, notable differences emerge, particularly around the Great Recession, where it identifies a deeper cyclical trough. The positive contribution of the external environment prior to the crisis dissipated by 2010. Simultaneously, the domestic economy began driving the output gap further into negative territory as early as 2009. A stronger-than-expected Czech koruna amplified the downturn by contributing negatively through the exchange rate channel (Figure A3: Panel B). Nonetheless, in line with the benchmark, the negative output gap estimated using the endogenous HP filter closed around 2015. This development reflected the fading negative contributions of both the domestic economy and the exchange rate, while foreign factors began to exert downward pressure. This shift coincided with the ECB's constrained monetary stance at the effective lower bound, which resulted in a prolonged undershooting of its inflation target and a persistent negative output gap across the euro area (Figure 3: Panel B).

The output gap derived from technological growth aligns with the benchmark narrative but indicates a larger positive gap in the years immediately following EU accession in 2004. Foreign demand was the primary driver of the positive gap during this period, although its contribution diminished with the onset of the Great Recession. In contrast, foreign factors contributed to a negative output gap during the subsequent European sovereign debt crisis and the period when the ECB's interest rates were constrained by the effective lower bound (Figure A3: Panel C). The rapid nominal appreciation of the Czech koruna in the pre-crisis years further dampened the domestic output gap. Between 2014 and 2018, the exchange rate floor led to undervaluation of the Czech koruna, thereby boosting the output gap. Since 2014, robust domestic demand—including export growth outpacing foreign demand—has increasingly compensated for the subdued external conditions.

Finally, the output gap identified through real marginal costs—which reflect cost pressures in the consumption sector—exhibits a markedly different evolution from both the benchmark and the other alternative approaches. This measure typically leads both inflation and the benchmark exogenously defined QPM-based output gap, as cost pressures transmit to prices via the Phillips curve before being reflected in real economic activity. The historical decomposition of this measure (Figure A3: Panel D) indicates that rising domestic and external cost pressures preceded the onset of the global financial crisis in 2008. However, at that time, the marked appreciation of the exchange rate together with weakening domestic demand exerted downward pressure on the output gap. A negative exchange rate contribution, further dampening the output gap, was also present between 2011 and 2014, reflecting the fact that the Czech koruna did not depreciate commensurately with the degree of economic slack. This effect diminished after the introduction of the exchange rate floor. Meanwhile, weak foreign growth and subdued global inflation increasingly weighed on the economy, reflected in persistent negative contributions to the output gap. As a result, the real marginal cost-based output gap has remained mildly negative for most of the period since 2008.

Figure A3: Historical Decompositions of the Output Gap for (Semi-)Structural Approaches



Note: Deviations from potential output in %. Contributions of observed data to the output gap in percentage points.

Appendix A3: Impulse Response Functions

The responses correspond to an annualized unit shock and cover the 20 quarters following the initial shock. Deviations from the steady state are expressed in percentage points. Quarter-on-quarter dynamics are annualized, and the output gap is measured as the deviation from potential output.

A3.1 Flexible Equilibrium Measures

Figure A4: Innovation in Labor-Augmenting Technology

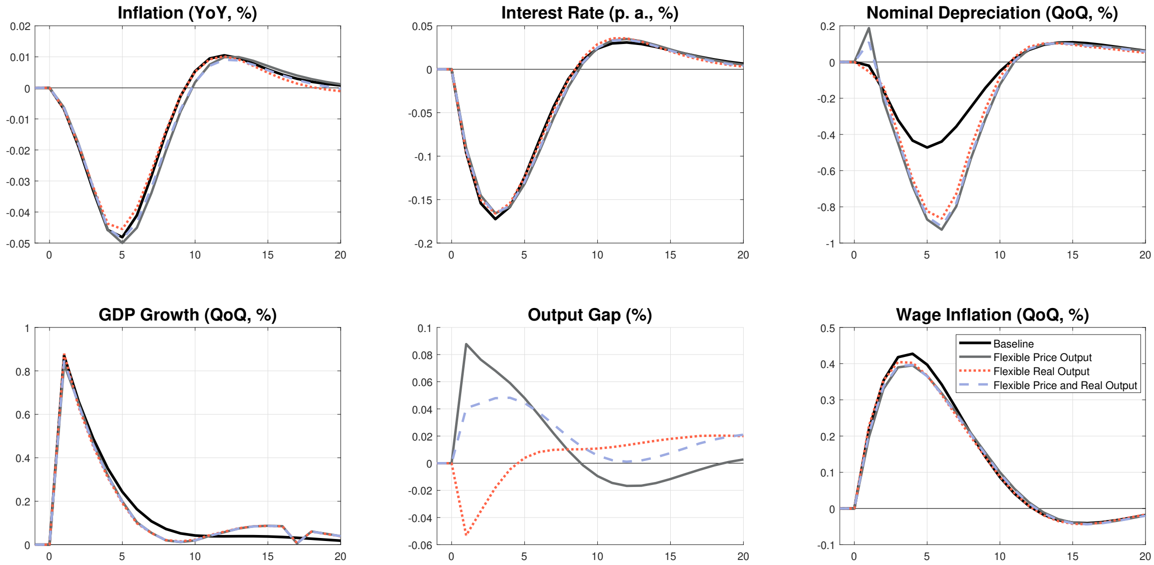


Figure A5: Consumption Cost Push Shock

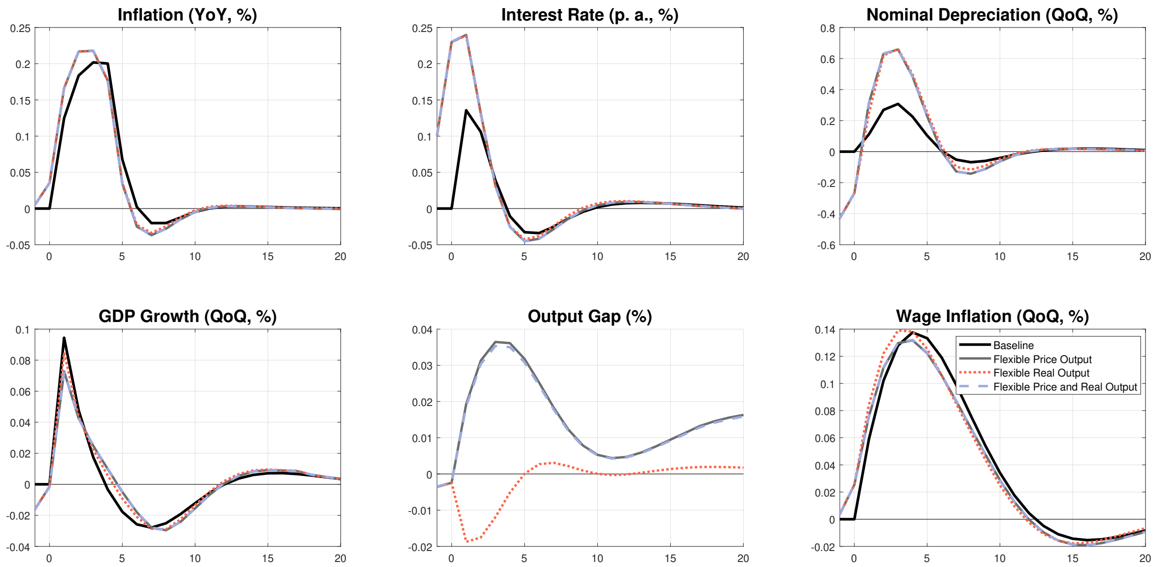


Figure A6: Household Demand Shock

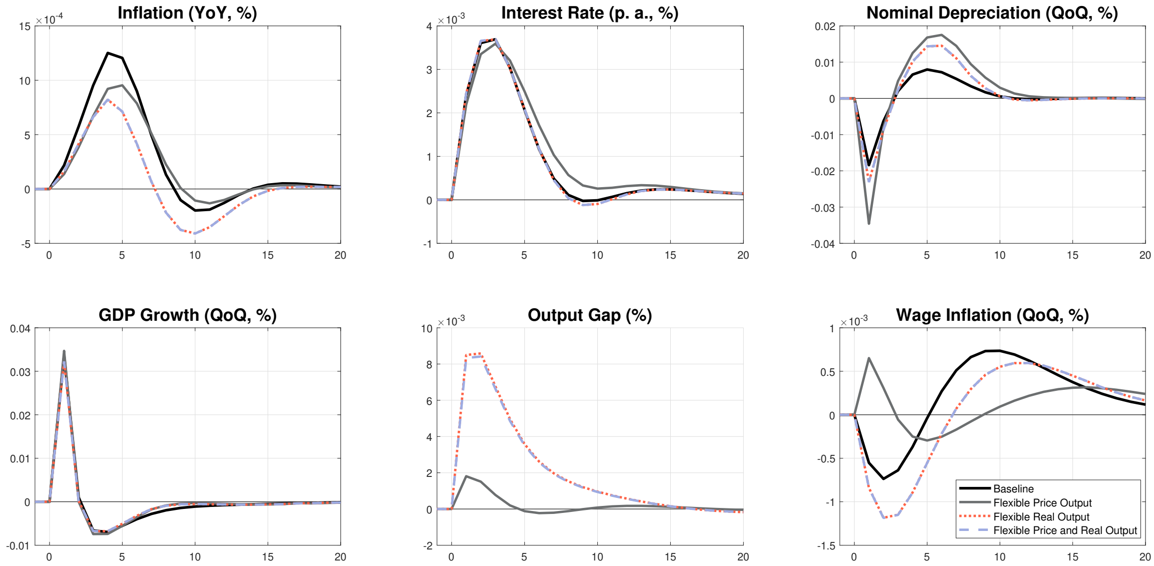


Figure A7: Monetary Policy Shock

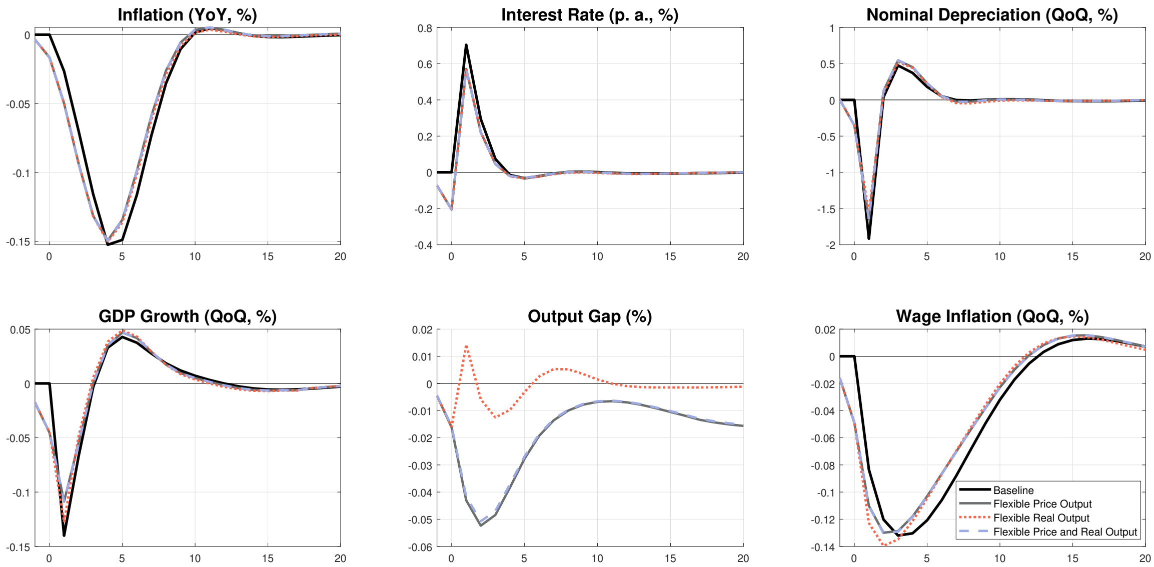
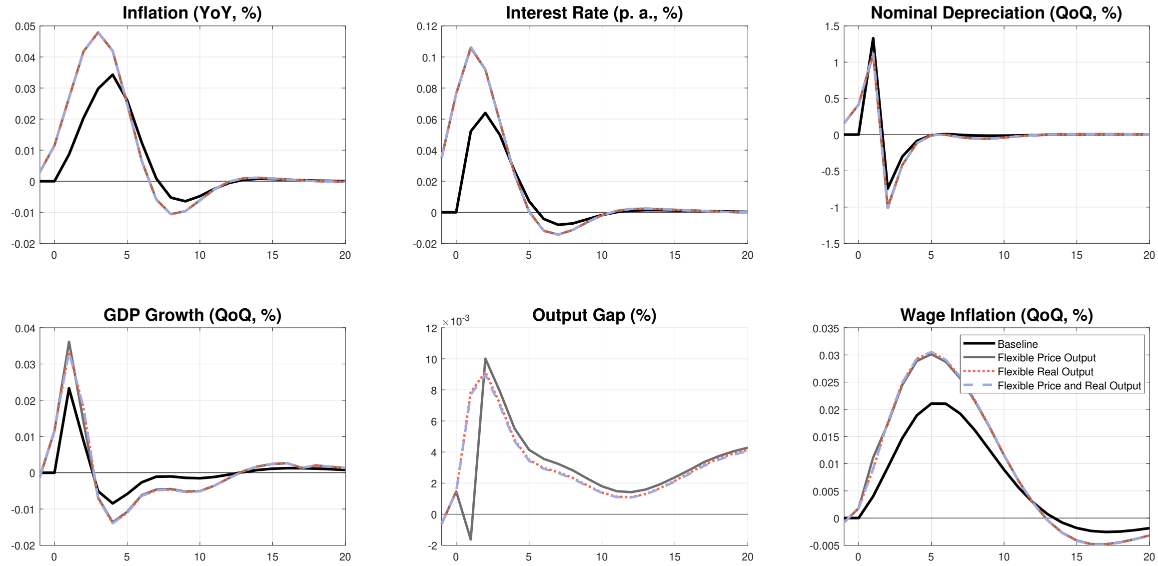


Figure A8: White Uncovered Interest Parity Shock



A3.2 (Semi-)Structural Approaches

Figure A9: Innovation in Labor-Augmenting Technology

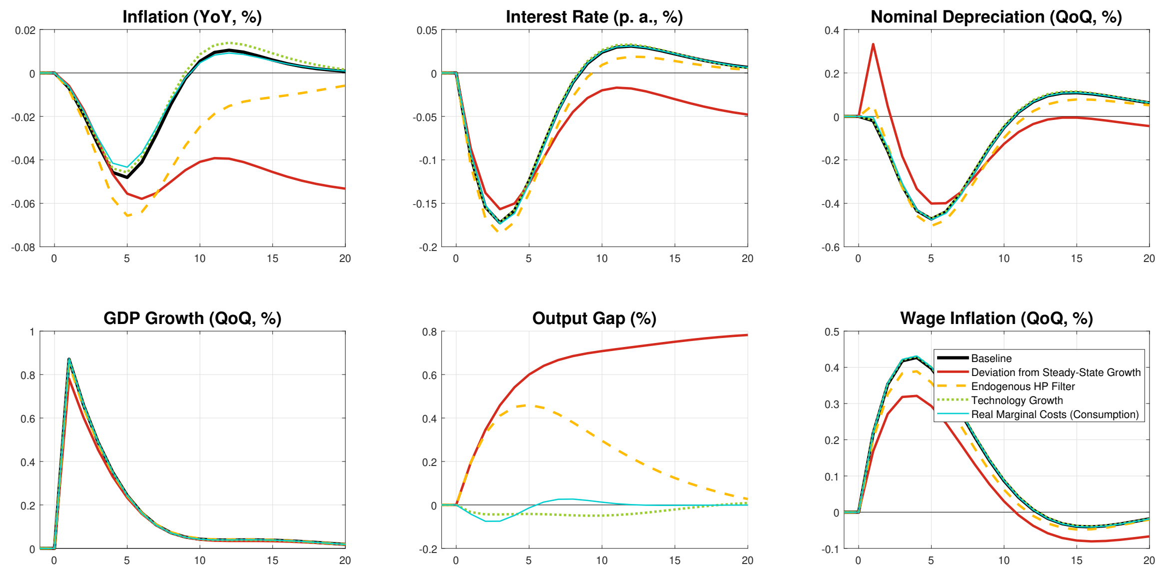


Figure A10: Consumption Cost Push Shock

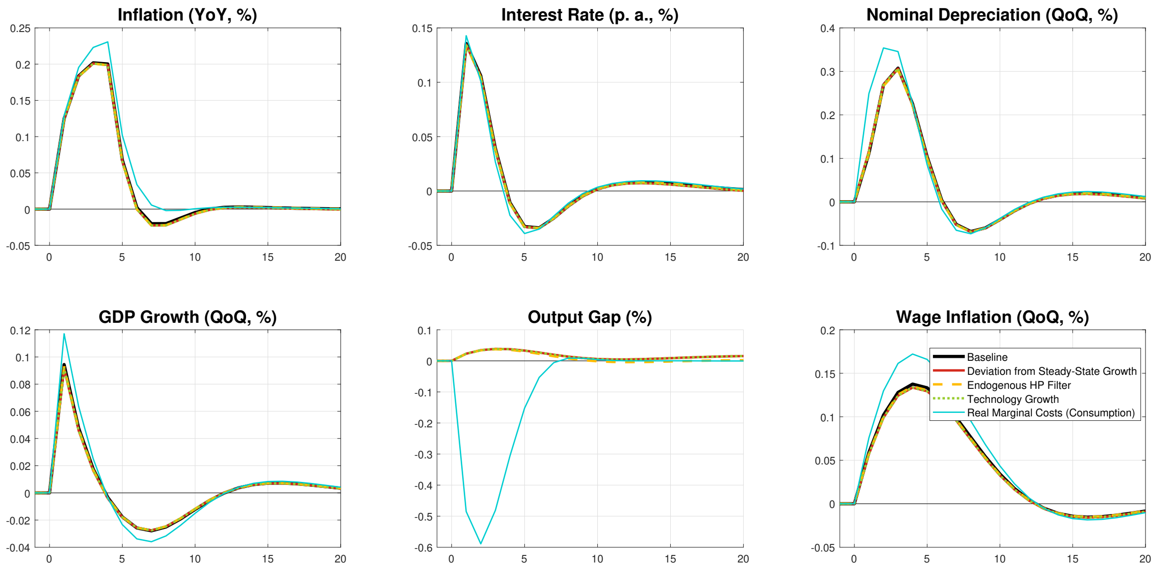


Figure A11: Household Demand Shock

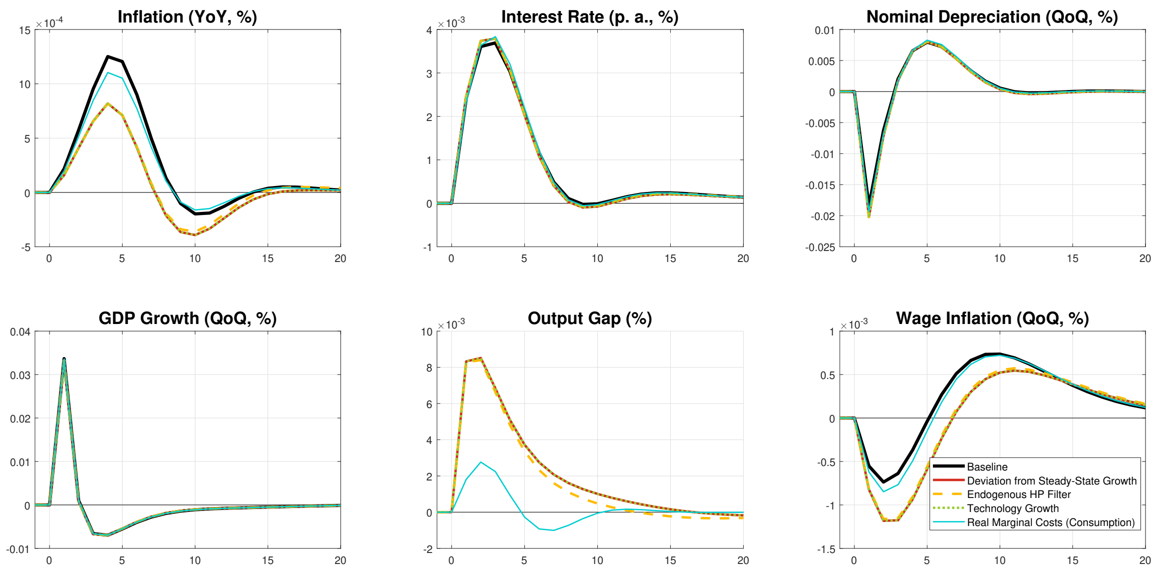


Figure A12: Monetary Policy Shock

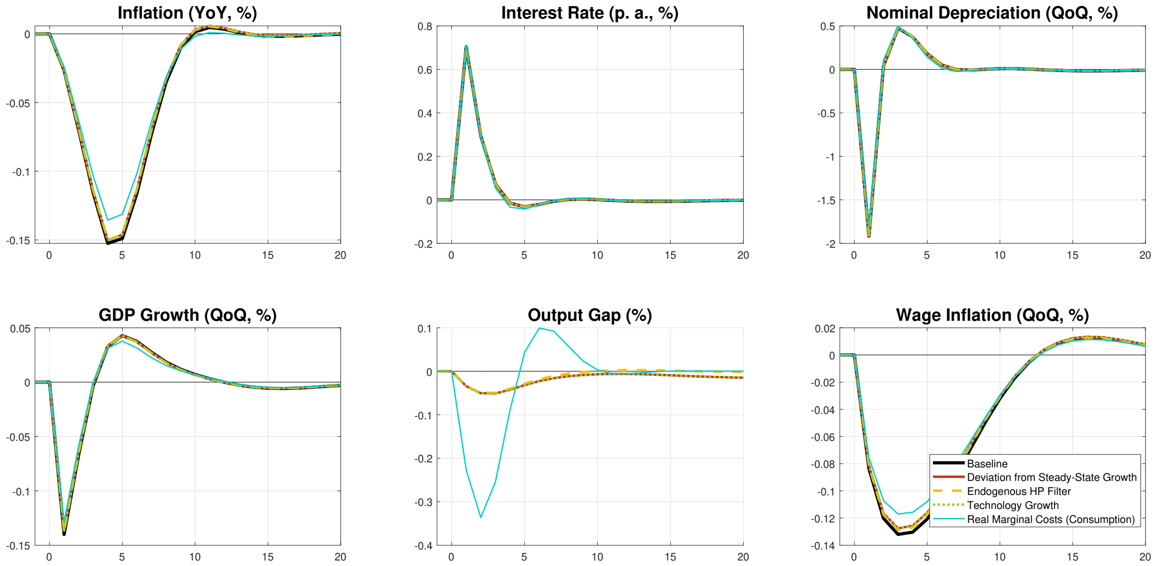
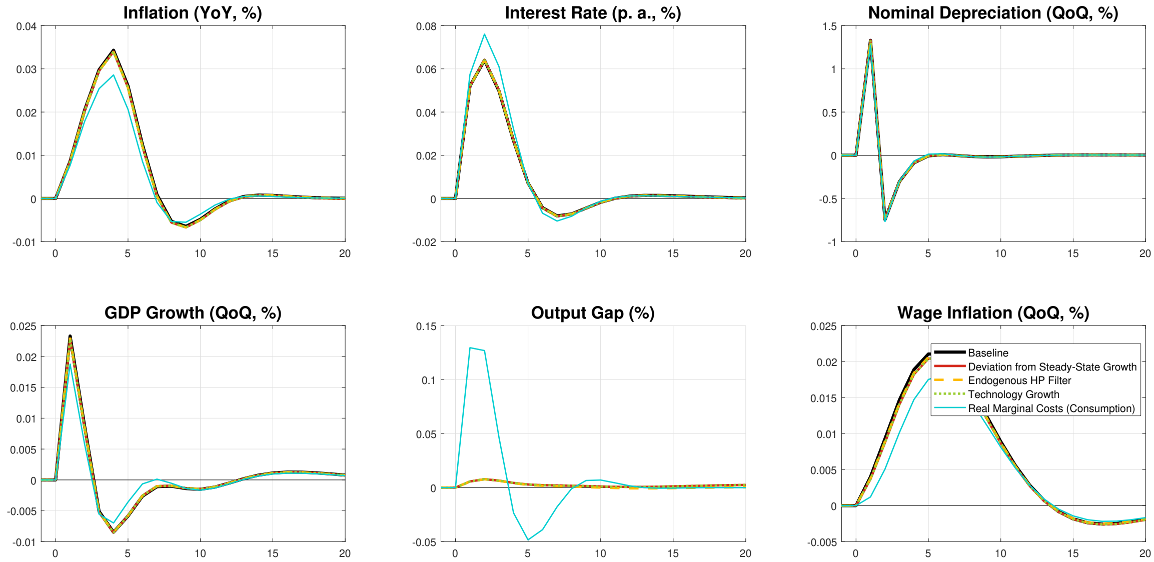


Figure A13: White Uncovered Interest Parity Shock



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