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Matthias Burgert
Matthiey Darracq Paries
Luigi Durand
Mario González
Romanos Priftis
Oke Röhe
Matthias Rottner
Edgar Silgado-Gómez
Nikolai Stähler
Janos Varga

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Teléfono: (56-2) 3882475; Fax: (56-2) 38822311

Macroeconomic Effects of Carbon-Intensive Energy Price Changes: A Model Comparison*

Matthias Burgert
Swiss National Bank

Matthieu Darracq Pariès
European Central Bank

Luigi Durand
Central Bank of Chile

Mario González
Central Bank of Chile

Romanos Priftis
European Central Bank

Oke Röhe
Deutsche Bundesbank

Matthias Rottner
BIS, Deutsche Bundesbank

Edgar Silgado-Gómez
Banco de España

Nikolai Stähler
Deutsche Bundesbank

Janos Varga
European Commission

Resumen
Este artículo presenta, en primer lugar, una comparación de modelos para analizar los desafíos que plantean los cambios en los precios de la energía intensiva en carbono para la política monetaria. Asimismo, los modelos monetarios ambientales empleados cuentan con una estructura multisectorial detallada, lo que permite capturar las interacciones entre sectores. En segundo lugar, la comparación evalúa los efectos tanto de un aumento temporal como permanente en el precio de la energía, con especial atención a la zona del euro y a Estados Unidos. Finalmente, el análisis indica que las respuestas cualitativas y cuantitativas presentan amplias similitudes; no obstante, dichas respuestas dependen de los supuestos utilizados en cada modelo y de la reacción de la política monetaria.

Abstract
This paper presents a novel model comparison to examine the challenges posed by changes in carbon-intensive energy prices for monetary policy. The employed environmental monetary models have a detailed multi-sector structure. The comparison assesses the effects of both a temporary and a permanent energy price increase with a particular focus on the euro area and the United States. Temporary and permanent price shocks are both inflationary. However, the inflationary impact of the permanent shock depends on the underlying model assumptions and monetary policy response. The analysis also establishes that these models share large commonalities in their quantitative and qualitative results, while also pointing out cross-country differences.

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Corresponding authors: Matthias Burgert (matthias.burgert@snb.ch) and Matthias Rottner (matthias.rottner@bis.org).

1 Introduction

The transition towards a green economy, while critical to address climate change, can also pose significant challenges for central banks as it affects inflation and thus their primary mandate of maintaining price stability. To evaluate these challenges, various institutions have developed macroeconomic models that are capable to analyse climate-related phenomena. A key insight in this context is the importance of taking sectoral developments into account. Climate policies, for example, may hit certain economic sectors especially hard, which could have far-reaching consequences for financial stability, monetary policy transmission, and aggregate growth.

This study examines the macroeconomic effects and monetary policy implications of both temporary and permanent carbon-intensive energy shocks with a particular focus on the euro area and the United States. It utilizes a set of institutional macroeconomic models to verify the robustness of the results and to highlight the significance of specific modeling assumptions. The models used in this exercise are fully-fledged multi-sector monetary models. Monetary models in general, and New Keynesian models in particular, play a key role in central banks' efforts to assess the implications of the green transition.[1] Despite a growing literature embedding environmental aspects in standard macro frameworks, the multi-sectoral dimension is often either absent or kept stylized.[2] However, accounting for the interactions across sectors in such analytical frameworks can be particularly useful to assess climate-related issues, as they provide a detailed understanding of how different economic sectors interact and respond to climate policies and shocks.

The model comparison encompasses several large-scale models developed within four central banks and two international organisations: including the BIS-MS model by the Bank for International Settlements (Burgert et al., 2025b), the SEEM model by the Banco Central de Chile (Beltrán et al., 2024), the EMuSe model by the Deutsche Bundesbank (Hinterlang et al., 2023), the NAWM-E model by the European Central Bank (Coenen et al., 2024), the E-QUEST model by the European Commission (Varga et al., 2022), and the C-EAGLE model by the Eurosystem (García et al., 2024). These models, which are widely used for policy analysis, incorporate various sectoral, nominal, and real rigidities to evaluate interactions between prices, sectoral dynamics, and economic outcomes. Each model features monetary policy rules, enabling analysis of monetary policy responses to supply-side disturbances, such as energy price shocks, and their propagation through the economy. A common feature is the detailed representation of sectoral linkages, particularly in the energy sector.

[1]Examples include studies by Airaudo et al. (2023), Annicchiarico et al. (2023), Del Negro et al. (2023), Nakov and Thomas (2023), Olovsson and Vestin (2023), Sahuc et al. (2024), Chafwehé et al. (2025), Kaldorf and Rottner (2025), Giovanardi and Kaldorf (2025), Priftis and Schoenle (2025), among many others.

[2]Notable exceptions include Del Negro et al. (2023) and Aguilar et al. (2023), both of which emphasize the role played by production networks.

Benchmarking macroeconomic models against each other is crucial for validating their accuracy and robustness, identifying strengths and weaknesses, and improving their design. Macroeconomic data are unlikely to provide sufficient testing grounds for selecting a single, preferred model for policy purposes. If many competing models describe historical data of key aggregates reasonably well, they can be used to establish the robustness of policy recommendations. This approach is recommended by McCallum (1988), Blanchard and Fischer (1989), Taylor (1999), and others. Despite the benefits, systematic comparisons of empirical implications across many models are rare due to the intensive and costly nature of such evaluations. Initiatives like those reported in Bryant et al., eds (1993), Taylor (1999), Coenen et al. (2012), and Darracq Pariès et al. (2022) have produced influential insights.

The model comparison exercise conducted in this study explores the frameworks in three ways: (i) by describing and discussing the commonalities and differences of the models, (ii) by comparing model simulations across aligned simulation scenarios, (iii) by exploring particular model features in sensitivity analyses. In the aligned scenario, the target variable is the price of carbon-intensive energy, for which the oil price can be used as a proxy. The applied shocks, e.g. an exogenous variation in total factor productivity (TFP) in the carbon-intensive energy sector or in imports of fossil resources, vary across models and are tailored to the specific characteristics of each model.[3]

The examination of both temporary and permanent energy price increases uncovers significant insights into their economic impacts. For instance, simulations of a temporary increase in the price of carbon-intensive energy highlight an overall temporary inflationary impact, with the euro area being more exposed to these shocks than the United States. Despite cross-country differences, alternative models show large commonalities in their quantitative and qualitative results, but also some differences, such as the timing of the inflation rate peak, with some of them suggesting a more gradual build-up.

Permanent increases in energy prices affect the real-side of the economy, similarly to what observed in the case of temporary price shocks. The decline in real variables (GDP, consumption) is permanent across models, even though the strength of transmission differs quantitatively, with an average decline close to -1% after 10 years. Our baseline specification suggests that a permanent price increase is associated with an inflation surge. We further analyze how the monetary policy response and the expectations mechanism both amplify or mitigate this outcome. Specifically, the effects on inflation crucially depend on the assumed interest rate rule of the central bank. Different rules can reflect, in part, how the central bank perceives the transition to a new, lower level of potential output. Fully and immediately factoring in

[3]The focus is on carbon-intensive energy price shocks, or also commonly referred to as brown, dirty, or fossil-based energy price shocks. For this reason, we abstract from green energy price shocks.

the future decline in output can lead the central bank to provide relatively less stimulus to aggregate demand, which, however, does not fully compensate for the negative demand side effects arising from the reduction in expected future income, leading to deflation. Instead, if the perception regarding the adjustment to the new lower long-run level of output is more gradual, the central bank provides more accommodation, leading to an inflationary outcome. Notably, the formation of expectations during the transition is also a crucial determinant of the responses of real and nominal variables, following permanent energy price shocks. By emphasizing the role of the output target and expectation formations, our paper contributes to the ongoing debate on whether the green transition will lead to inflationary or deflationary outcomes, as highlighted, for instance, in Ferrari and Nispi Landi (2024).[4]

The exercise focusing on a temporary increase in the price of carbon-intensive energy reveals that different monetary policy rules tend to perform rather equally in terms of their responses of inflation and output. However, these rules necessitate varying degrees of interest rate adjustments, highlighting the challenge that such sectoral supply shocks pose for central banks. Despite the differences in the degree of interest rate adjustments required, all three rules studied in this analysis cannot avoid a surge in inflation. This emphasizes the difficulty central banks face in stabilizing the economy in the wake of significant energy price shocks, necessitating careful consideration of the trade-offs involved in different policy approaches.

The paper is organized as follows: Section 2 introduces the models. Section 3 describes the results from a temporary carbon-intensive energy price shock, while also discussing the role of monetary policy, sectoral price rigidities, and the production structure. Section 4 discusses the results from a permanent increase in the price of carbon-intensive energy and discusses the role of expectations. Finally, Section 5 concludes.

2 Overview of the Multi-Sector Models

This section provides an overview of the institutional models used in the analysis. The set of models used is the BIS-MS model by the Bank for International Settlements (Burgert et al., 2025b), the SEEM model by the Banco Central de Chile (Beltrán et al., 2024), the Eurosystem's C-EAGLE model (García et al., 2024), the EMuSe model by the Deutsche Bundesbank (Hinterlang et al., 2023), the NAWM-E model by the European Central Bank (Coenen et al., 2024), and the E-QUEST model by the European Commission (Varga et al., 2022). The strength of the models lies in integrating the energy sector within a macroeconomic framework.

[4] While several papers, such as Del Negro et al. (2023) and Olovsson and Vestin (2023), argue for inflationary outcomes, Ferrari and Nispi Landi (2024) suggests that the green transition may be deflationary, due to expectations of higher future taxes that are already adversely affecting demand in the present.

Table 1 provides an overview of the various models. Appendix A summarizes the key features of each model.

All referenced models belong to the class of Dynamic Stochastic General Equilibrium (DSGE) models, which are extensively used for policy analysis. These models allow for stochastic events such as energy price shocks, adding an important layer of complexity. They incorporate various sectoral, nominal, and real rigidities, so that the interactions between prices, sectoral dynamics, and economic outcomes can be evaluated. Additionally, these models feature a detailed fiscal block and a monetary policy rule which can be adapted to account for different targeting regimes such as strict inflation targeting, core inflation targeting, and average inflation targeting. This makes them particularly well-suited for analyzing the interplay of supply-side disturbances such as energy price increases and monetary-fiscal dynamics over different horizons. Energy price increases can stem from various sources, such as the short-term and medium-term impacts of climate change, as well as the effects of climate policies (e.g., carbon pricing or taxation) implemented to promote the energy transition or for adaptation purposes.

A particular emphasis is put on the modelling of the energy sector. The BIS-MS model, for instance, uses input-output tables to map the multi-sector structure to real-world data, differentiating between intermediate inputs, value-added, intermediate use, and final demand. This allows for a detailed representation of production networks and the amplification of shocks. The EMuSe model also includes a multi-sectoral production structure with detailed input-output linkages and an environmental module, enabling green and carbon-intensive energy sector representations. NAWM-E disaggregates sectors into intermediate goods and two energy sectors producing carbon-intensive and clean energy. SEEM focuses on imported fossil fuels and electricity production from hydro, thermo, and renewable technologies. The C-EAGLE model incorporates energy sectors, distinguishing between carbon-intensive and green energy goods, as well as services and manufacturing sectors. E-QUEST distinguishes seven sectors, including two energy-providing sectors and several capital-producing sectors. The rest of the economic activities are allocated into two sectors depending on their emission intensity. This allows for a detailed examination of emission reduction burdens.

The calibration of sectoral linkages is a critical aspect of these models. For instance, EMuSe employs data from sources like the World Input-Output Database (WIOD) and FIGARO tables to calibrate input-output linkages and sector-specific production parameters. Similarly, BIS-MS uses inter-country input-output (ICIO) tables from the OECD and multi-regional input-output (MRIO) tables from the Asian Development Bank (ADB) to calibrate the multi-sector structure. The E-QUEST model also uses the FIGARO database to integrate the input-output production structure into a DSGE framework. The dataset employed for the calibration of the

Table 1: Multi-sector climate models

	Banco Central de Chile "SEEM"	**Bank for International Settlements "BIS-MS"**	**Deutsche Bundesbank "EMuSe"**	**European Central Bank "NAWM-E"**	**European Commission "E-QUEST"**	**Eurosystem "C-EAGLE"**
Type	DSGE	DSGE	DSGE	DSGE	DSGE	DSGE
Sectoral coverage	Intermediate goods, energy	15+	Up to 62	Intermediate goods, energy	7	Energy, services and manufacturing
Country coverage	Chile, euro area	80+	40+	Euro area, RoW	2 (EU, RoW)	Euro area, US, RoW
Energy sector	Imported fossil and electricity produced from hydro, thermo and renewables energy	Energy produced in mining and manufacturing	Separate energy sectors (green and carbon-intensive)	Disaggregated into clean and carbon-intensive with renewables and fossil resources	Fossil fuel and electricity	Energy firms producing green and carbon-intensive goods
Pass-through of energy price change	Through consumers and producers	Indirect on consumption through production	Indirect on consumption and investment through production	Direct into consumption and indirectly into production through marginal costs	Households and firms use both types of energy	Through consumers and producers
Energy price shock	Shock in international prices of oil, coal and natural gas	TFP/markup in mining and manufacturing	TFP in the carbon-intensive energy sector	Fossil resource price	TFP/markup in fossil fuel supplying sector (alternatively: carbon tax)	TFP/taxes
Nominal and real rigidities	Prices	Prices and wages	Prices and wages	Prices and wages	Prices and wages	Prices and wages
Data mapping	Calibrated	Calibrated (OECD-ICIO or ADB-MRIO)	Calibrated (WIOD or FIGARO)	Calibrated	Calibrated (FIGARO)	Calibrated
Main focus	Monetary	Monetary	Policy analysis	Monetary and fiscal policy	Fiscal	Monetary and fiscal policy
Horizon	Business cycle	Business cycle and trends	Business cycle and trends	Business cycle frequency	Business cycle and long-run	Business cycle frequency
Forward looking	Yes	Yes	Yes	Yes	Yes	Yes
Household heterogeneity	No	Yes	Yes, Ricardian and financially-constrained households	Yes, Ricardian and financially-constrained households	Yes, Ricardian and financially-constrained households	Yes, Ricardian and financially-constrained households
Fiscal policy	Shocks	-	Yes	-	Yes	Detailed
Monetary policy	Interest rate rule	Interest rate rule	Interest rate rule	Interest rate rule	Interest rate rule	Interest rate rule

energy sector in C-EAGLE originates from the OECD Input-Output Tables (IOTs).

Since each model's energy sector has distinctive features, the precise definition of a ”carbon-intensive” energy price shock can differ between models. The NAWM-E model incorporates shocks to the price of fossil resources imported from outside the euro area, allowing the price of carbon-intensive energy to respond endogenously. The EMuSe model features various mechanisms for modelling energy price shocks. In the subsequent analyses, energy price shocks are introduced through productivity changes in the sector for carbon-intensive energy production. In the BIS-MS model, the energy price increase is modelled as a combination of productivity and markup shocks to the mining and manufacturing sectors. In E-QUEST, a productivity shock to the fossil fuel supplying sector serves as the source of the carbon-intensive energy price shock. The C-EAGLE model features energy price shocks through tax changes imposed as a surcharge on the price of carbon-intensive energy, targeting both consumers and intermediate producers. The SEEM model introduces a shock to the international price of oil, coal, and natural gas, which are the equivalents of carbon-intensive energy in the model.

Finally, the models exhibit differences in country coverage. For instance, the BIS-MS model covers up to 20 sectors in more than 80 countries, allowing cross-country comparisons on the effects of sectoral specialization on the macroeconomic effects of climate change. The EMuSe model can also be specified for multiple regions, allowing for the assessment of climate policies in an open-economy context. The SEEM model is a small open-economy model, thus covering a single country, currently calibrated for Chile and the euro area. The NAWM-E model comprises the euro area, the US, and a small country exporting fossil resources. The E-QUEST model covers two regions: EU and rest of the World (RoW). The C-EAGLE model covers the euro area, the US, and the RoW.

3 Temporary increase in carbon-intensive energy price

This section evaluates the potential impact of a temporary increase in carbon-intensive energy prices using our set of multi-sector models. The model-based simulations provide insights into the economic outcomes, the inflation response, and the monetary policy reaction through a quantitative lens. Using a cross-model comparison helps to identify key dynamics that are shared among the different models but also highlights uncertainties that instead require additional investigation. Another advantage of our comparison is that the set of models covers different jurisdictions, giving our exercises a cross-country dimension too. Additionally, counterfactual scenarios under alternative monetary policy rules are analyzed to evaluate possible approaches for central banks dealing with energy price shocks.

3.1 Cross-model comparison

The cross-model comparison uses an aligned simulation scenario. The scenario's target variable is the price of carbon-intensive energy, for which the oil price can be used as a proxy. The carbon-intensive energy price increases by 25% in the first four quarters. The price then decays with a persistence of 0.5 thereafter. The participating institutions independently determine the most suitable shock(s), e.g., TFP in mining or carbon-intensive energy sector.[5] Such a flexible approach ensures scenario harmonisation by drawing on the expert knowledge of the different modelling teams.[6] The central bank follows a Taylor rule that targets headline inflation and the output gap. The rule also has a persistent component to incorporate more gradual interest rate adjustments, which is harmonized to 0.7 across models. Note that the rule will be extended to allow for alternative targeting regimes in the next subsection.

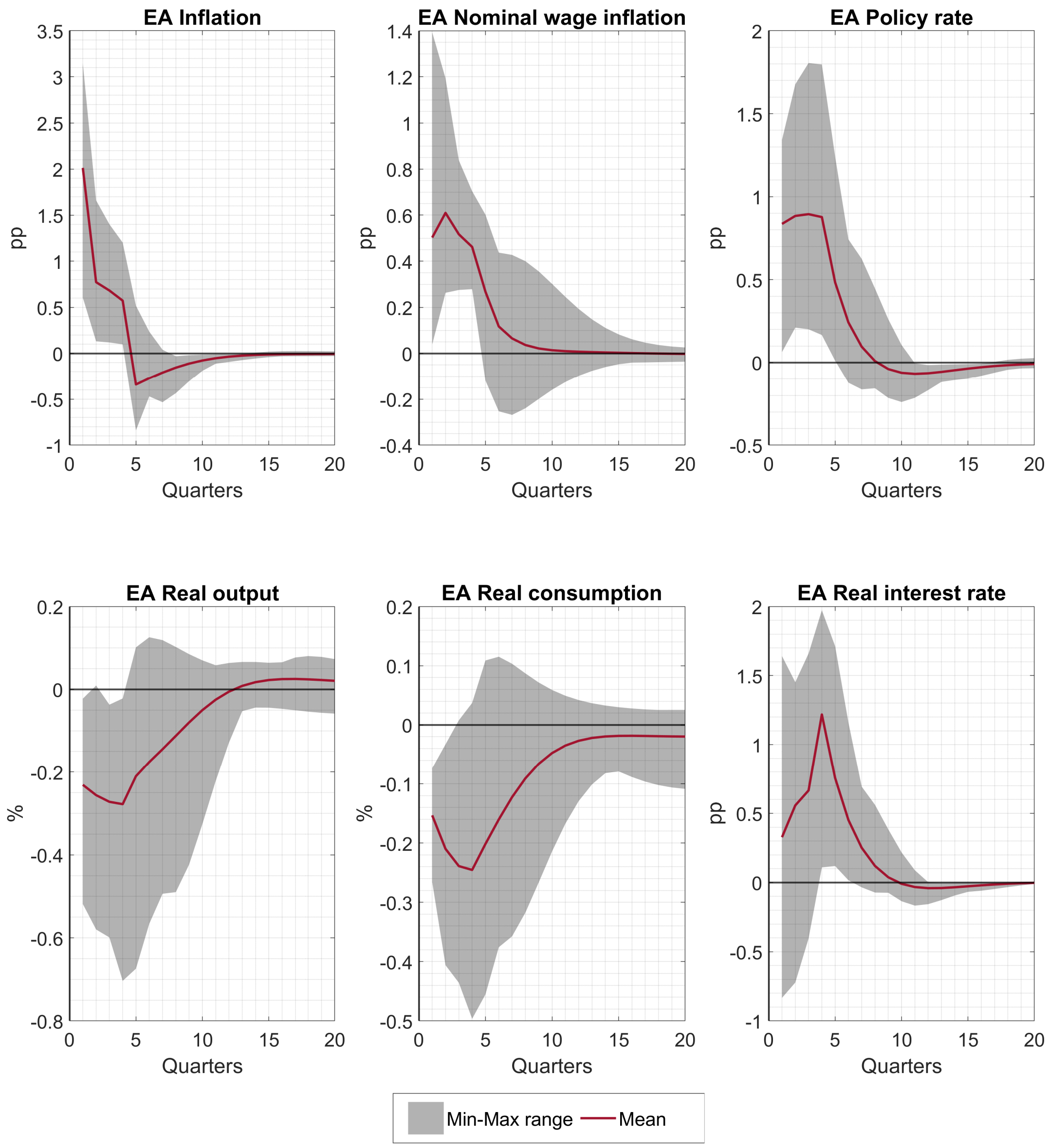
Figure 1 shows the dynamics for the euro area in response to a 25% increase in the price of carbon-intensive energy. We report the mean of the different models as well as the minimum-maximum range of the model simulations. The displayed results are based on the following set of models: BIS-MS, SEEM, C-EAGLE, EMuSe, NAWM-E, and E-QUEST. The model-specific responses are shown in Figure 2, which highlights the differences and commonalities across models. To evaluate the dynamics of the carbon-intensive energy price shock, the focus is on inflation, wage inflation, the policy rate, real output, real consumption, and the real interest rate in both figures.

On impact, a strong inflation response with an average of around 2 percentage points (pp) is observed. There is some notable cross-model variation in the peak inflation response, varying from approximately 1pp to 3pp. Almost all models simulate an inflation increase in a range of two to three percentage points. NAWM-E instead finds a smaller response with slightly less than 1pp at the peak. However, the latter features a hump-shaped inflation response that results in a more prolonged elevated level of inflation, which is less strong than in the other models. The hump-shaped response of inflation in the NAWM-E follows from the two sets of nominal rigidities that the increase in the fossil price encounters before passing through to HICP inflation. In line with empirical evidence, the NAWM-E model features monopolistically

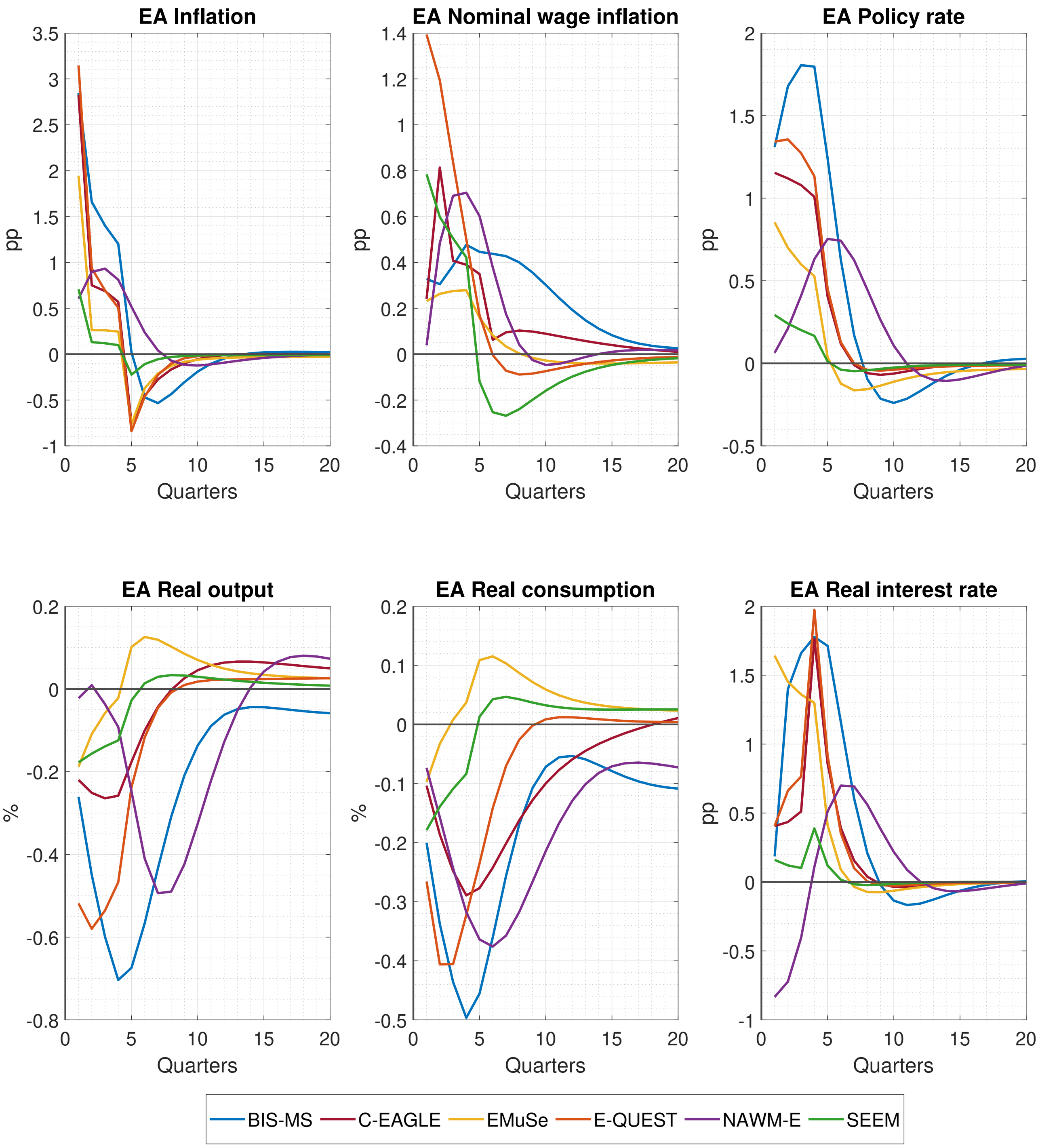
[5] BIS-MS model targets a 25% increase in the mining sector deflator and incorporates additional increases in the markup in the manufacturing sector. The SEEM focuses on a 25% increase in the international price of oil, gas, and coal. The EMuSe framework models a 25% increase in the price of carbon-intensive energy. The shock is scaled to reflect the share of the mining sector in the carbon-intensive energy sector. The C-EAGLE model focuses on a 25% increase in the price of carbon-intensive energy. The NAWM-E model exogenously targets an increase in the price of fossil resources over the first four quarters (which decays with persistence equal to 0.5). Given that fossil resources are utilized for the production of carbon-intensive energy (together with labor and capital), the shock endogenously leads to an increase in the price of carbon-intensive energy by 25%. The E-QUEST model targets a 25% increase in the fossil fuel mining and manufacturing sector producer price.

[6] Another direct advantage of this approach is that we directly work with the different workhorse models of the various institutions.

Figure 1: Temporary scenario for the euro area



competitive firms both at the level of carbon-intensive energy production and at the level of intermediate good production, which change prices infrequently and index their domestic prices to past inflation. These features combined result in a hump-shaped and mitigated pass-through of fossil price shocks to the nominal side. More broadly, the strong uptick in prices is rather short-lived, and inflation is close to zero already in the fifth quarter. When inspecting wage inflation, we observe a smaller increase at the outset. But wage inflation stays elevated for longer than headline inflation and displays a strong hump-shaped pattern. This indicates

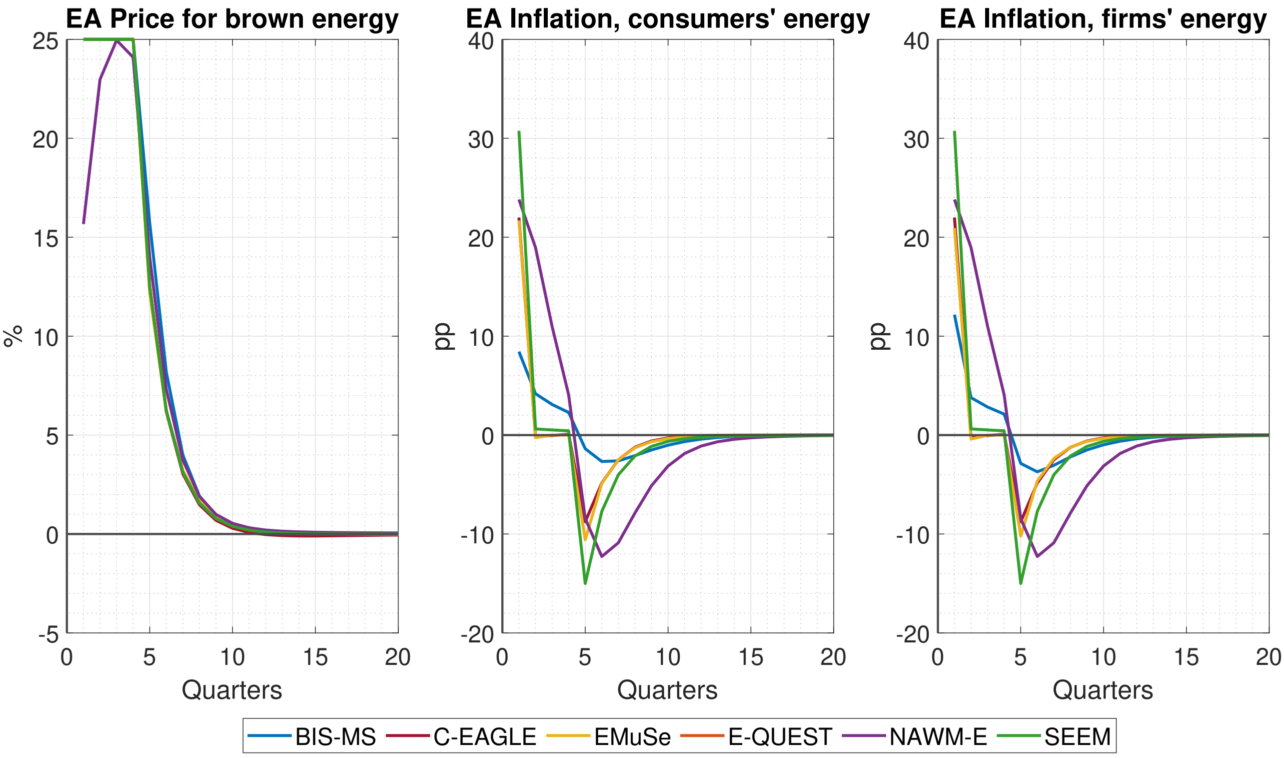


substantial wage catch-up effects that are associated with carbon-intensive energy price shocks.[7]

As a response to the inflation surge, monetary policy tightens across all models. Policy rates stay elevated until they slowly converge back to their initial level in period six. On

[7]One outlier to this result is the SEEM model, because it does not have wage rigidities

Figure 3: Temporary scenario for the euro area



average, the policy rate returns to the initial level two years after the shock. This is a result of the rather short-lived nature of the conducted scenario. A more persistent shock scenario would result in a more elevated policy stance for a longer period. While the dynamics across models are rather similar, there is some heterogeneity in the initial response. Most models predict a policy rate increase of around 1 pp, which is then gradually lowered. The BIS-MS and E-QUEST models suggest a more hump-shaped response, where the policy rate peaks at a later stage. This gradual response comes mostly from the dynamics of output, where the fall in output evolves over a few periods.

The model simulations depict a substantial output contraction resulting from the carbon-intensive energy price shock. On average, real output falls by 0.3%, with a maximum drop of around 0.7% in the BIS-MS model before gradually returning to zero. Two models stand out. First, the NAWM-E displays almost no output drop on impact, which is the result of a strong underlying hump-shaped pattern of inflation and the associated response of the real interest rate, which provides accommodation in the short term. In the second year of the simulation (quarters 5 to 8), the NAWM-E then exhibits a stronger fall in real output over all models, with a trough at around -0.5%. Second, the BIS-MS model also exhibits a hump-shaped pattern. Output contracts the most after four quarters due to the inclusion of backward-looking elements, such as habit formation, which improves the fit with the data.

The average consumption response closely aligns with the output response, substantially declining on impact and only gradually returning to zero afterwards. One difference here is that all model simulations yield an initial decline in consumption. Finally, the real interest rate is, on average, elevated, leading to a reduction in both output and consumption. Most model simulations exhibit a peak real interest rate after a few periods, as policy rates remain elevated while inflation has already decreased by this stage.[8]

The transmission of the increase in the price of carbon-intensive energy through the multi-sector structure to headline inflation is contingent upon several factors, including the sets of monopolistically competitive firms, the degree of nominal rigidity and inflation indexation, the substitutability of carbon-intensive energy, the capacity of production to substitute away from energy, and the adjustments in household consumption patterns. The initial stage of our analysis focuses on the price of carbon-intensive energy. In the left panel of Figure 3, we present the price of carbon-intensive energy, which serves as the target variable for this scenario. All models assume a 25% increase in the price of carbon-intensive energy sustained over four quarters. As mentioned previously, the NAWM-E targets an increase in the exogenous fossil resource price, which endogenously leads to an increase in the price of carbon-intensive energy by 25% in the short run.[9]

The transmission of the price of carbon-intensive energy to the energy price indices for households and firms (middle and right panels in Figure 3) is further influenced by the degree of substitutability between carbon-intensive energy and other energy sources, the extent to which firms can substitute energy with other inputs in the production process, and the manner in which consumers modify their consumption mix.[10] The models display considerable heterogeneity in their responses to the energy price indices relevant for consumers and firms, with SEEM showing the strongest reaction. Overall, the analysis underscores the critical role of the production network in the transmission of energy price shocks, cascading through various sectors.

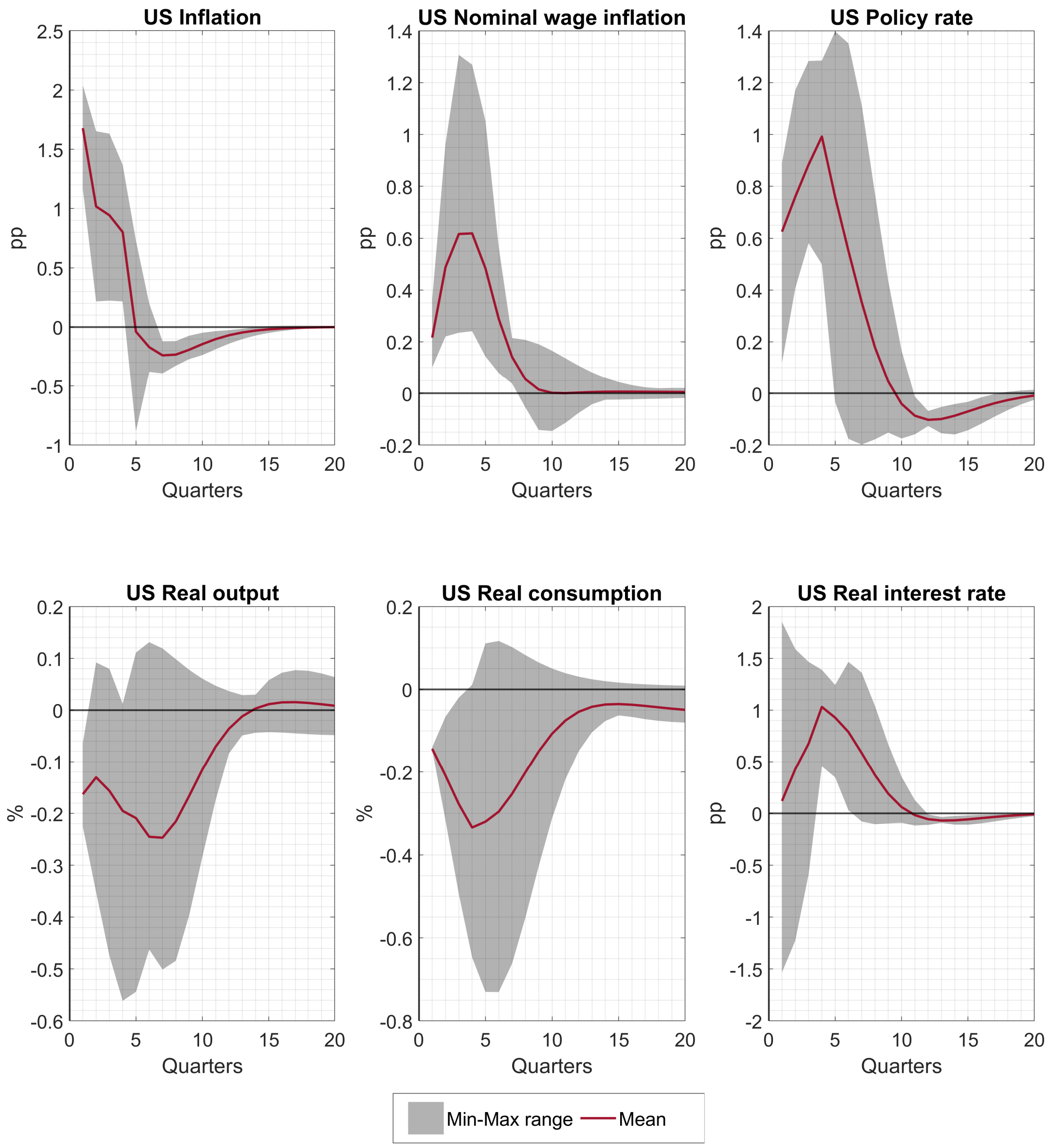
Figure 4 shows the dynamics for the US. The simulations are based on the following set of models: BIS-MS, EMuSe, and NAWM-E. As the set of models is different and smaller here, differences in the mean and min-max range cannot be directly assessed and should be treated with caution. For this reason, Figure 5 shows the specific responses for the US of the different

[8]Differences in the responsiveness of the real interest rate are likely to depend not least on the specification of capital accumulation costs. For example, it may make a difference whether investment adjustment costs or capital adjustment costs are chosen.

[9]It should be noted that the definition of the "carbon-intensive energy sector" differs across the models. In order to make the shocks comparable, some have been scaled in the technical implementation to the respective value-added shares of the carbon-intensive energy sector.

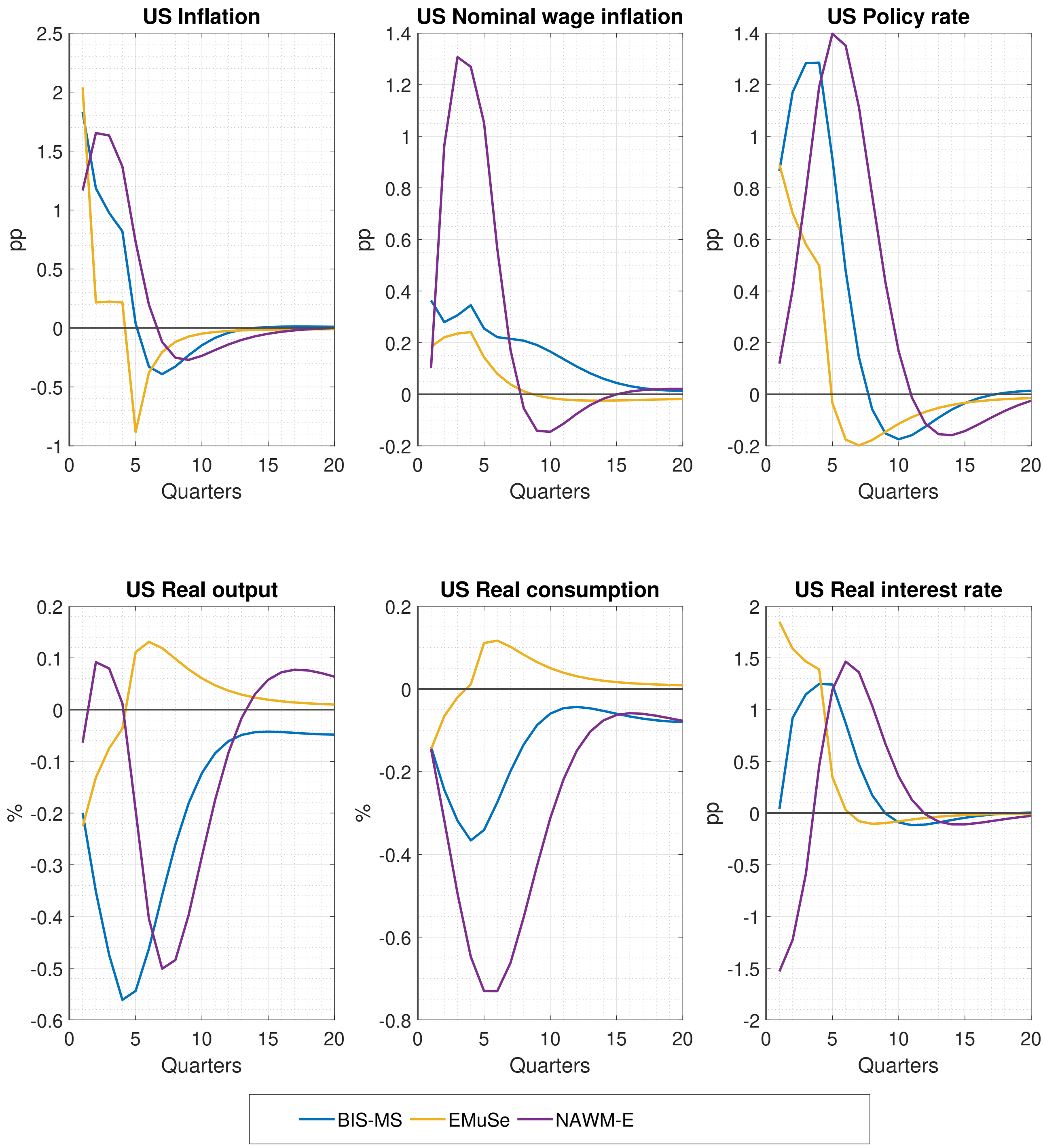
[10]There is no aggregate energy variable in E-QUEST. Economic agents use either electricity or fossil fuel, with capital that is, respectively, electricity- or fossil-fuel-intensive, and the two types of energy are not aggregated into a single energy variable.

Figure 4: Temporary scenario for the United States



models. Generally, the observed pattern for the US is qualitatively similar to the euro area.

When evaluating the results across models that provide both euro area and US inflation impulse responses (BIS-MS, EMuSe, and NAWM-E), we observe, however, quantitative differences. The BIS-MS finds that the energy shock has a weaker impact on inflation and the real economy in the US. This difference is driven by the distinct input-output structure in the euro area and US. The EMuSe model suggests rather minor differences. This masks, however, some noticeable heterogeneity between the region's impulse responses at the sectoral level. The latter result from an interplay of region-specific price rigidities, markups, and production networks.



The NAWM-E model suggests that inflation responds more in the US, while output responds rather similarly. Because in the US the share of energy utilized in consumption is lower than in the euro area, the region-specific steady shares of consumption and investment to output imply that, for a given decline in output and harmonized monetary policy rule, inflation responds more strongly.

We also repeat the same analysis for Chile using the BIS-MS and SEEM model, as shown in Figure B.1 in the Appendix. An energy impact has a more pronounced effect on inflation than in the euro area and the US. The BIS-MS model and the SEEM model both suggest an inflation response on impact for Chile of around 4 pp. Similarly, a stronger impact on output is also predicted. The models suggest a peak fall in output by around 1.2% across both models. One reason for this additional amplification for the Chilean economy comes from the different input-output structure with a large weight on the mining sector.

To sum up, the model simulations highlight the inflationary impact of large temporary energy price shocks. For example, there is an average initial increase in inflation of around 2.0 percentage points in the euro area. This requires a forceful monetary policy response, which results in an elevated nominal interest rate. Such a shock also depresses output, with a peak reduction of around 0.3%. The analysis shows that the alternative models share, to a large extent, commonalities in terms of their qualitative and quantitative results. However, there are differences in the timing of the peak impact of such a shock. While most models show responses peaking at the outset, a few exhibit a more gradual build-up, with the peak occurring later on. The results also highlight cross-country differences, as the euro area, the United States, and Chile have different exposures to the shock.

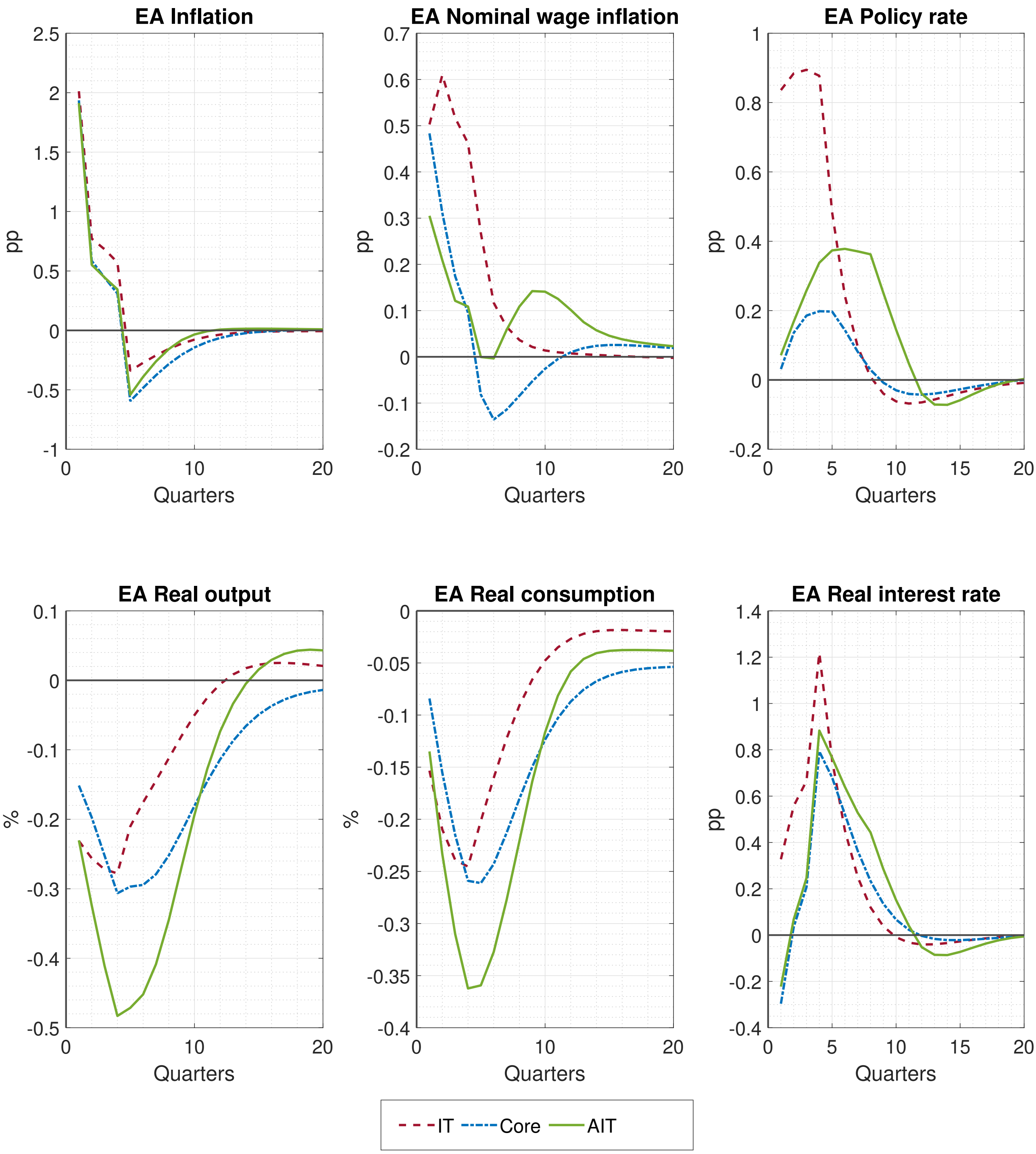
3.2 The role of monetary policy

We also use the previous scenario to evaluate the role of monetary policy. In particular, the baseline monetary policy rule that targets headline inflation is compared to a specification that uses core inflation, and an average inflation targeting (AIT) approach that responds to the mean over 8 quarters.[11]

Figure 6 shows the mean response from the employed models for each rule for the euro area. The simulations are based on the following set of models: BIS-MS, the SEEM, C-EAGLE, EMuSe, NAWM-E, and E-QUEST. Figure B.2 in the Appendix also provides each model's impulse responses for each of the monetary policy rules considered.

The first observation is that the inflation dynamics are relatively similar across rules, which holds for all models employed. One reason is that a large share of the inflation surge comes directly from the change in the price of carbon-intensive energy. Monetary policy is rather targeting the potential spillovers, which are relatively smaller. Thus, the dynamics display a similar pattern across rules. However, wage inflation highlights that the inflation impact differs across rules. The baseline inflation targeting rule results in the most sustained wage inflation increase. In contrast, AIT and core inflation targeting result in a more short-lived response.

[11] The carbon-intensive energy price shock is calibrated using the baseline scenario.



Note: Lines depict means across models for headline inflation targeting (IT), core inflation targeting (Core) and average inflation targeting (AIT).

We also see a smoother response at the policy rate. Core inflation targeting and AIT increase more gradually and peak at a substantially lower level than in the case of headline inflation targeting. The pecking order across rules for the largest peak response is the same in all studied models.

The real impact differs marginally across rules, as the responses of output and consumption highlight. Even though the rules fare rather equally and result in a hump-shaped pattern, AIT leads to the strongest real contractions. In general, the output and consumption losses are the smallest for the headline targeting rule. Most models suggest that the peak real output response for headline targeting is either the smallest for headline targeting or very close to the smallest one.

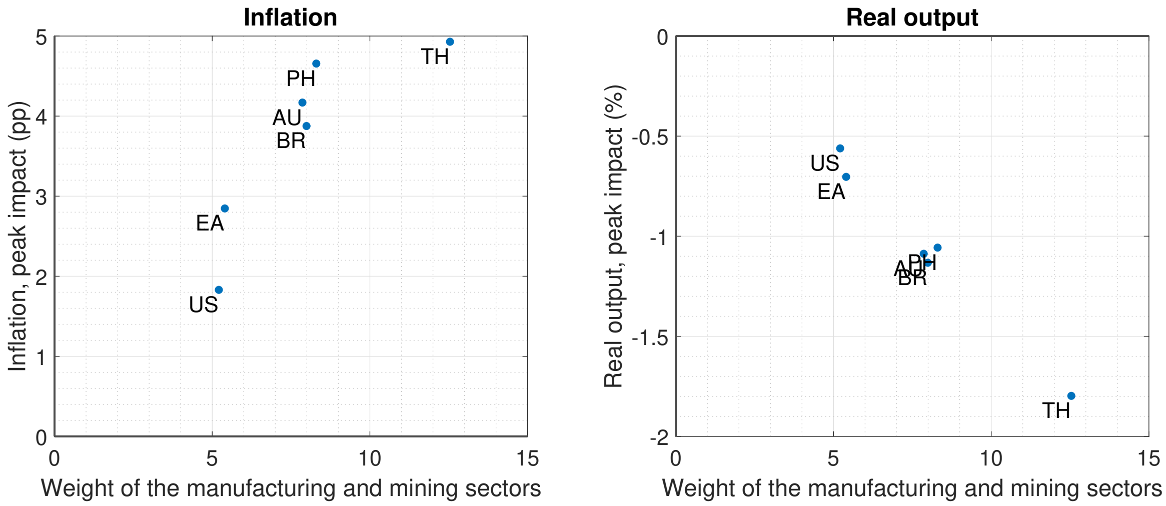
The same exercise was also conducted for the US using the BIS-MS, EMuSe, and the NAWM-E models. The model-specific responses are shown in Figure B.3 in the Appendix. The results of the comparison are similar to those of the previous analysis of the euro area, which can be attributed to the similar structure of the two economies.

3.3 Input-output structure and the energy shock transmission

The input-output (IO) structure in multi-sector DSGE models is a crucial part for understanding the transmission of energy shocks. Specifically, it captures sectoral interlinkages and allows a more detailed shock propagation analysis. Network effects, characterized by sectoral heterogeneity (i.e. different degrees of price stickiness or the relative size of the affected sector) are key. Del Negro et al. (2023), among others, show how shocks in one sector can spill over to other sectors, which is essential for understanding monetary policy and energy price shocks. For example, substituting carbon-intensive energy affects the inflation-output tradeoff, with high CO_2 emission sectors changing prices frequently. Larger sectors experiencing shocks have more significant macroeconomic effects. Sectoral heterogeneity, including emissions intensity and input dependencies, shapes the transmission of shocks. High-emission sectors with flexible prices, for instance, may quickly raise prices, impacting downstream sectors, while low-emission sectors with stickier prices may absorb costs longer. Therefore, incorporating the IO structure in our models helpful for evaluating the impact of energy shocks and for designing effective climate policies.

As the IO structure is a key driver in the transmission of energy shocks, different countries may experience varied impacts from the same shock. For example, the relative weight of the sectors affected by the shock in a country is a crucial determinant of the economic impact. Figure 7 highlights this by displaying the peak effects of a 25% increase in carbon-intensive energy prices on inflation and real output in the BIS-MS model for a selected sub-sample (Australia, Brasil, Euro area, Philippines, Thailand, United States) of its full coverage. The heterogeneity across countries is reflected in the relative sizes of the mining and manufacturing sectors in intermediate production. Specifically, the chosen measure uses the full weight of

Figure 7: Impact of carbon-intensive energy shock on inflation and output across countries



Note: The simulations are generated with the BIS-MS model.

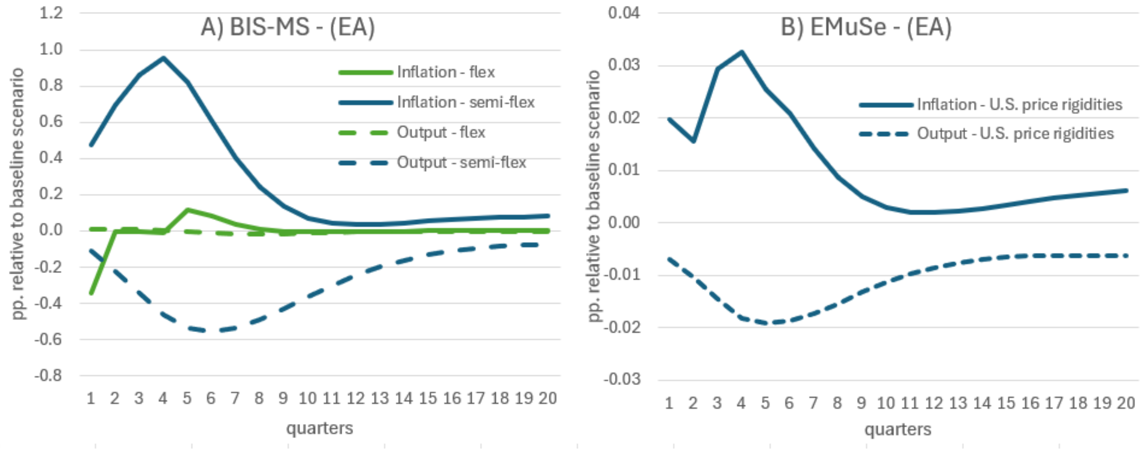
the mining sector and scales down the weight of the manufacturing sector by a factor of 10. This measure accounts for the fact that the carbon-intensive energy shock targets both the mining and manufacturing sectors. The greater the combined weight of these two sectors, the more pronounced the response in both inflation and output in absolute terms, with inflation showing a positive response and output a negative one. The country comparison highlights the importance of incorporating the IO structure when assessing energy shocks.

3.4 Role of price rigidities

Energy price shocks are a well-known source of macroeconomic volatility. The extent to which these shocks affect key variables such as output and inflation depends critically on the degree of (nominal) price rigidities present in goods, labor, and energy markets. These rigidities slow down adjustments and amplify the persistence of shocks, thereby increasing their real economic costs. Understanding these dynamics is essential for assessing macroeconomic impacts and designing effective policy responses. For example, Del Negro et al. (2023) demonstrate that a tax on carbon-intensive energy sources can create an inflation-output trade-off, with its magnitude depending on the relative price flexibility in the 'carbon-intensive' and 'green' sectors compared with the rest of the economy. Similarly, Pasten et al. (2020) use a DSGE model with sectoral heterogeneity to show that price rigidities at different points in the production chain influence how shocks spread through the economy, with more rigid sectors experiencing prolonged adjustments.

Simulation exercises with two of the models in this technical report, BIS-MS and EMuSe,

Figure 8: Sensitivity to price rigidities



Note: The lines depict the percentage-point deviation from the respective baseline scenarios under benchmark calibration. Panel A: flex (semi-flex) – increasing the price rigidity of flexible (semi-flexible) pricing sectors.

demonstrate that the complexity of the IO structure and the price rigidity settings influence cross-model differences in the impulse response of inflation and output to energy price shocks (see panels A and B of Figure 8 respectively). The BIS-MS model indicates that higher price rigidity in the semi-flexible manufacturing sector can prolong inflationary effects and worsen the negative output impact of a carbon-intensive energy price shock, while increasing the price rigidity of flexible-price sectors, such as energy and agriculture, has a muted effect on the same variables. On the other hand, simulation experiments using the EMuSe model show that adjusting the calibrated euro area price rigidity parameters to align with their US counterparts would only marginally affect the macroeconomic variables, because the implied changes in sectoral price rigidities roughly balance each other at the aggregate level.

3.5 Key Takeaways

A first takeaway is that the different monetary policy rules perform rather equally following a temporary energy price increase. This result highlights the challenge that such a sectoral supply shock poses for the central bank. There is often an argument to look through supply shocks. The reason is that price rigidities in the directly affected sectors are lower, which is a key determinant for the impact of energy shocks as discussed. However, this exercise does not point clearly to such a result when using these fully-fledged large-scale sectoral models designed for quantitative policy analysis. Instead, the model comparison suggests quite a similar impact on inflation and output for all three specified rules. However, the associated interest rate dynamics are quite different as a headline inflation targeting requires a quick and forceful response, which can be challenging to implement in practice.

4 Permanent increase in carbon-intensive energy price

We extend the previous analysis by exploring the macroeconomic impact of a permanent increase in energy prices. Given the forward-looking nature of our suite of models, confronting them with a permanent shock enables us to assess the ability of monetary policy to stabilize the macroeconomy over the transition to a different steady state, characterized by permanently higher energy prices.

4.1 Cross-model comparison and the role of monetary policy

Methodologically, the exercise is constructed by gradually increasing the price of carbon-intensive energy by 25% over 10 years, which remains constant at that level thereafter. Similar to the exercise with temporary shocks, each model and institution delivers this increase in the price of carbon-intensive energy in a model-specific manner. For instance, the NAWM-E model targets an increase in the price of fossil resources, which endogenously leads to a permanent increase in the carbon-intensive energy price by 25%.

Given that all models are forward-looking, the permanent increase in the energy price is known with certainty and perfectly foreseen by all agents in the model. Due to expected future declines in aggregate demand, real activity also falls in the short run. However, as will become clear, an important dimension that affects responses of nominal variables relates to how real activity affects the central bank interest rate reaction function. We consider two specifications, by allowing the central bank to target output: i) in deviation from a trend that gradually adjusts toward the new (lower) long-run level of output, and ii) in deviation from the new steady state where output is permanently lower.[12] The first rule that responds to output trend deviations is given as:

$$R_t = 0.7\, R_{t-1} + (1 - 0.7)\left[\, R + 1.5\,(\Pi_t - \Pi)\right] + 0.5\left(\mathrm{Y}_t - \overline{\mathrm{Y}}_t\right), \tag{1}$$

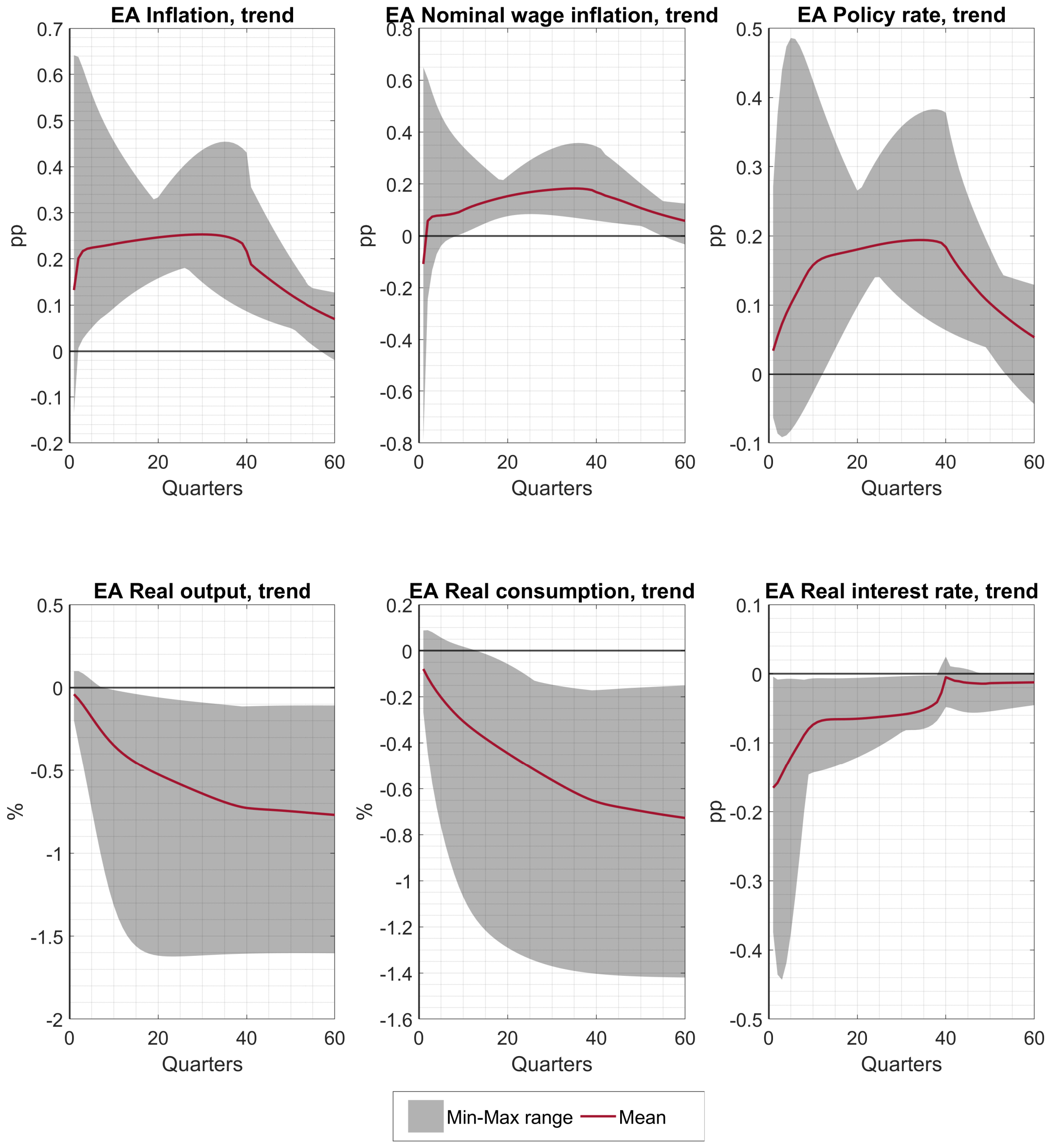
where R_t is the nominal interest rate, Π_t is inflation, Π denotes the inflation target, Y_t is output and $\overline{\mathrm{Y}}_t$ is geometrically converging path from the initial towards the new steady-state value of real output. The persistence for the GDP trend is set to 0.98. The second rule that responds to a steady state with permanently lower long-run level of output is:

$$R_t = 0.7\, R_{t-1} + (1 - 0.7)\left[\, R + 1.5\,(\Pi_t - \Pi)\right] + 0.5\,(\mathrm{Y}_t - \mathrm{Y}), \tag{2}$$

[12] Notably, the mechanism whereby the central bank immediately adjusts its output target to the long-run value is also found in e.g., Bartocci et al. (2024), while the intermediate policy where the monetary policy rule targets deviations of output from its long-run trend is found in e.g., the NAWM-E model (see, Coenen et al., 2024).

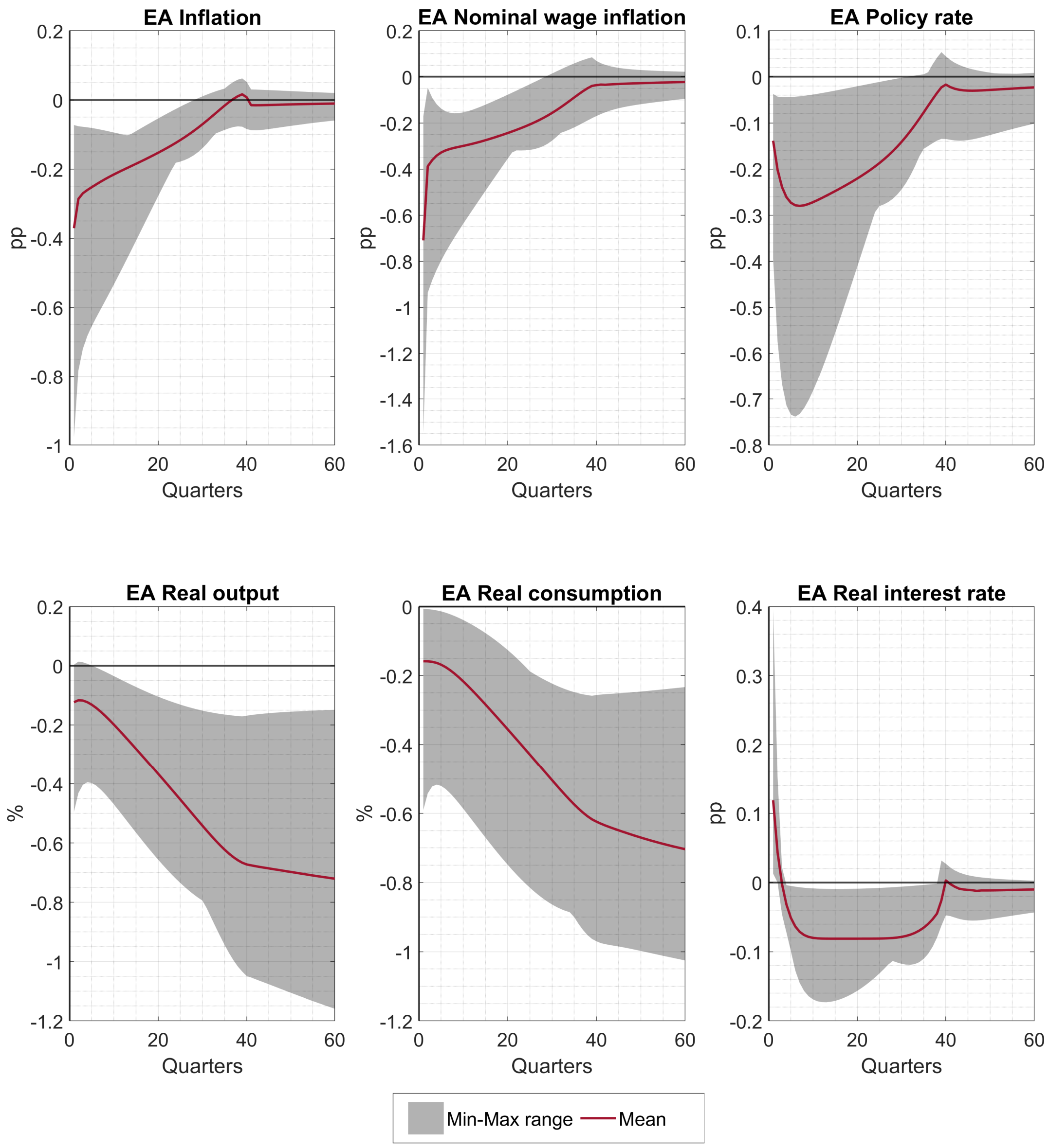
where Y is the steady state of real output in the new long-run.

Figure 9: Permanent scenario for the euro area; monetary policy targets a long-run trend



Figures 9 and 10 and illustrate the two cases. On the real side – regardless of the way that the interest rate reaction function is specified – higher energy prices lower households' current and expected future real income, leading to a reduction in consumption, while the decline in firms' current and expected future profitability leads to a drop in investment, arising from the need to reduce the economy-wide capital stock. Quantitatively, consumption persistently declines in both cases by around 0.8% after 40 quarters for the mean over models, while GDP experiences a stronger persistent decline and falls by around 0.9% after 40 quarters for the mean

Figure 10: Permanent scenario for the euro area; monetary policy targets long-run output



over models. As a result, the new steady state after the energy price increase is characterized by lower output compared to the initial level.

The higher energy price increases marginal costs for energy producers, which are subsequently passed on to intermediate and final goods producers. Consequently, holding all else constant, core and consumer price inflation are expected to rise, consistent with the increase in marginal costs. In our baseline scenario, where the monetary authority targets output deviations from a trend that only *slowly* adjusts to the new long-run output level (Figure 9), we observe such an increase in inflation.

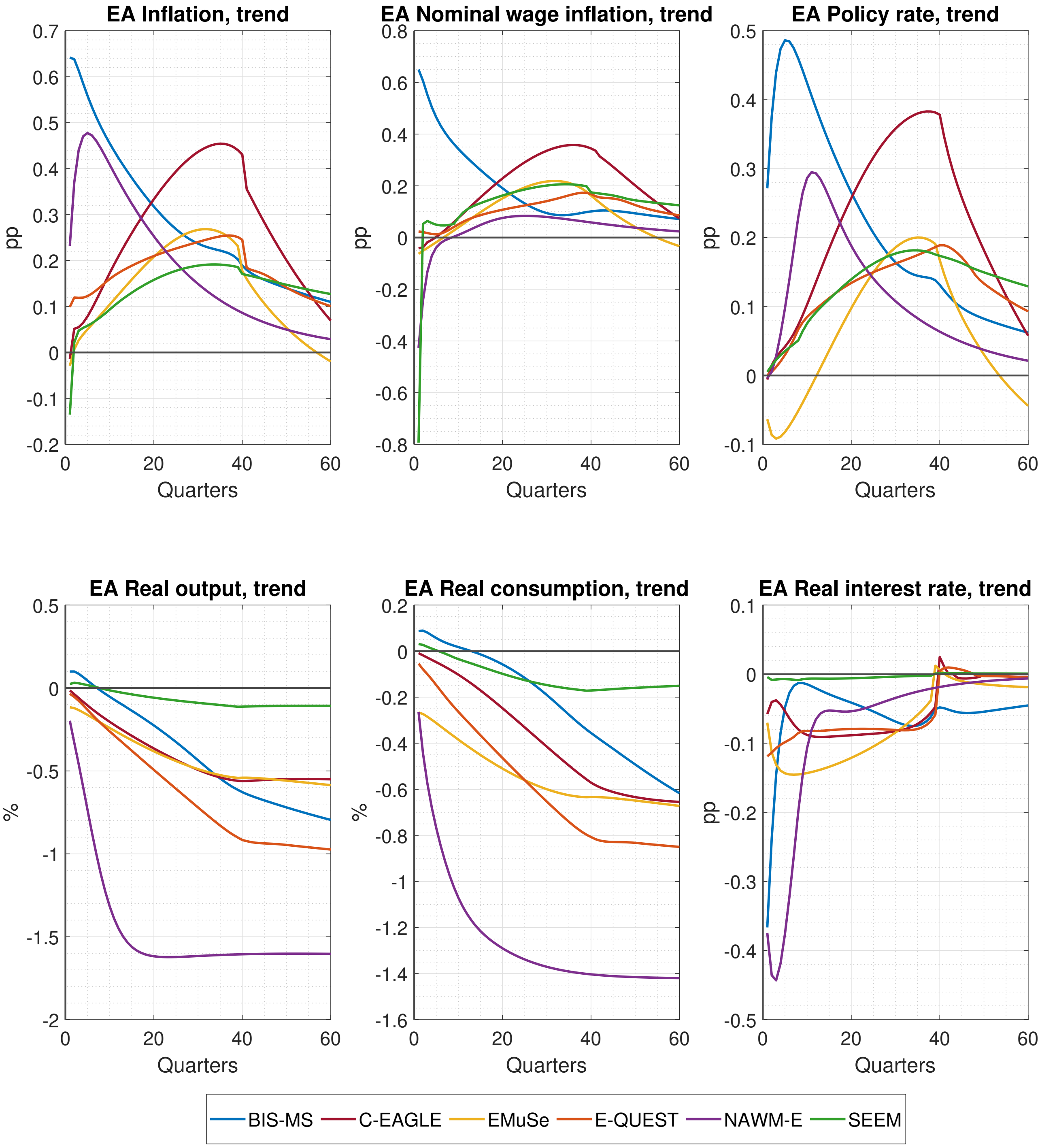
The monetary authority persistently attempts to offset the demand decline relative to the permanent lower output observed in the interest rate rule. As higher demand cannot be supplied profitably given the expected future decline in supply, prices must rise in the short term, driving inflation. The central bank, therefore, consistently elevates the nominal interest rate in the short term, which is reconciled through a reduction in the real interest rate to provide additional monetary accommodation. In this case, the mean nominal interest rate increases by roughly 20 basis points in the medium term, and the real interest rate declines strongly on impact by around 20 basis points, reflecting the more accommodative stance of monetary policy.

However, if the monetary policy rule reacts to output deviations from this new long-term equilibrium value (Figure 10), inflation decreases in the short to medium term. The result is driven by the output term in the interest rate rule, whereby the central bank perfectly foresees that output in the long run will be permanently lower and, as such, does not aggressively provide stimulus to the economy over the transition. As a result, negative demand effects from the reduction in permanent income and profitability prevail, pushing inflation down. Specifically, the mean response for annual consumer price inflation is around -0.4 pp in the short term before peaking at around 0.05 pp above the target after roughly 40 quarters, before gradually returning to its steady-state level.

In order for deflation to emerge, for the mean over models, the nominal interest rate falls by 30 basis points in the short term and reverts to the baseline after 40 quarters, also reflecting the decaying but persistent deflationary effects of the shock. Consequently, on average, the real interest rate increases on impact by around 10 basis points, reflecting the tighter stance of monetary policy in this environment, which aims at stabilizing consumer price inflation on the one hand and the decline in output on the other.

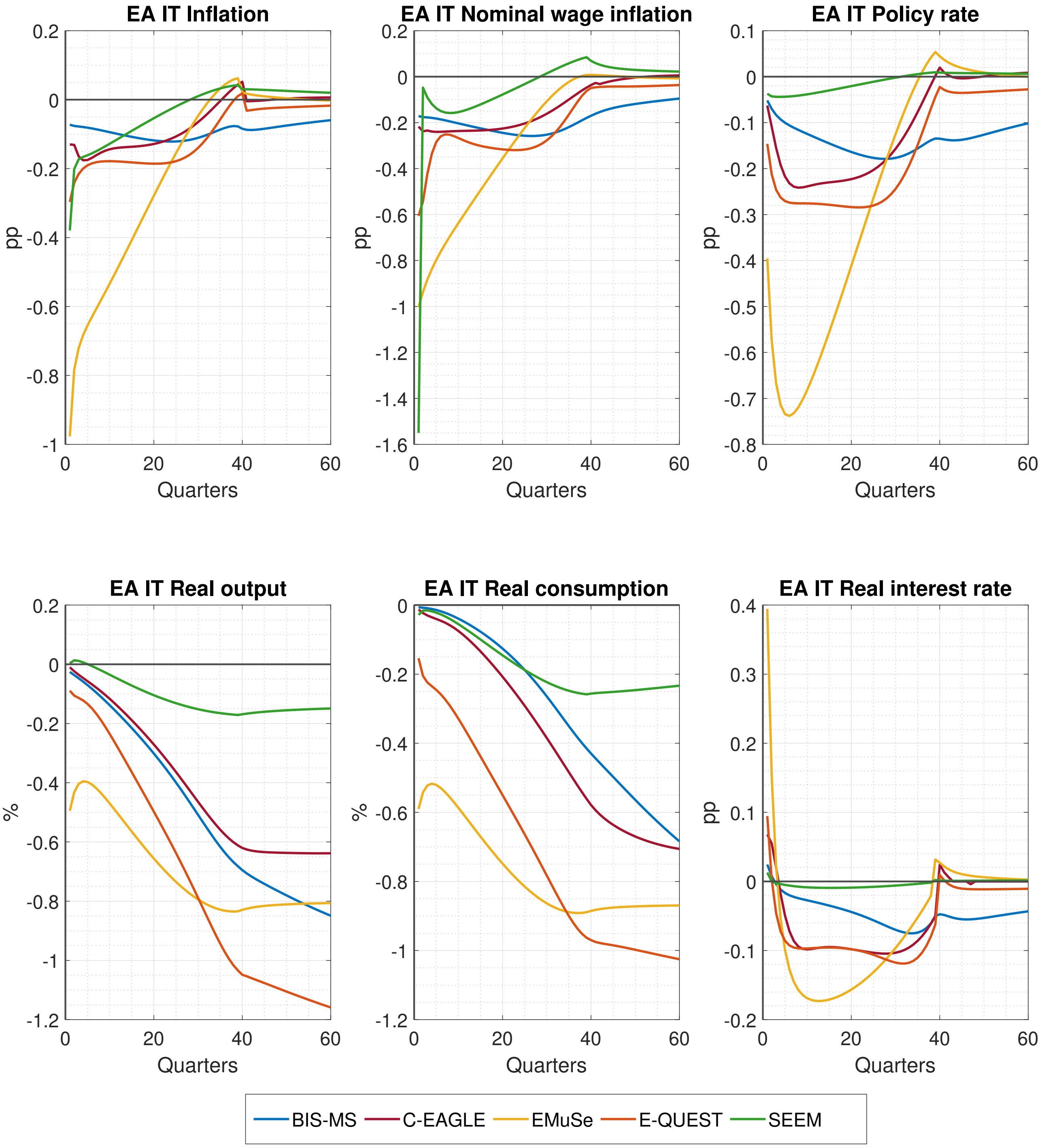
Taken together, as energy prices directly affect the price of final consumption goods, consumer price inflation is therefore determined by the strength of the pass-through of energy prices relative to the strength of the associated negative demand effects brought about by the central bank reaction. Notably, the latter is ultimately reflected in the response of the nominal and real interest rates, which drives the behavioral responses of agents, and is driven by the perception of the central bank regarding the future level of output. Analogously to the development in prices, the overall strength of the negative demand effects also affects wage inflation.

Altogether, these results resonate with the policy mistakes of the 1970s. In the extreme case where the central bank does not realize that the supply potential of the economy has receded (e.g., suppose it erroneously targets the initial level of output before the permanent energy price increase), it may feed inflation by overstimulating demand above the new, lower

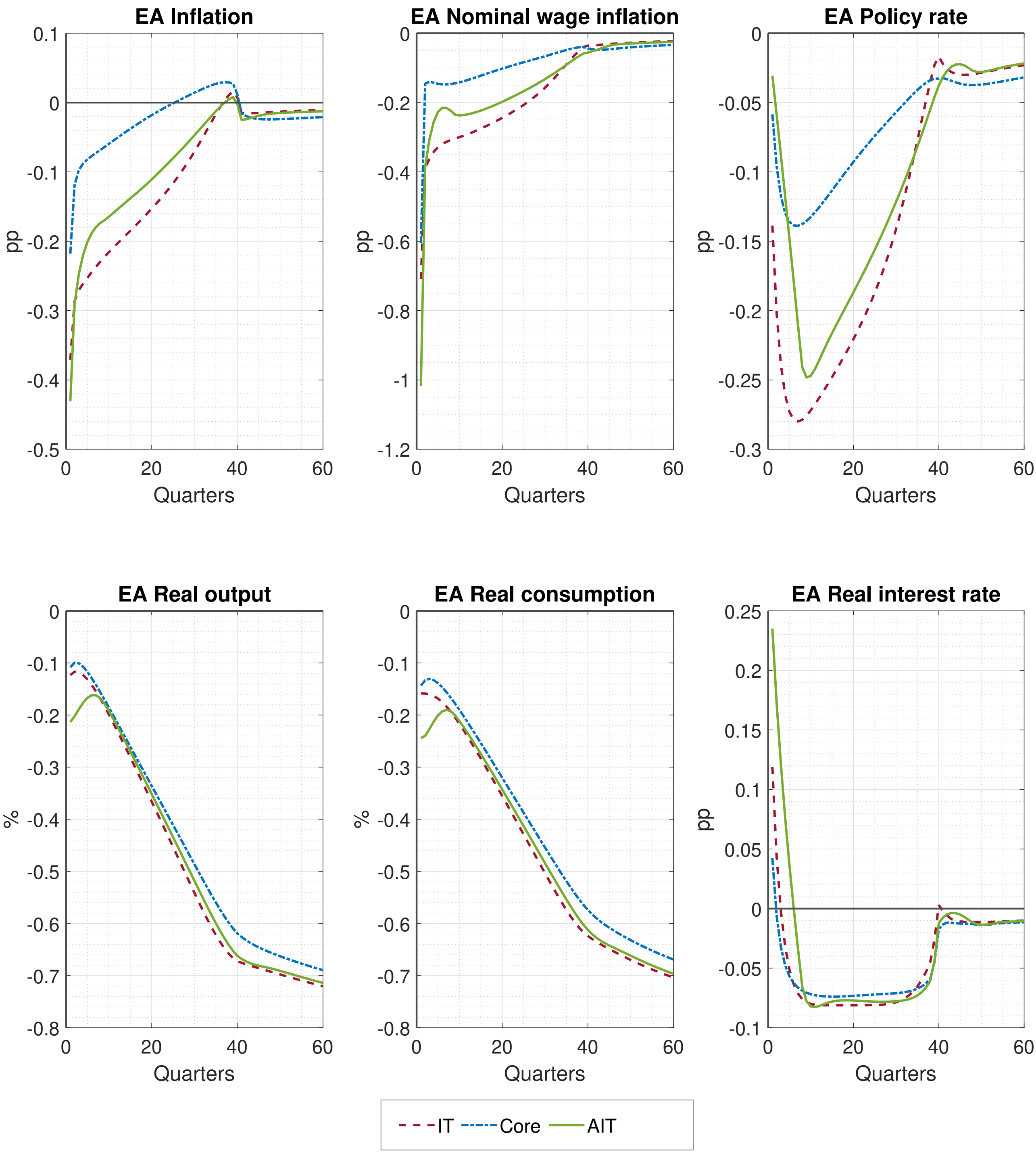


potential of the economy. If, on the contrary, as is the case where there is some foresight over the fall in output potential, it can avoid this excessive stimulus and stabilize inflation.

Notably, focusing on the case where the central bank targets deviations of long-run output relative to a slow-moving trend, the results can be broadly seen as being comparable to the case of a temporary shock, both in magnitude and sign for real variables, although particu-



lar model differences emerge. However, the response of inflation is smaller on average and more hump-shaped, and in several models, the reaction of inflation is more delayed relative to the temporary energy price shock. Figure 11 reports the range of responses across models following a permanent increase in carbon-intensive energy prices under this case. While the mean consumer price inflation increases, the range of responses varies; for example, the EMuSe



Note: Lines depict means across models for headline inflation targeting (IT), core inflation targeting (Core), and average inflation targeting (AIT).

model implies around a 0.3 percentage point increase at the peak, which is reached after approximately 30 quarters, whereas the BIS-MS model delivers 0.6 percentage point inflation on impact.

Figure 12 instead reports the cross-model responses where the central bank targets long-run output. As can be seen, the model responses are more homogeneous across models, with the exception of the EMuSe model, which overall predicts stronger deflationary effects on impact, and a consistently more negative response of the nominal interest rate and more stronger positive response of the real interest rate.

Finally, Figure 13 illustrates how alternative inflation measures in the interest rate reaction function influence the results. The exercise focuses on the case where the central bank targets output in deviation from its long-run value. In particular, when the central bank follows an interest rate rule targeting core inflation rather than consumer price inflation, the inflationary effects are greater on average. This occurs because the central bank does not react to the direct inflation impact of the increase in energy prices, and accordingly, monetary policy is considerably tighter in this environment.

4.2 Role of expectations during the transition

The green transition is likely to bring about unprecedented structural changes, accompanied by significant uncertainty.[13] One key area of concern is the uncertainty surrounding the public's expectations about the lasting nature of price increases. This underscores the importance of accurately modelling the expectations regarding the transition. A common criticism of the type of models employed in our exercise is that they feature a very powerful expectations channel. Most existing approaches assume perfect foresight, meaning that the transition path is known with certainty upon announcement. The analysis presented in this document follows this convention.

We introduce two alternative scenarios: disbelief and staggered expectation. In the disbelief scenario, the public believes that prices will revert to their initial levels throughout the transition. Only when the permanent price level is reached, does the public align with this new reality. In the staggered expectation scenario, the public anticipates some reversion to previous price levels. It is only after 20 years that agents believe the price change is lasting. Figure 14 illustrates the actual price trajectory and the public's price expectations under the scenarios.

Figure 15 highlights the role of alternative expectation formations for the transmission of the permanent scenario, as modeled using the BIS-MS model. First of all, the results demonstrate that the small inflation response is robust across the different expectation formations. Instead, the alternative expectation paths affect the output dynamics considerably. Specifically, the real consequences of the shock vary, taking longer to materialize under the alternative expectation

[13]One dimension of uncertainty is the likelihood that the government adopts a climate policy (Fried et al. (2022)) and the stringency of such policy.

Figure 14: Alternative expectations about the permanent scenario

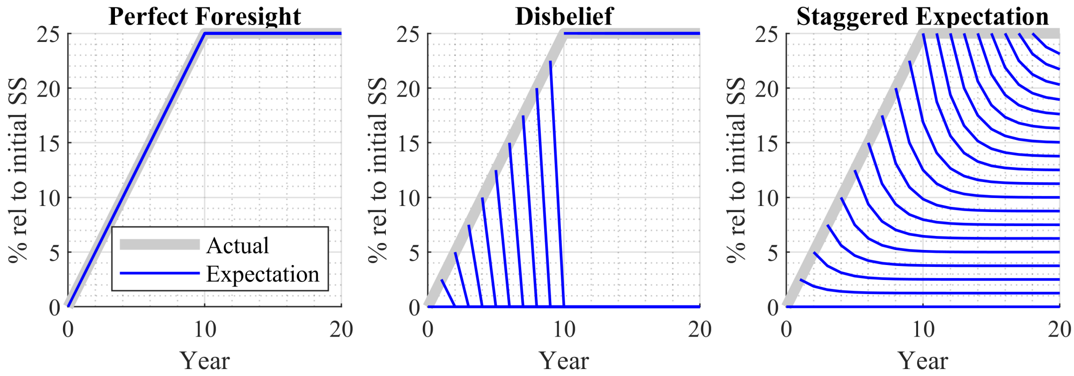
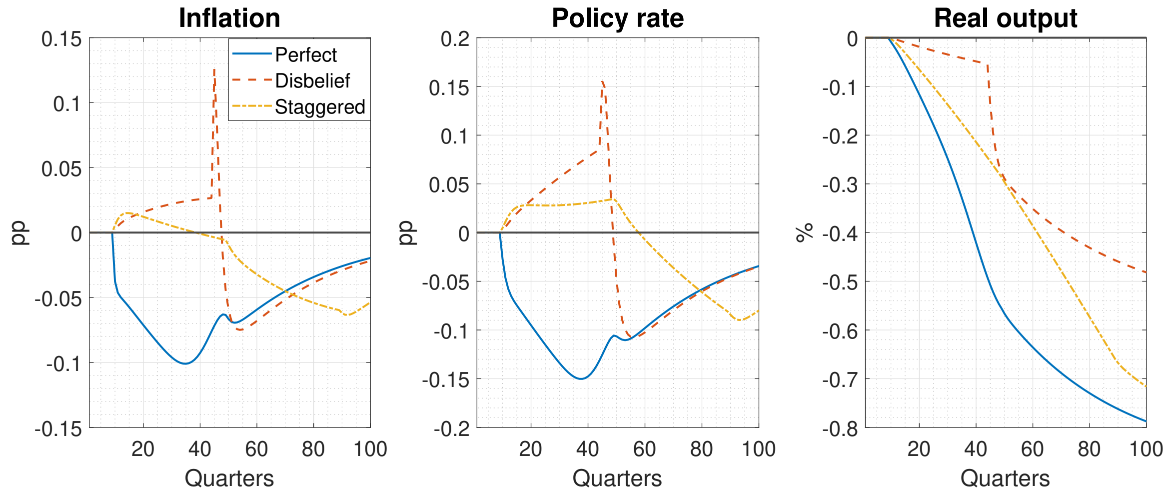


Figure 15: Impact of expectation formation on the transition



Note: The simulations are generated with the BIS-MS model.

paths of disbelief and staggered adjustment. Thus, the chosen expectation mechanism affects mostly the real variables, while inflation does not respond much in all cases.

4.3 Key Takeaways

Persistent increases in energy prices propagate to the economy in a manner similar to that of temporary price increases on the real side. The decline in real variables (GDP, consumption) is consistently permanent throughout models; however, the strength of transmission differs quantitatively, with an average decline close to -1% for GDP after 10 years. The effects on inflation crucially depend on the way that the interest rate rule of the central bank is specified, which reflects in part the perception of the central bank over the transition to a new, lower level of output potential. Fully and immediately factoring in this decline can lead the central bank to provide less stimulus to demand and, in turn, not compensate for the negative demand effects, leading to deflation. Instead, if the perception regarding the adjustment to the new lower long-run level of output is slower, the central bank provides more accommodation, generating inflation. In our baseline specification, where the monetary policy authority targets the long-run trend, we observe an inflationary impact.

5 Conclusion

This paper compares different models used by various institutions to analyze the macroeconomic impact of environmental issues in the context of monetary policy. Specifically, the paper evaluates the questions of how temporary and permanent energy price shocks propagate through the macroeconomy and the role played by monetary policy in its stabilization.

The models employed include the BIS-MS model by the Bank for International Settlements (Burgert et al., 2025b), the SEEM model by the Banco Central de Chile (Beltrán et al., 2024), the EMuSe model by the Deutsche Bundesbank (Hinterlang et al., 2023), the NAWM-E model by the European Central Bank (Coenen et al., 2024), the E-QUEST model by the European Commission (Varga et al., 2022), and the C-EAGLE model by the Eurosystem (García et al., 2024).

The results suggest that following a temporary increase in the price of carbon-intensive energy, consumer price inflation increases. The euro area is more exposed to these shocks than the United States. Despite cross-country differences, alternative models show large commonalities in their quantitative and qualitative results, although the timing of the inflation peak varies, with some models suggesting a more gradual build-up.

In turn, permanent increases in energy prices affect the real side of the economy in a comparable manner. The level of economic activity is depressed, and it reaches a lower level gradually. In our baseline specification, we observe an inflationary impact after a permanent energy price shift. However, the response of inflation is smaller than in the case of the temporary shock, as can be expected following a shock to relative prices, provided it does not de-anchor inflation expectations, a feature that we assume across the models used in this simulation comparison exercise.

The exercises are complemented with an investigation of the role of monetary policy by comparing model responses across interest rate rules. For temporary shocks, alternative monetary policy rules tend to perform rather equally in the case of inflation and output. However, these rules necessitate varying degrees of interest rate adjustments, highlighting the challenge that such sectoral supply shocks pose for central banks. Following temporary increases in the price of energy, average inflation targeting rules imply a much more persistent increase in the nominal and the real interest rate, which, in turn, depresses economic activity more than core inflation or headline inflation targeting. For permanent shocks, interest rate rules targeting core inflation imply greater inflationary effects on average, as the central bank does not react to the direct inflation impact of the increase in energy prices. Accordingly, monetary policy is considerably tighter.

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A Models

A.1 SEEM by Banco Central de Chile

The SEEM (Beltrán et al., 2024) extends the New Keynesian Small Open Economy model of Gali and Monacelli (2005) by allowing for a detailed energy input matrix. The model, at a general level, includes nominal price rigidities, sector-specific capital (with associated adjustment costs), and assumes incomplete financial markets. More specifically, households consume a bundle of two final goods, one produced by domestic final good firms, one produced by foreign final good firms. The model assumes Local Currency Pricing (LCP) in the price of imported foreign goods and investments and exported goods along the lines of Adolfson et al. (2007).

The model innovates compared to the standard New Keynesian frameworks by assuming that the intermediate goods also require a rich energy input. Similarly, households also consume a rich energy bundle. In both cases, the energy bundle is made by combining oil and electricity. The electricity is generated using various technologies, including thermo-electricity, hydroelectricity, and other non-conventional renewable electricity. A representative agent is responsible for aggregating the electricity from different sources and for determining how much of each type enters the electric grid.

In relation to each specific electricity producing technology, we assume that thermo-electricity is generated by combining oil, natural gas, and coal together with physical capital. For hydroelectricity, we assume that electricity is produced in a dam. In this process, physical capital is combined with two water-related variables. The first is water flow, which is responsible for spinning the turbine to generate electricity. The second is the water level, which creates downward pressure on the generator. Within this characterization, the stock of water is assumed to renew through time at a given exogenous rate acts as the effects of rain and the melting of ice on the mountains. Finally, in the case of the non-conventional renewable electricity, the output is obtained combining sector-specific capital and a renewable energy source (solar, wind, run-of-the-river-hydro). The latter is modeled as a random variable to reflect that the amount of primary energy received is exogenous to the firm.

The model is closed via a central bank that sets the short-term nominal interest rate using a standard Taylor-type rule, reacting to increases in consumer price inflation and real activity at the EA level.

A.2 BIS-MS by Bank for International Settlements

BIS-MS is a multi-sector New Keynesian model that is used to study the interplay between monetary policy and energy shocks (Burgert et al., 2025b).[14] Its foundation is a medium-scale DSGE model, augmented with a detailed multi-industry structure. The model is used to assess the heterogeneous impact of energy shocks across different parts of the economy and the amplification of these shocks through production networks. The model features 15-20 industries (depending on the setup), such as mining and manufacturing. The model also features imperfect substitutability in demand, labor supply, and production across these industries, and includes a comprehensive intermediate goods structure. Industries within the model differ in their production functions, price stickiness, centrality in the production network, and role in final demand. Monetary policy is modeled as a Taylor rule that can be flexibly adjusted to study headline inflation, core inflation, and average inflation targeting, among others.

A key feature of our approach is to map the model's multi-sector structure to the data through the use of input-output tables. This allows us to differentiate between intermediate inputs and value added, as well as to distinguish between intermediate use and final demand (consumption and investment). We can calibrate the model to replicate the input-output structure of more than 80 economies, employing either the OECD inter-country input-output tables or the Asian Development Bank multi-regional input-output tables. We calibrate key parameters, such as shock variances, to country-specific data with a method of moments approach. Thus, the model provides the flexibility to study a large set of countries and opens up the possibility of cross-country comparison using a coherent framework.

BIS-MS can model a range of scenarios. These include temporary shocks and permanent structural changes, both of which can be of either an aggregate or a sectoral nature. To study the effects of a temporary energy price shock, we focus on a shock that directly affects both the mining and manufacturing sectors and then propagates through the production network, amplifying the aggregate response. We implement a permanent energy price shock through a sectoral consumption tax applied to the mining and manufacturing sectors. When studying the permanent increase in energy prices, the model allows for a flexible set of expectation mechanisms, such as staggered expectation formation.

BIS-MS is available as a toolbox, including a learning guide.[15] It features the following capabilities: adaptable to more than 80 countries, flexible choice of monetary policy rule type, sectoral and aggregate shocks, temporary and permanent shocks, and an alternative expectation formation mechanism.

[14] More generally, the BIS-MS model can be applied in various contexts. For example, it can be employed to evaluate the impact of tariffs, with a particular emphasis on sectoral dynamics (Burgert et al., 2025a).

[15] The toolbox can be accessed at https://github.com/bis-med-it/BIS_Multisector_Model.

A.3 EMuSe by Deutsche Bundesbank

The **E**nvironmental **Mu**lti-**Se**ctor model EMuSe is a (non-linear) dynamic stochastic general equilibrium (DSGE) model. It is primarily designed to study the impact of climate-related adjustment processes taking into account both the sectoral and international dimension. Like prototypical DSGE models, EMuSe features several model blocks. The first block comprises the optimal behavior of households, the second block describes the optimal behavior of firms, and a government block characterizes the behavior of monetary and fiscal policy. Each block is derived from the underlying microeconomic structure of the model, i.e., explicit assumptions regarding the specific behavior of agents as well as the technological, budget and institutional constraints in the economy. The model agents form rational expectations about future outcomes.

Two features of the EMuSe model stand out compared to prototypical DSGE models: i) a multi-sectoral production structure and ii) an environmental module. In contrast to standard production technologies used in DSGE models a bundle of intermediate inputs is needed in addition to labor and capital. This bundle combines output from all sectors using a constant elasticity of substitution production technology, which implies that the extent to which various inputs are substitutable is limited. This representation allows considering sectoral linkages across all sectors. Hence, EMuSe is able to capture a detailed production network. The environmental module characterizes emissions as a by-product of production. Specifically, emissions in a given sector are proportional to its output, which is captured by the emissions intensity. Negative pollution externalities can be taken into account by a damage function.[16]

In addition to a closed-economy, flexible-price baseline model, a range of different EMuSe versions are available. This includes multi-region variants to assess the implications of climate policies in an open-economy context, model specifications with nominal rigidities enabling to study the interrelation of climate action and monetary policy as well as model specifications with a more detailed energy sector distinguishing between "green" and "brown" energy production.[17] The EMuSe model is implemented using the software Dynare. So far, EMuSe versions with up to 4 regions and up to 62 sectors have been used. The model's rich sectoral structure leaves many sector-specific production parameters to be specified. For this purpose, a MATLAB-based calibration toolkit has been developed, pinning down most of the sector-specific production parameters using data from, inter alia, the World Input-Output Database (Timmer et al., 2015).[18] It allows to specify the EMuSe model quite flexibly for a custom choice of regions and sectors. An EMuSe handbook, program codes for various model versions and the EMuSe Calibration Toolkit are publicly available.[19]

[16] The model can also be extended to capture pollution abatement efforts.

[17] See, e.g., Hinterlang et al. (2022), Hinterlang et al. (2023), Ernst et al. (2023) and Hinterlang (2024).

[18] An alternative data source with more recent data are FIGARO tables provided by Eurostat.

[19] https://www.bundesbank.de/en/publications/reports/technical-papers/

A.4 NAWM-E by European Central Bank

The NAWM-E (Coenen et al., 2024) is an extension of the ECB's New Area-Wide Model,[20] which is a calibrated open-economy DSGE model of the euro area. The original NAWM incorporates optimizing firms and households alongside a broad set of nominal and real frictions.

The NAWM-E represents a two-region model of the global economy comprising the euro area (EA), the United States (US), extended with a small country exporting fossil resources. The agents in the model are forward-looking, optimizing their decisions based on future expectations. The model features sectoral disaggregation, encompassing three distinct sectors: the intermediate-good sector and two energy sectors producing dirty and clean energy, respectively. This sectoral detail allows for a nuanced analysis of the interactions between energy markets, fiscal and monetary policies, and macroeconomic outcomes.

The main feature of the model relates to the introduction of disaggregated energy production and use, where intermediate-good firms and households demand an energy composite for their production and consumption decisions. The energy composite is produced by a perfectly competitive firm, which combines "dirty" and "clean" energy inputs. These inputs are in turn produced by two sets of monopolistically competitive firms: firms in the dirty energy sector combine imported fossil resources, the use of which causes carbon emissions, with a capital-labour bundle, whereas firms in the clean energy sector combine domestic "green" renewable resources with a capital-labor bundle. The energy composite is then utilized as a distinct input in the production of intermediate goods, and as a separate good in households' aggregate consumption bundle. The specification of imperfect competition across firms in the clean and dirty energy sectors allows for sectoral energy production costs to be passed through to intermediate-good and aggregate consumption prices in a staggered fashion. Over and above carbon emissions from dirty energy use, the model also accounts for non-energy carbon emissions from intermediate-good production.

The fiscal framework employs a standard fiscal rule, prescribing that lump-sum taxes adjust gradually to ensure the government debt-to-GDP ratio returns to its target value over time. Monetary policy is governed by an inertial interest-rate rule, which responds to deviations in annual inflation (excluding energy) from its target and to deviations in quarterly real GDP growth from potential growth.

the-environmental-multi-sector-dsge-model-emuse-a-technical-documentation-914846

[20] For details on the original NAWM, see Coenen et al. (2007).

A.5 E-QUEST by European Commission

E-QUEST (Varga et al., 2022) is a dynamic general equilibrium model that builds on standard DSGE models by incorporating sectoral disaggregation to address climate policy measures targeting fuel- and electricity-intensive sectors. The model belongs to the expanding family of large-scale E-DSGE models with input-output production network. A distinguishing feature of the model is that it also allows for endogenous technological progress in a parsimonious learning-by-doing framework.

There are seven sectors in the model: two energy provider sectors, three tangible capital producing sectors and the rest of the economic activities are allocated into two sectors depending on their emission intensity. More specifically, there is a sector which extracts and provides the economy with fossil fuels and another energy provider sector producing electricity from clean (renewable) or dirty sources. Two of the tangible capital types require either fossil fuel or electricity to operate, each produced separately by a fossil fuel-intensive (dirty) capital manufacturing sector and an electricity-intensive (clean) capital manufacturing sector. The third tangible capital producing sector manufactures general, non-energy related capital. As for the remaining economic activities, an emission intensive sector is separated from the rest of the sectors. The rationale for separating an emission intensive sector is to examine the consequences of extending the burden of emission reductions from energy producing sectors to other non-energy producing sectors with high greenhouse gas emission potential. The model distinguishes between two main sources of GHG emissions: emissions linked to the burning of fossil fuel and other GHG emissions (CO2 emissions from industrial processes and non-CO2 emissions). While the former type of emissions appears in all segments of our model-economies, the latter one is allocated to the emission intensive sector. Emission abatement technologies in the model address these two types of emissions in a targeted manner. Emissions linked to the burning of fossil fuel can be abated by substituting away from the fossil fuels towards clean electricity, capital, or intermediates while other GHG emissions can be mitigated by taking up additional abatement costs. Firms have imperfect substitution possibilities between fossil fuel and electricity-intensive capital-energy bundles. This differentiation into 'dirty' or 'clean' allows for representing the substitution potential between energy sources. The model features two regions: the European Union and the rest of the world.

The rest of the model incorporates a comprehensive set of features from New Keynesian macroeconomic models, including different household groups (liquidity constrained and *Ricardians*), endogenous labor supply, market friction, government policies with fiscal rule, and monetary policy governed by a Taylor-rule.

A.6 C-EAGLE by the Eurosystem

The C-EAGLE model (García et al., 2024) is an extension of the euro area and Global Economy (EAGLE) model (Gomes et al., 2012). Like the ECB's New Area Wide Model (Coenen et al., 2007) and the IMF's Global Economy Model (Laxton and Pesenti, 2003), the EAGLE model is micro-founded and includes nominal price and wage rigidities, capital accumulation, and international trade in goods and bonds. The EAGLE model extends the NAWM by introducing tradable and non-tradable sectors and a monetary union.

The C-EAGLE model includes energy sectors, drawing on the works of Golosov et al. (2014), Känzig (2023) and Coenen et al. (2024). However, the model differs from Coenen et al. (2024) in several key aspects. Households consume final non-energy, brown energy, and green energy goods. The shares of energy goods in the consumption bundle are treated as preference parameters. This structure allows for different shares of energy goods for Ricardian and non-Ricardian households (as in Känzig, 2023). Moreover, households invest in regular, brown, and green capital, allowing to differentiate between taxes on brown capital and subsidies for green investment.

On the supply side, the model distinguishes between monopolistically competitive brown and green energy firms. Brown energy firms use brown capital and labor, while green energy firms use green capital and labor. The product of the energy firms is sold only domestically to households for final consumption or to domestic intermediate tradable and non-tradable goods firms that use it as an input. These intermediate goods firms are also monopolistically competitive and use regular capital, labor, and energy inputs with a Cobb-Douglas production function.

The central bank sets the short-term nominal interest rate using a standard Taylor-type rule, reacting to increases in consumer price inflation and real activity at the EA level. The US and the RW have their own nominal interest rates and nominal exchange rates. The government collects tax revenues through various taxes, including lump-sum taxes, VAT, labor income tax, payroll contributions, and dividend taxes. Regarding climate policy, the government in each region uses carbon taxes and taxes on brown capital investment. In each block, the public debt is stabilized through a fiscal rule. Each region's size is determined by the share of resident households and domestic sector-specific firms.

B Additional Results

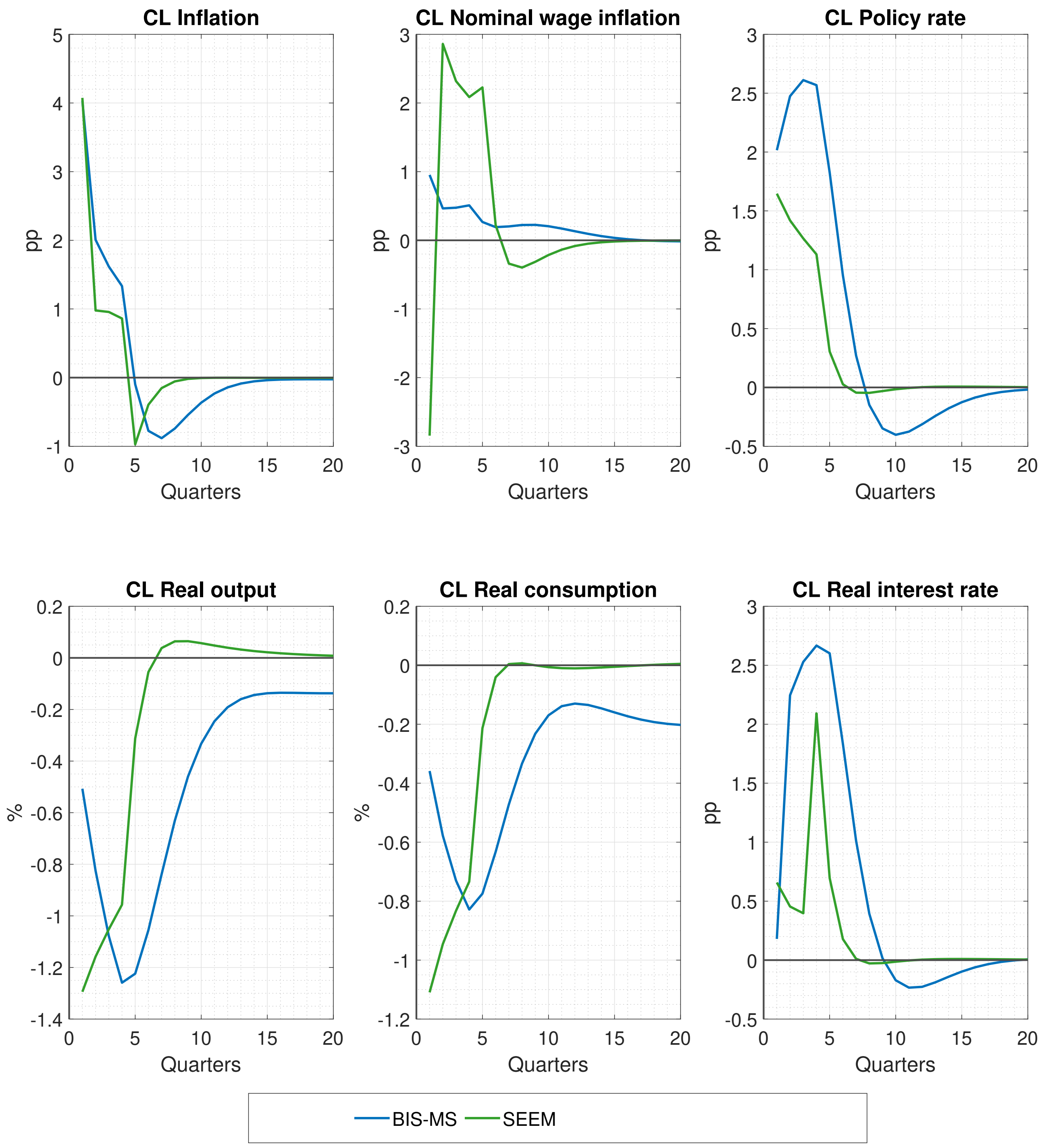
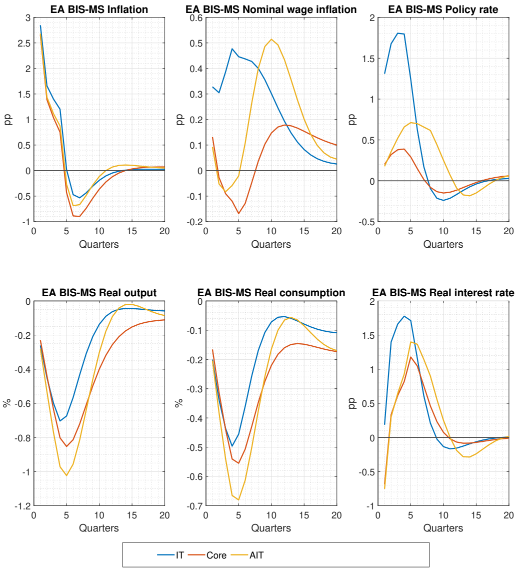
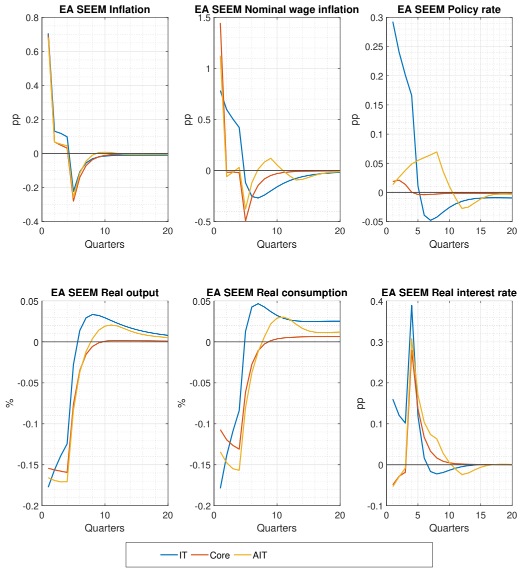


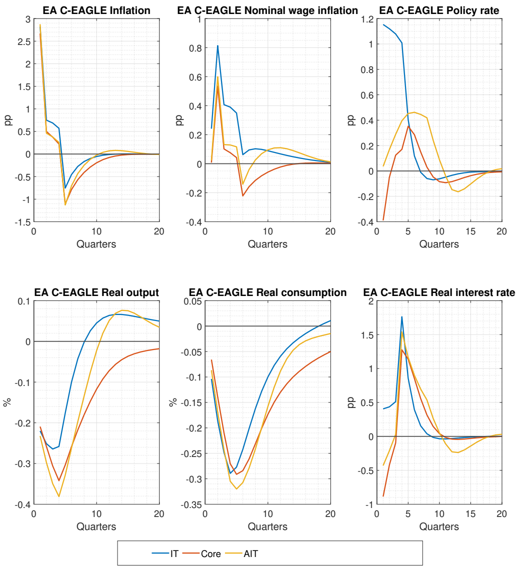
Figure B.2: Temporary scenario - Role of monetary policy for the euro area



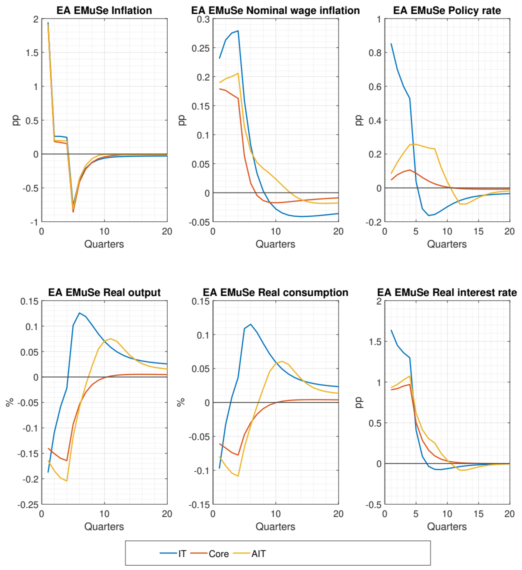
(a) BIS-MS model



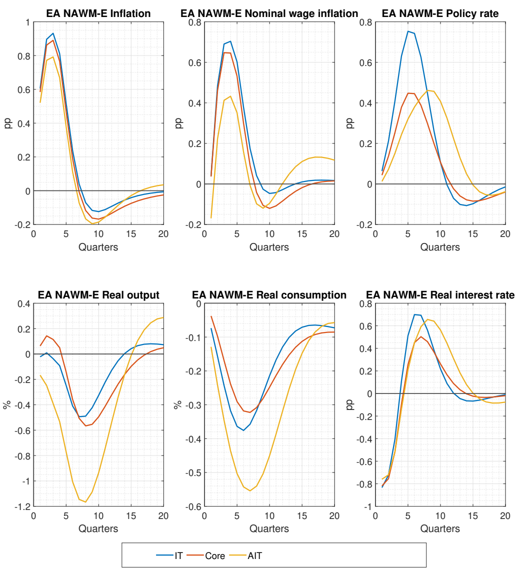
(b) SEEM model



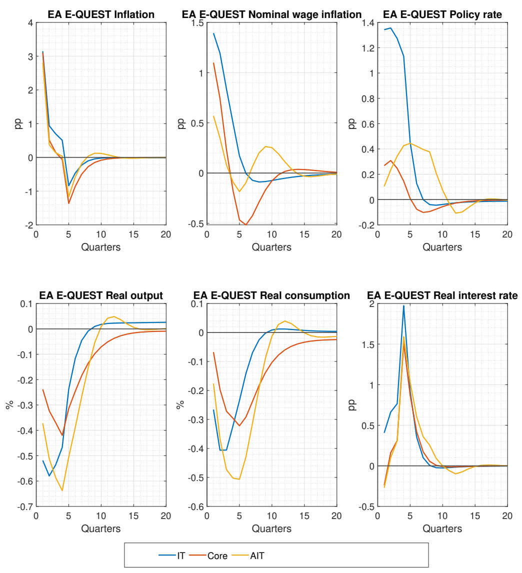
(c) C-EAGLE model



(d) EMuSe model

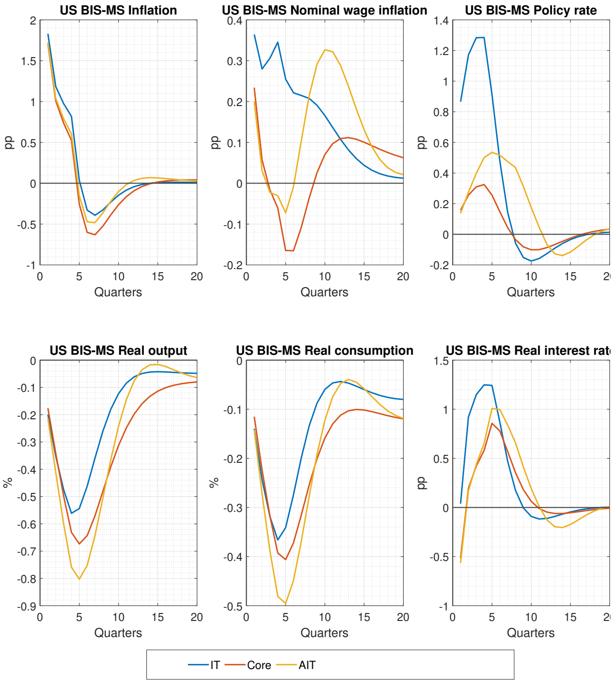


(e) NAWM-E model

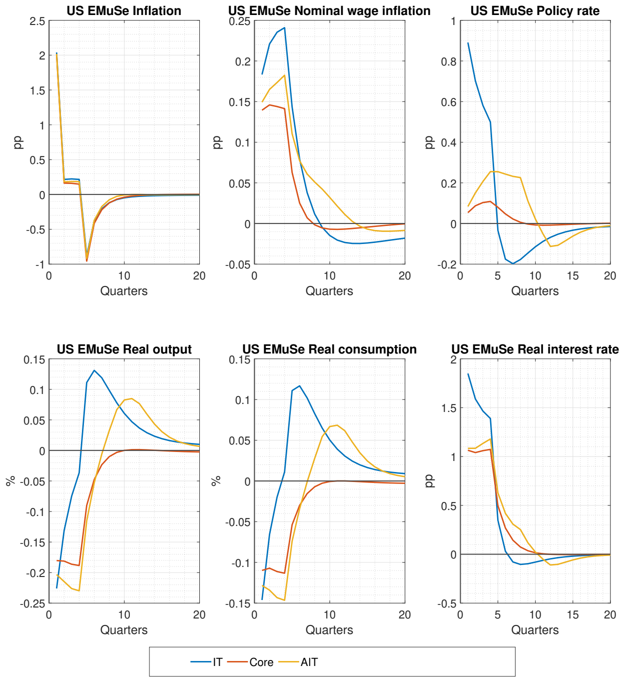


(f) E-QUEST model

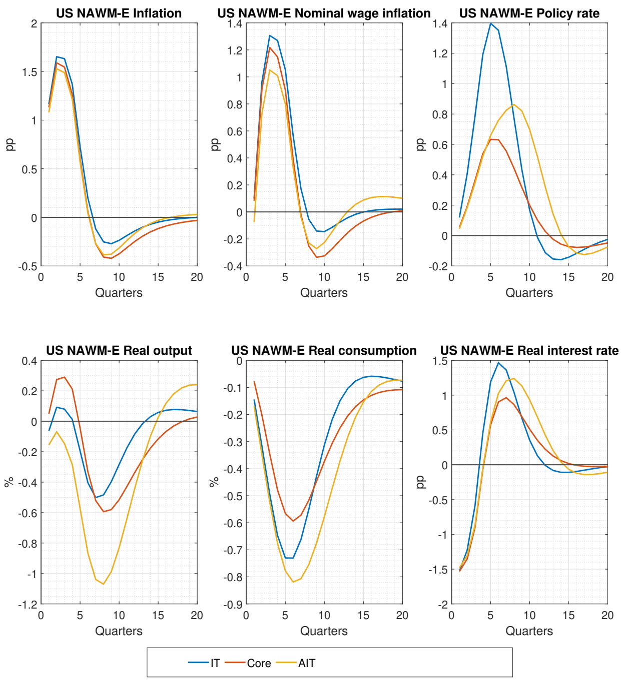
Figure B.3: Temporary scenario - Role of monetary policy for the United States



(a) BIS-MS model

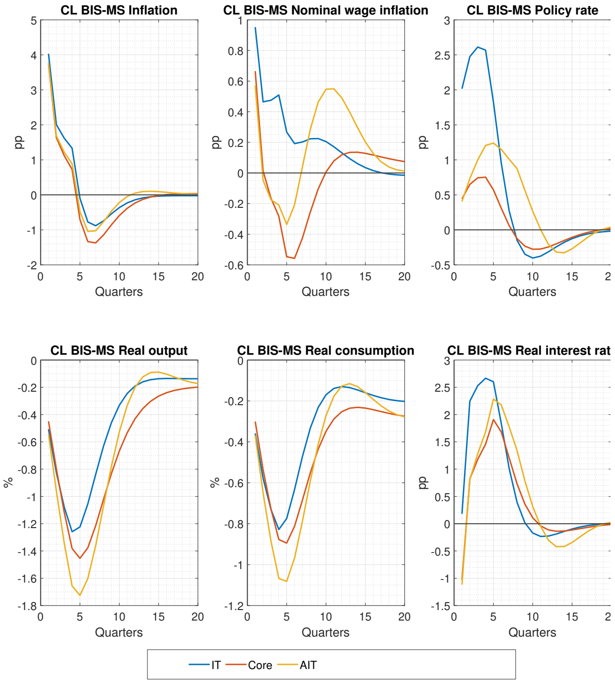


(b) EMuSe model

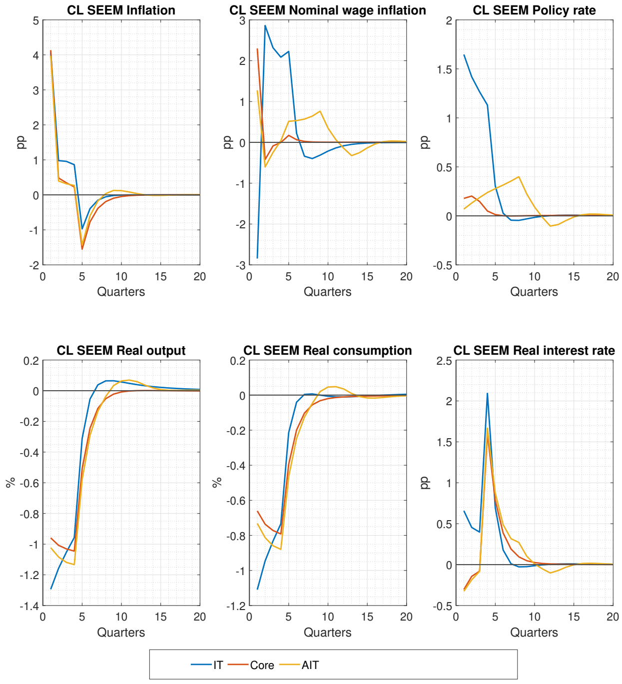


(c) NAWM-E model

Figure B.4: Temporary scenario - Role of monetary policy for Chile

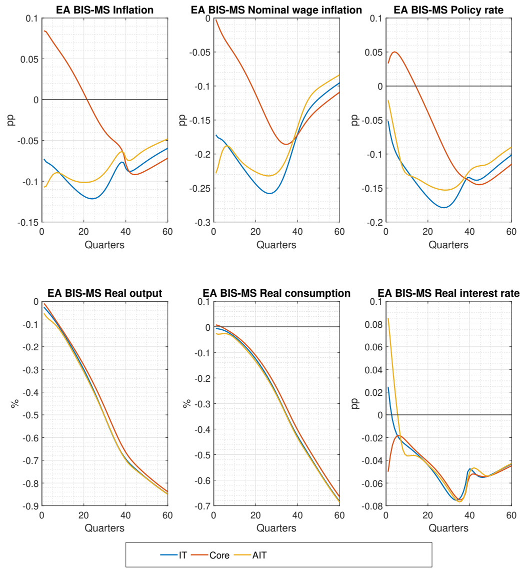


(a) BIS-MS model

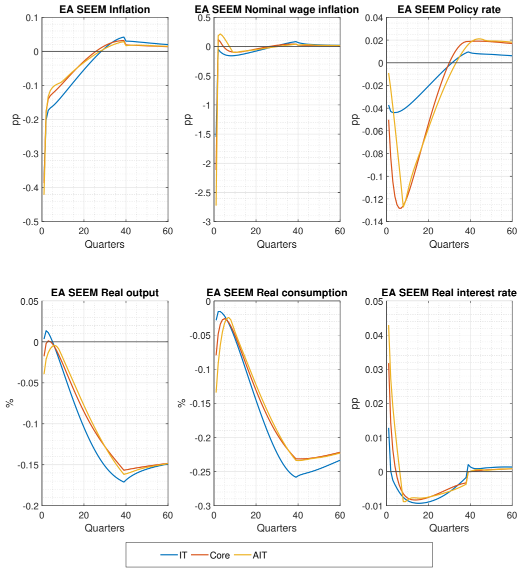


(b) SEEM model

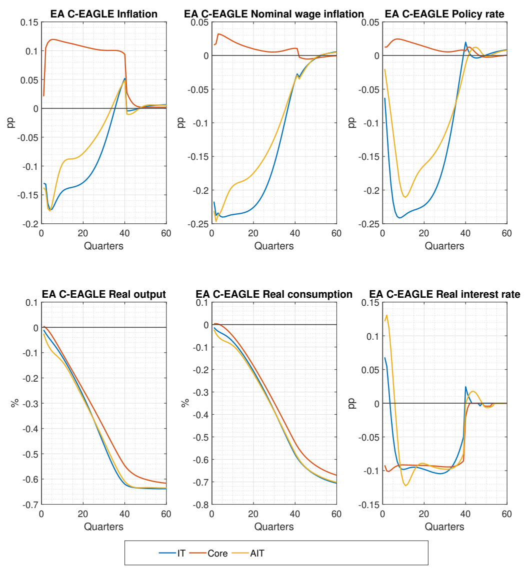
Figure B.5: Permanent scenario - Role of monetary policy for the euro area



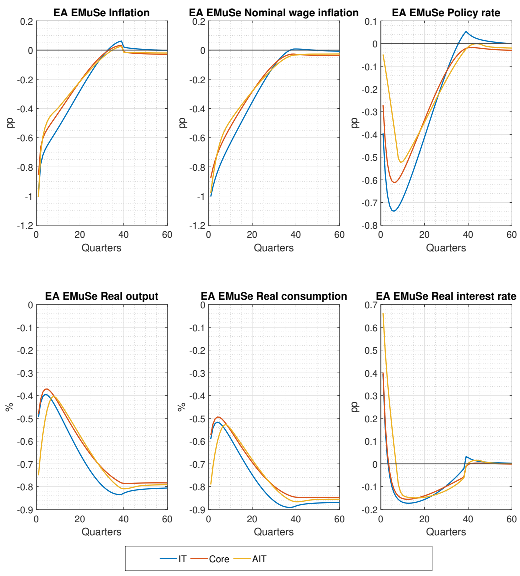
(a) BIS-MS model



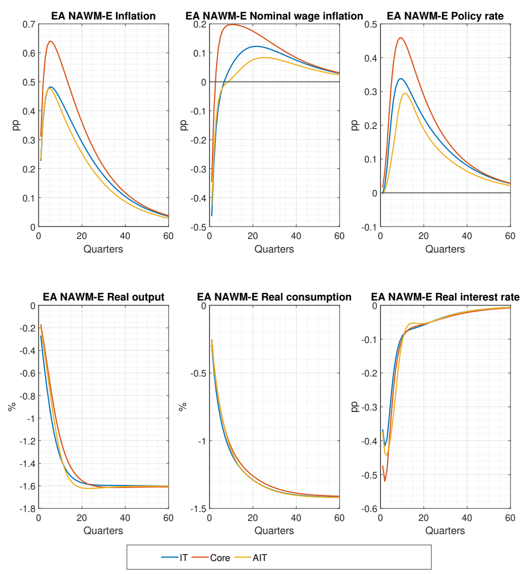
(b) SEEM model



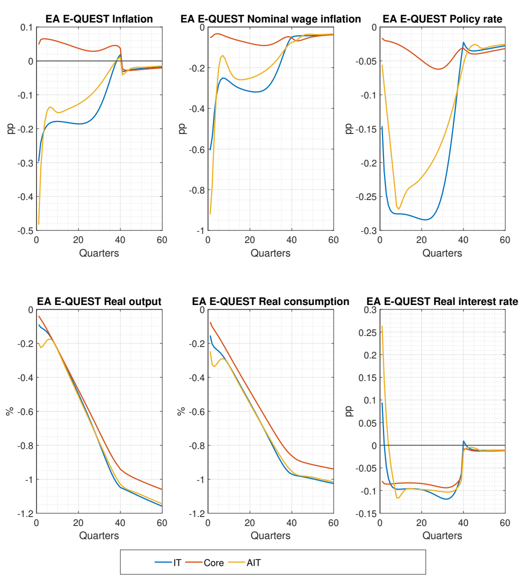
(c) C-EAGLE model



(d) EMuSe model

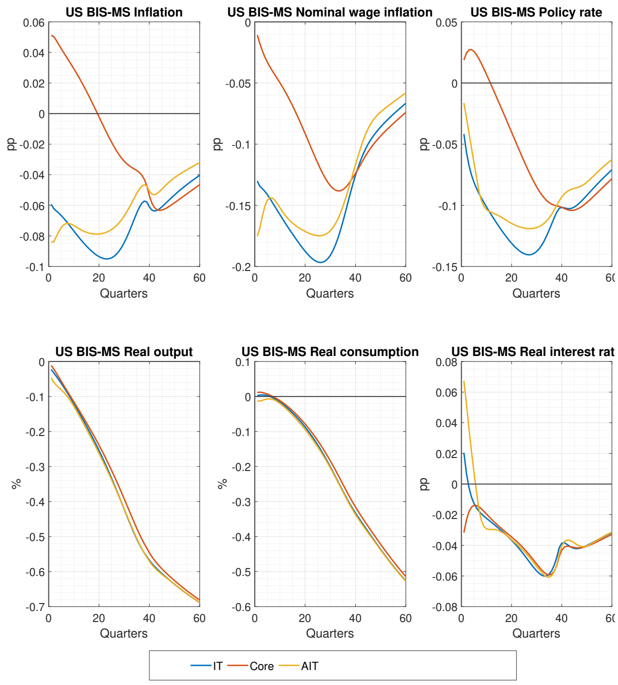


(e) NAWM-E model

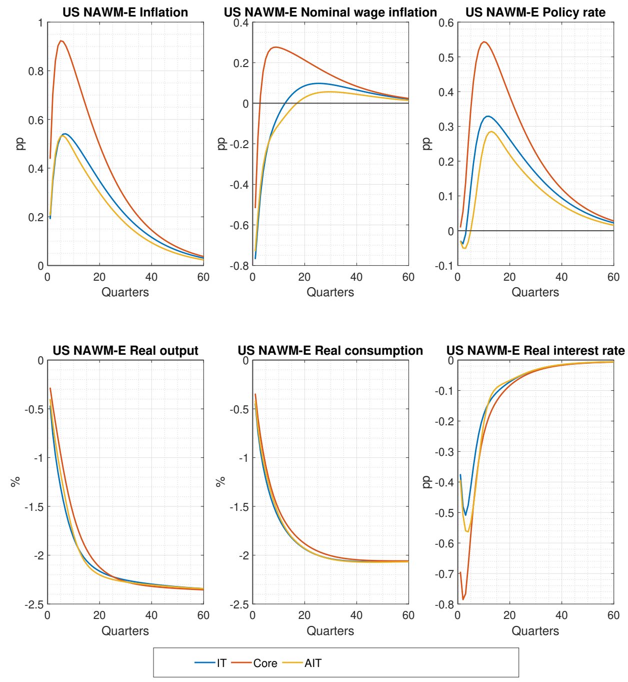


(f) E-QUEST model

Figure B.6: Permanent scenario - Role of monetary policy for the United States



(a) BIS-MS model



(b) NAWM-E model

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