

Macroeconomic effects of carbon-intensive energy price changes: A model comparison

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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 quantitative models are environmental monetary models with a detailed multisector structure, calibrated to the euro area, United States and other countries. The model comparison assesses the effects of both a temporary and a permanent energy price increase. Temporary and permanent price shocks are found to be 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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1 Introduction

The transition towards a green economy is a critical response to climate change, but it poses 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 to analyse climate-related phenomena. These models are used to examine energy price shocks and the chronic or temporary nature of climate change phenomena and to assess the role of the monetary policy framework.

To address the challenges posed by climate change on central banks' mandates, the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) aims to provide technical guidance to central banks and regulators on systematically addressing the economic impacts of climate change. For this purpose, the NGFS has published the NGFS Climate Macroeconomic Modelling Handbook (NGFS, 2024b), which guides central banks on incorporating climate change effects into their macroeconomic models, focusing on both physical and transition impacts. This guidance is intended to assist central banks at various stages of their modelling journey, ensuring they can better understand and integrate climate-related features into their economic analyses. The NGFS also stressed in their report Climate Change, The Macroeconomy and Monetary Policy (NGFS, 2024a) the importance of understanding the response of monetary policy to repeated and more persistent climate-related shocks.

The purpose of the present document is to shed light on the challenges for monetary policy by presenting a unique model comparison conducted by a group of institutions who have teams of economists dedicated to macroeconomic modelling. The work of the modelers follows up on the recommendations of the NGFS Climate Macroeconomic Modelling Handbook (NGFS, 2024b) and aligns closely with other NGFS workstreams and reports, ensuring continuity with ongoing efforts to address climate-related economic impacts. An important cornerstone for this project is its contribution to the NGFS principles of knowledge sharing and capacity building by documenting cross-country and cross-model comparisons in climate-macroeconomic models.

The models used in this exercise are fully-fledged monetary models that represent a detailed economy with multiple sectors. The use of monetary models, particularly those aligned with the New Keynesian paradigm, has been fundamental in central banks' efforts to evaluate the impact of the green transition.¹ At the same time, the multisector dimension has often been either absent or highly stylized in this body of work. However, multisector models are particularly useful for analyzing climate-related issues as they provide a detailed understanding of how different sectors of the economy interact and respond to climate policies and shocks. Pasten et

¹Examples include studies by Airaudo et al. (2023), Annicchiarico et al. (2023), Nakov and Thomas (2023), Ferrari and Nispi Landi (2024), Olovsson and Vestin (2023), Sahuc et al. (2024), Chafwehé et al. (2025), Kaldorf and Rottner (2025), Priftis and Schoenle (2025), among many others.

al. (2020) highlight that sectoral heterogeneity in price stickiness is an important mechanism for generating significant and persistent real output effects. Del Negro et al. (2023) demonstrate in a multisector model that the impact of the energy transition on inflation crucially depends on the relative price stickiness in “green”, “carbon-intensive” and “other” sectors and the conduct of monetary policy. They show that flexible prices negate inflationary effects, while the interplay between price stickiness and central bank actions can create short-lived trade-offs between stabilizing inflation and maintaining output. This document evaluates these findings through a model comparison using a set of large-scale macroeconomic models.

The model comparison encompasses several models developed within four central banks and two international organisations: including the BIS-MS model by the Bank for International Settlements (Burgert et al., 2025), 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 models, 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, which is crucial for understanding the impact of climate shocks.

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 explores the frameworks in three ways: (i) by describing and discussing the commonalities and differences of the models (Section 2), (ii) by comparing model simulations across aligned simulation scenarios (Sections 3 and 4), (iii) by exploring particular model features in sensitivity analyses (Boxes 1 to 3). 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 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.²

The examination of both temporary and permanent energy price increases uncovers significant insights into their economic impacts. Simulations of a temporary increase in the price of carbon-intensive energy highlight an overall 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, although the timing of the inflation peak varies, with some of them suggesting a more gradual build-up.

Permanent 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 permanent across models, even though the strength of transmission differs quantitatively, with an average decline by close to -1% after 10 years. Our baseline specification indicates that a permanent price increase is associated with an inflation surge. We further analyze how the monetary policy response and the expectations mechanism amplify or mitigate this outcome. Specifically, 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 potential output. Fully and immediately factoring in the future decline in output can lead the central bank to provide relatively less stimulus to demand, which does not compensate for the negative demand 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 slower, 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 (see Box 3). 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 \(2024\)](#).³

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

²The focus is on carbon-intensive energy price shocks or also commonly referred to fossil-based energy price shocks. For this reason, we abstract from green energy price shocks.

³[Ferrari and Nispi Landi \(2024\)](#) argue that the green transition may be deflationary, driven by expectations of higher future taxes that are already dampening demand today.

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, while Sections 3 and 4 describe the results from the scenarios on the temporary and permanent increases in the price of carbon-intensive energy, respectively. Various boxes throughout the document highlight relevant modelling aspects and sensitivity analyses. 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 are the BIS-MS model by the Bank for International Settlements (Burgert et al., 2025), 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. 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 embedding different targeting regimes such as strict inflation targeting, core inflation targeting as well as 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 arise, for example, from the short-term and more medium-term consequences of climate change but also from the effects of public policies (e.g. carbon pricing or taxing) that are put in place to either foster the energy transition or for adaptation.

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-

Table 1: Multisector 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

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

Due to the diverse structure of the energy sectors across different models, the characteristics of the shocks to carbon-intensive energy prices in the simulation exercises vary 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 BIS-MS model the energy price increase is modelled as a combination of productivity and markup shocks to the mining and manufacturing sector. 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 identify key dynamics shared among the different models but also highlights uncertain areas that require additional investigation. Another advantage of our comparison is that the set of models covers different jurisdictions, giving our exercises a cross-countries 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 of a carbon-intensive energy price shock

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.⁴ Such a flexible approach ensures scenario harmonisation by drawing on the expert knowledge of the different modelling teams.⁵ 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

⁴BIS-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 an 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 models 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 labour 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.

⁵Another direct advantage of this approach that we directly work with the different workhorse models of the various institutions.

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.

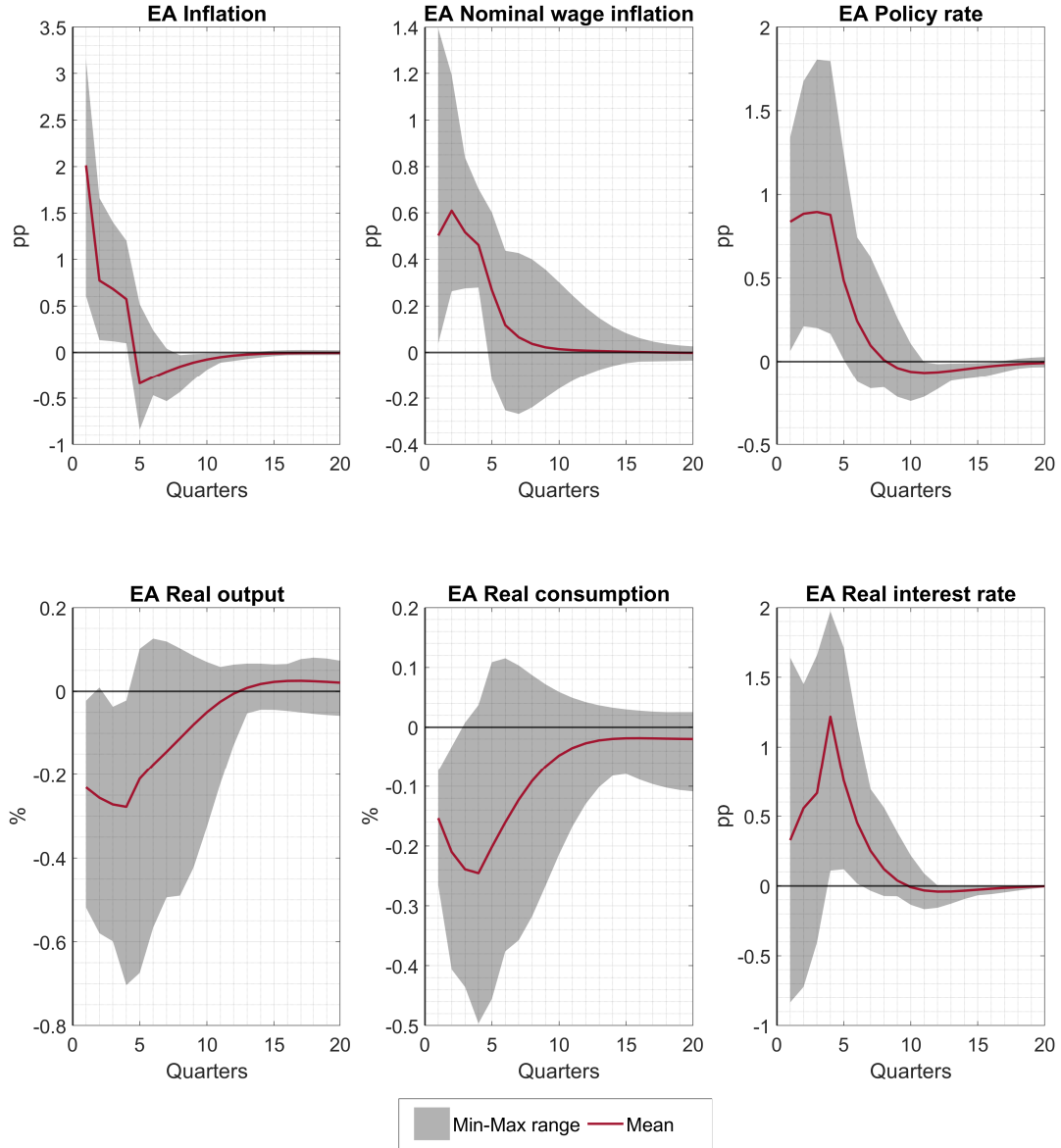
Figure 1 shows the dynamics for the euro area in response to a 25% increase in the price for carbon-intensive energy. We report the mean of the different models as well as the minimum-maximum range of the model simulations. The displayed results are based on the following set of models: BIS-MS, SEEM, 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.

To begin with, 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, this model features a hump-shaped inflation response that results in 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 competitive firms both at the level of carbon-intensive energy production and 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 inflation response 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.⁶

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

⁶One outlier to this result is the SEEM model, due to the fact that it does not have wage rigidities

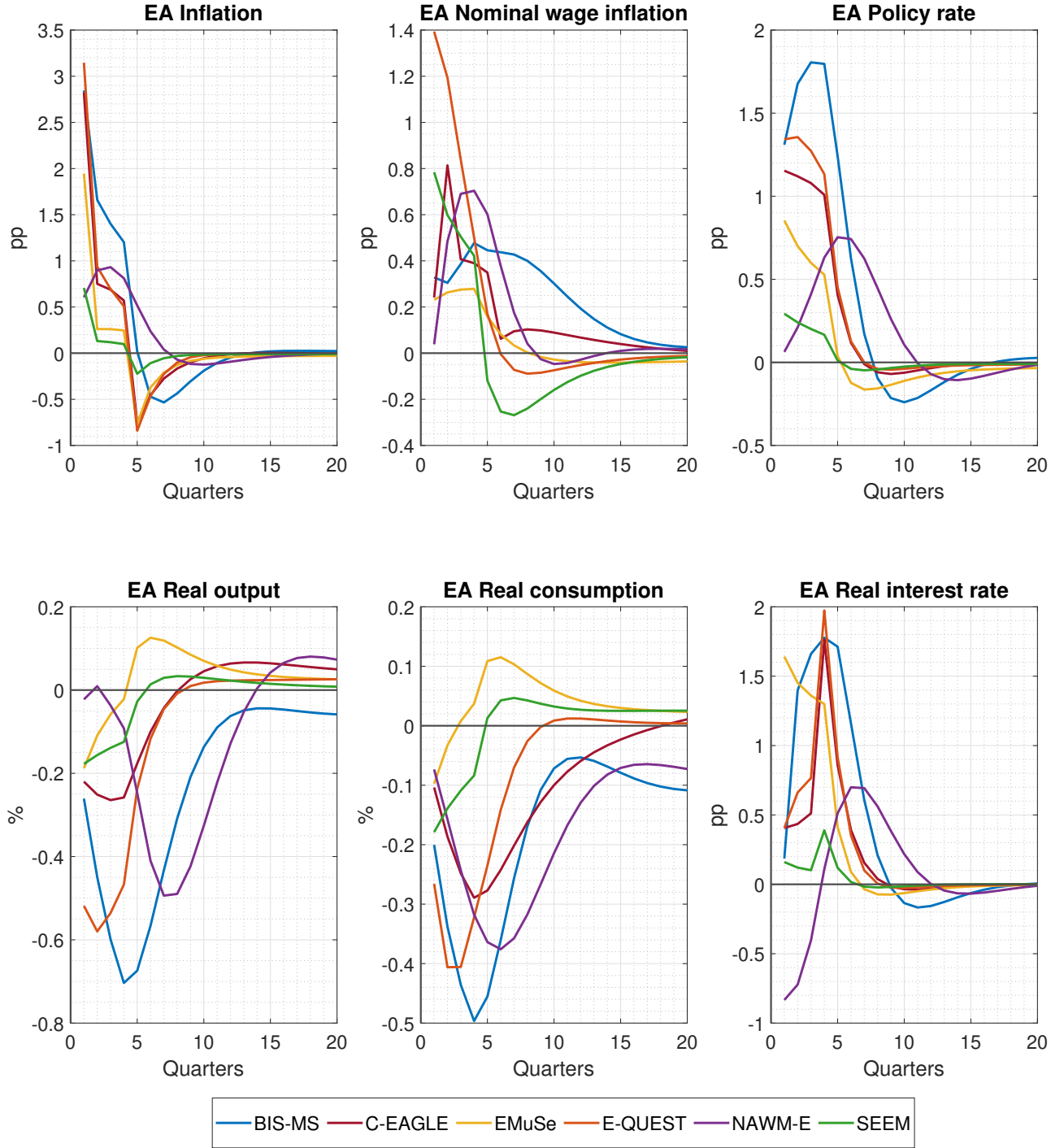
Figure 1: Temporary scenario for the euro area



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.

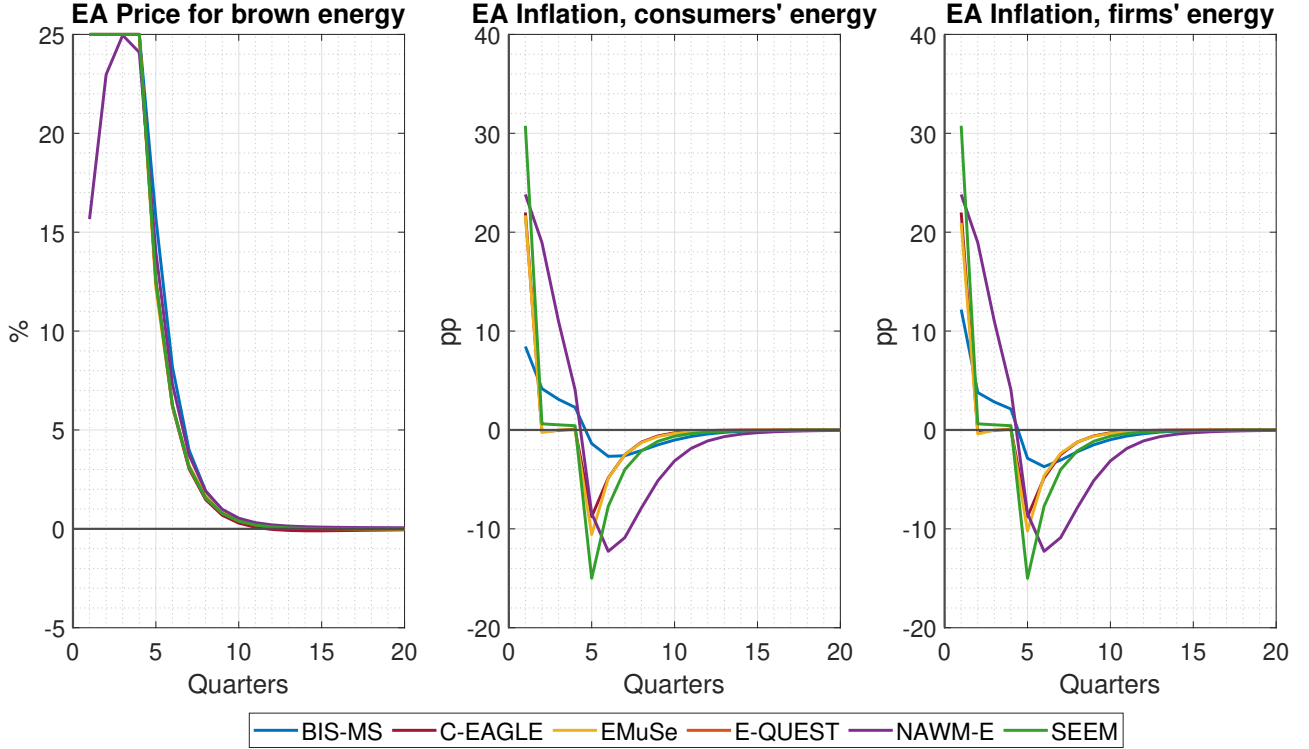
The model simulations depict a substantial output contraction resulting from the carbon-intensive energy price shock. On average, real output falls by 0.3%, with a maximum drop of around -0.7% in the BIS-MS model before gradually returning to zero. Two models stand out. First, the NAWM-E displays almost no output drop on impact, which is the result of a strong underlying hump-shaped pattern of inflation and the associated response of the

Figure 2: Temporary scenario for the euro area



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.

Figure 3: Temporary scenario for the euro area

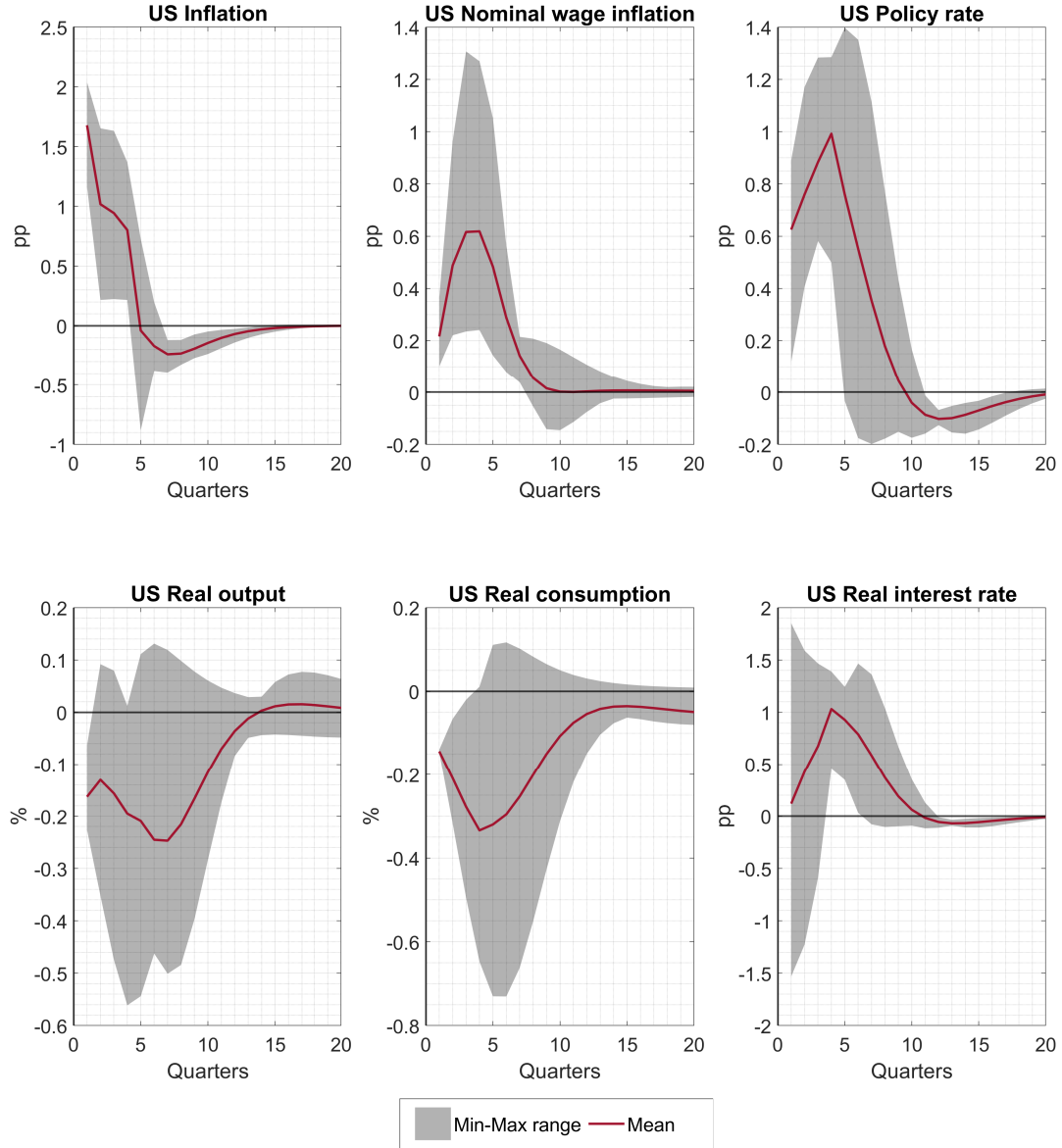


The average consumption response closely aligns with the output response, substantially declining on impact and only gradually returning to zero afterwards. One difference here is that all model simulations yield an initial decline in consumption. Finally, the real interest rate is on average elevated, 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.⁷

The transmission of the increase in the price of carbon-intensive energy through the multisector 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 indicate 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

⁷Differences 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.

Figure 4: Temporary scenario for the United States

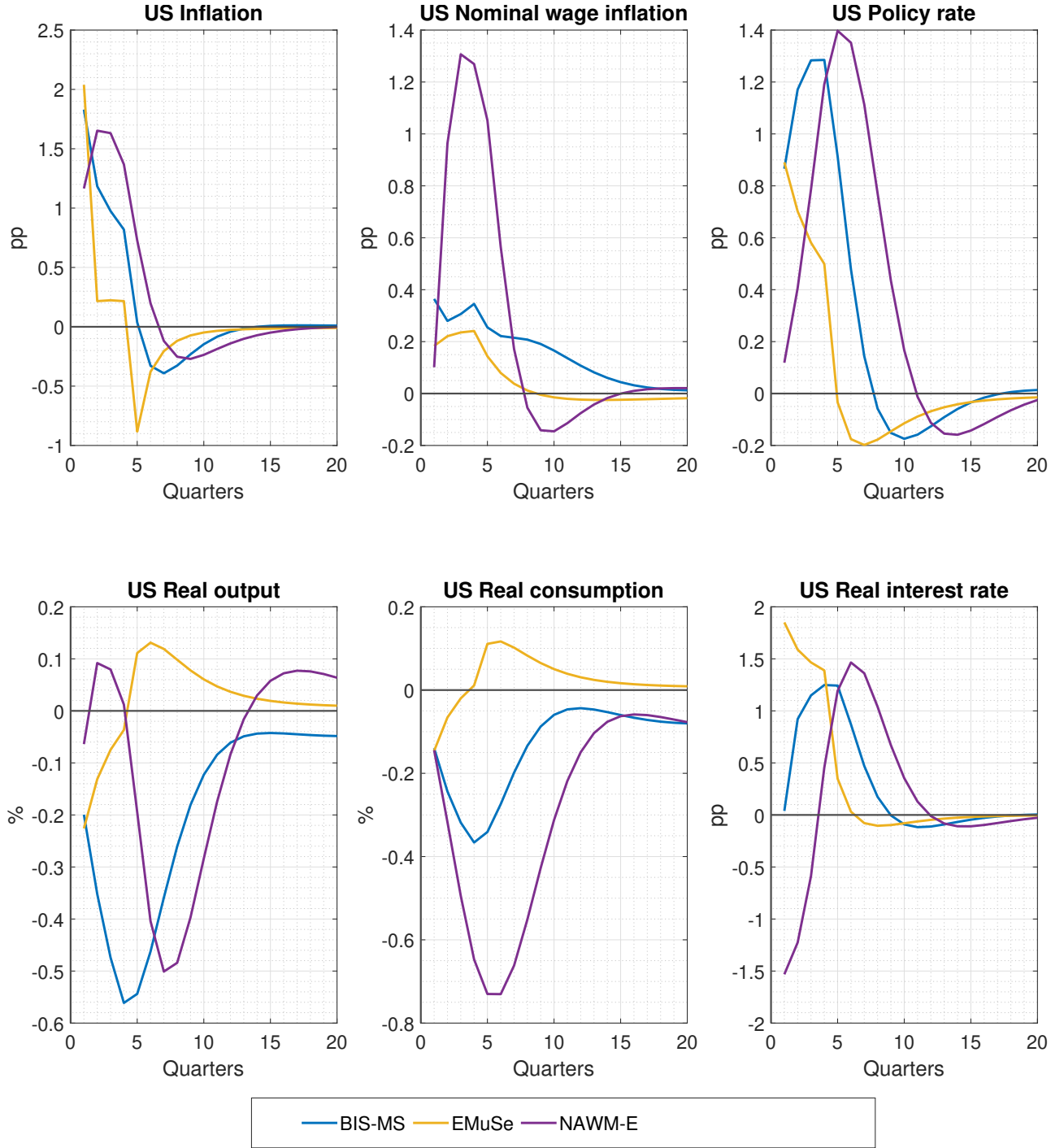


energy by 25% in the short run.⁸

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

⁸It 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.

Figure 5: Temporary scenario for the United States



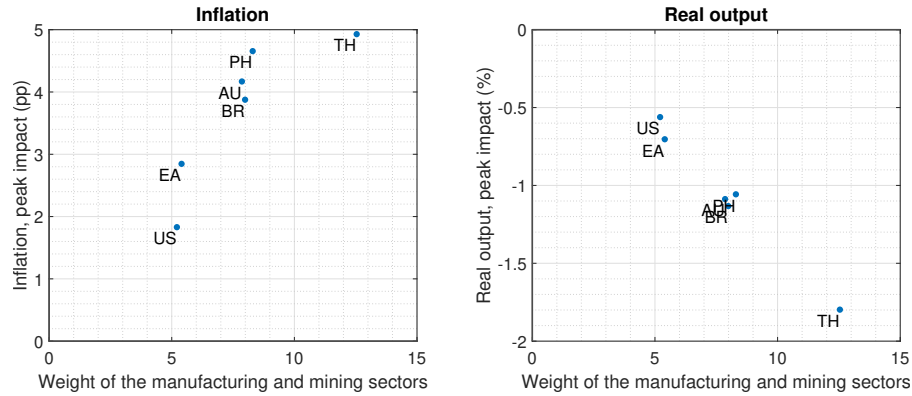
manner in which consumers modify their consumption mix.⁹ The models display considerable heterogeneity in their responses to the energy price indices relevant for consumers and firms,

⁹There 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.

Box 1: Input-output structure and the shock transmission

The input-output (IO) structure in multisector DSGE models is crucial for understanding the transmission of energy shocks (NGFS, 2024b). It captures sector interdependencies 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) 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 CO2 emission sectors changing prices frequently. Larger sectors experiencing shocks have more significant macroeconomic effects. Sectoral heterogeneity, including emissions intensity and input dependencies, shape the transmission of shocks. For instance, high-emission sectors with flexible prices 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 helps in assessing the impact of energy shocks and in designing effective climate policies.

Figure 6: Impact of carbon-intensive energy shock on inflation and output across countries



As the IO structure is a key driver in the transmission of energy shocks, different countries experience varied impacts from the same shock. The relative weight of the sectors affected by the shock in a country is a crucial determinant of the economic impact. Figure 6 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 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 sector. 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.

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.

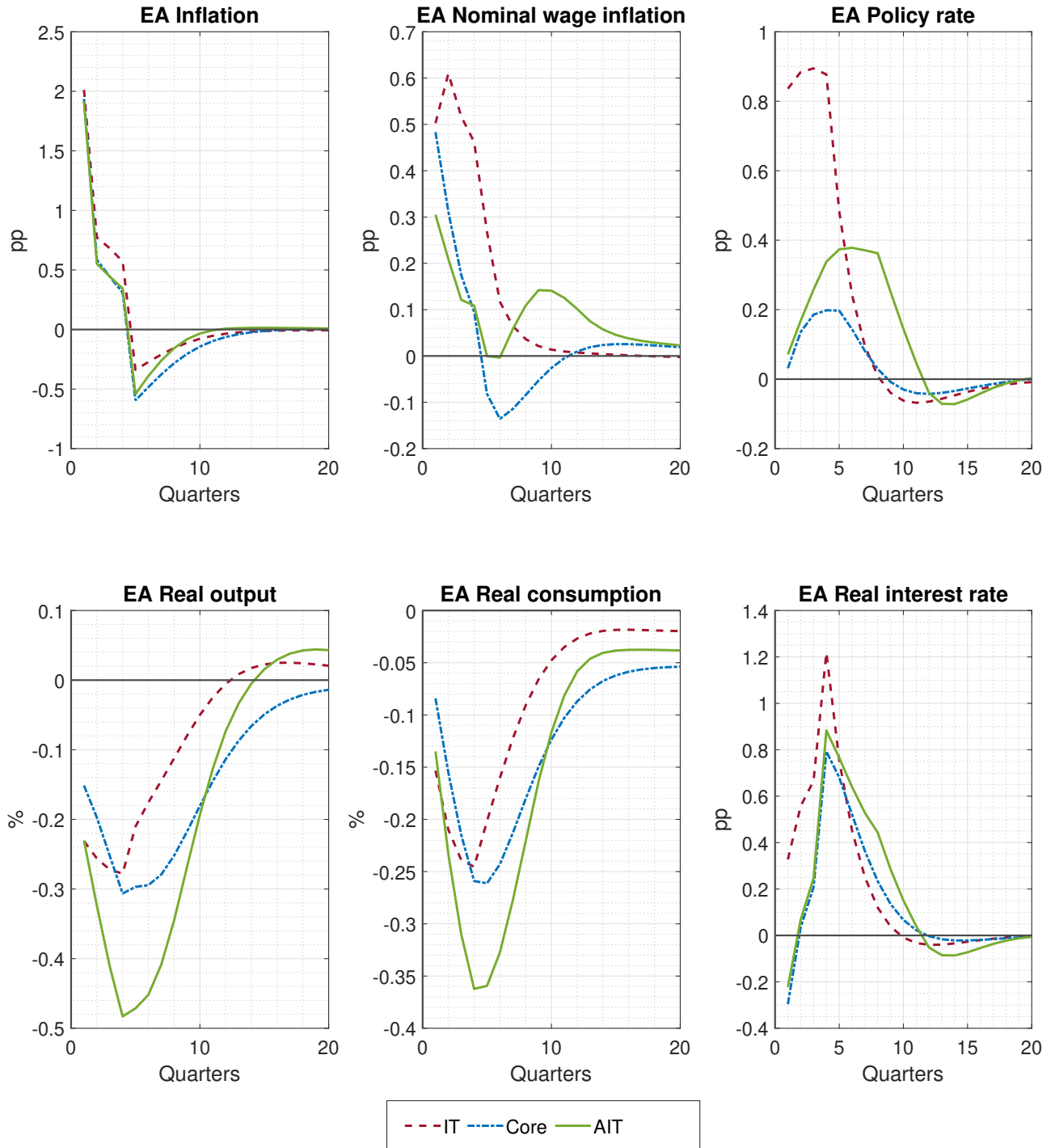
Figure 4 shows the dynamics for the US. The simulations are based on the following set of models: BIS-MS, EMuSe, and NAWM-E. As the set of models is different and smaller here, differences in the mean and min-max range cannot be directly assessed and should be treated with caution. For this reason, Figure 5 shows the specific responses for the US of the different 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 suggest 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. while in the US the share of energy utilised 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 for the euro area and the US. BIS-MS model and 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 suggests a peak fall in output by around 1.2% across both models. One reason of this additional amplification for the Chilean economy comes from the different input-output structure with a large weight on the mining sector.

Key Takeaways The model simulations highlight the inflationary impact of large energy price shocks, with for instance an average initial inflation increase of around 2.0 pp 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, the models differ in the timing of the peak impact of such a shock. While most models show responses peaking at the outset, a few models exhibit a more gradual build-up, with the peak occurring later on. The results also highlight

Figure 7: Temporary scenario: Monetary policy



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

cross-country differences as the euro area, United States and Chile have a different exposure to the shock.

3.2 The role of monetary policy

The same scenario - carbon-intensive energy price increases by 25% in the first four quarters - is now used to evaluate the role of monetary policy. 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. The carbon-intensive energy price shock is calibrated using the baseline scenario.

Figure 7 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 models' 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 employed models. 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. We also see the more smoothed response in 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.

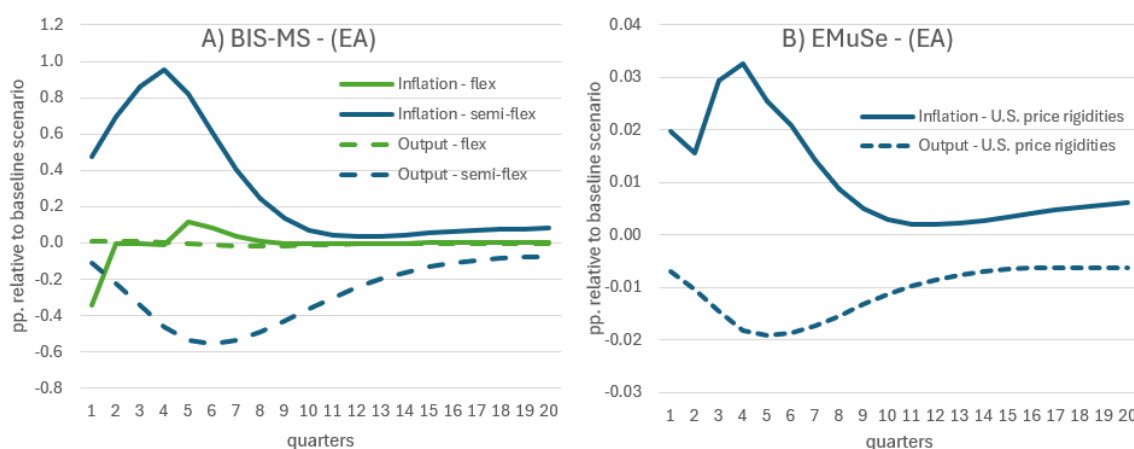
Key Takeaways A first takeaway is that the different monetary policy rules perform rather equally following a temporary energy price increase. This result highlights the challenge that such a sectoral supply shock poses for the central bank. There is often an argument to look

Box 2: 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 price rigidities present in goods, labour and energy markets. These rigidities slow 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, 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 U.S. counterparts would only marginally affect the macroeconomic variables, because the implied changes in sectoral price rigidities roughly balance each other at the aggregate level.

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.

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 in Box 2. 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 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.

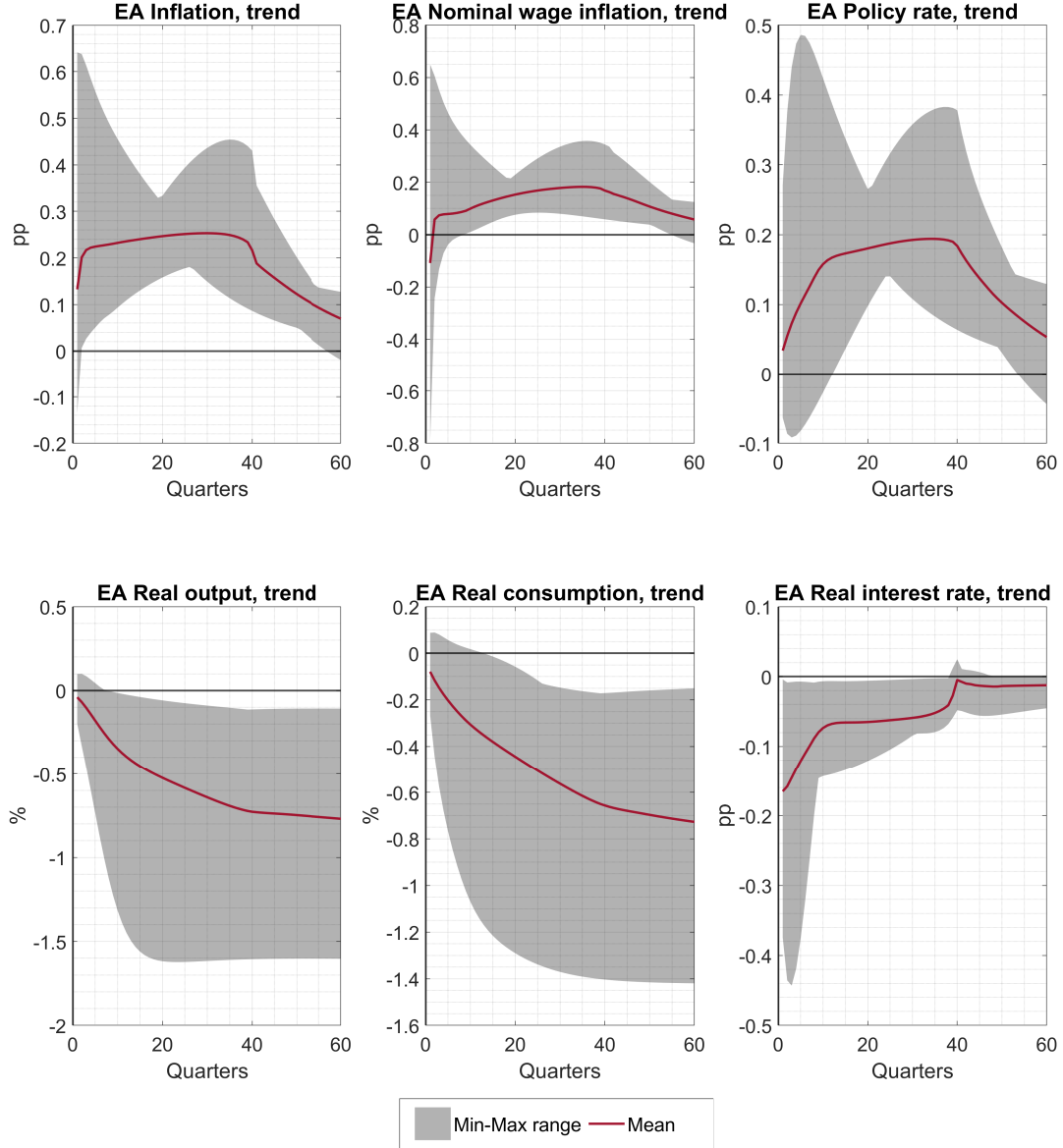
Methodologically, the exercise is constructed by gradually increasing the price of carbon-intensive energy by 25% over 10 years, which remains constant at that level thereafter. Similar to the exercise with temporary shocks, each model and institution delivers this increase in the price of carbon-intensive 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 falls also in the short run. However, as will become clear, an important dimension which 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.¹⁰

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

¹⁰Notably, 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. \(2024\)](#)).

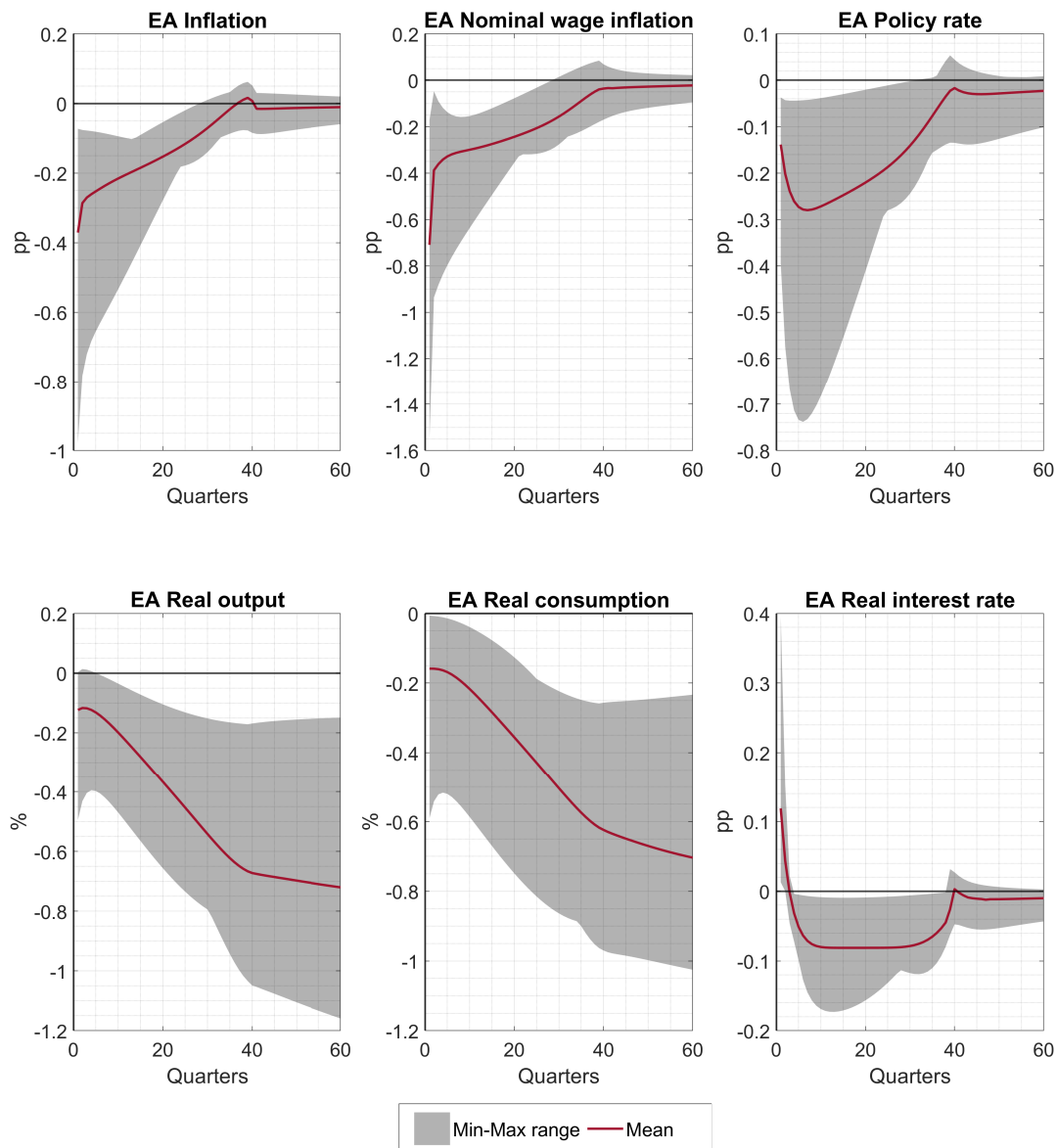
Figure 9: Permanent scenario for the euro area; monetary policy targets a long-run trend



and expected future real income leading to a reduction in consumption, while the decline in firm's 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 over models. As a result, the new steady state after the energy price increase is characterised by lower output compared to the initial level.

The higher energy price increases marginal costs for energy producers, which are subse-

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



quently 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.

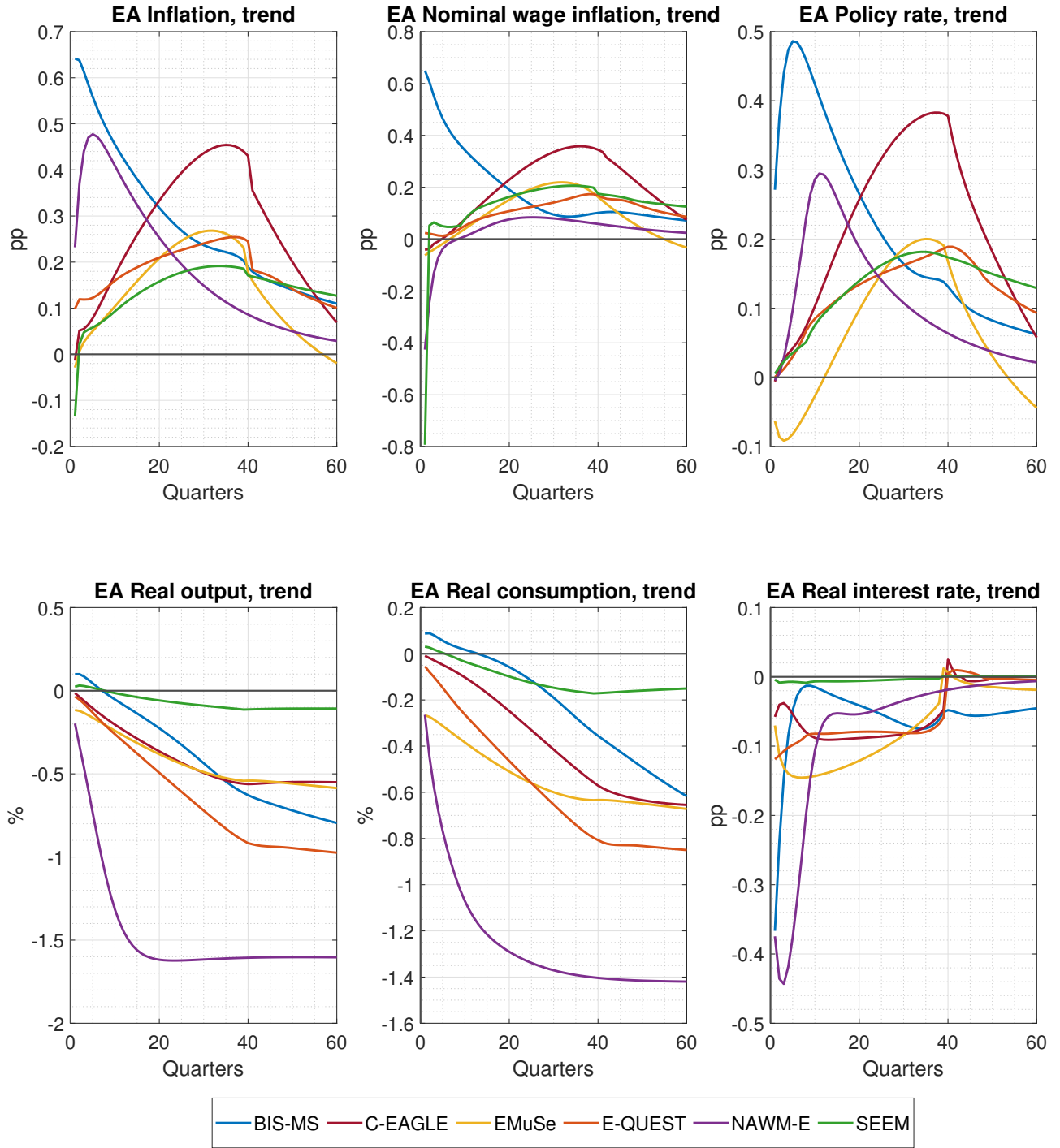
In order for deflation to emerge, for the mean over models, the nominal interest rate falls by 30 basis points in the short term and reverts to the baseline after 40 quarters, also reflecting the decaying but persistent deflationary effects of the shock. Consequently, on average, the real interest rate 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 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 (i.e. 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 stabilise inflation.

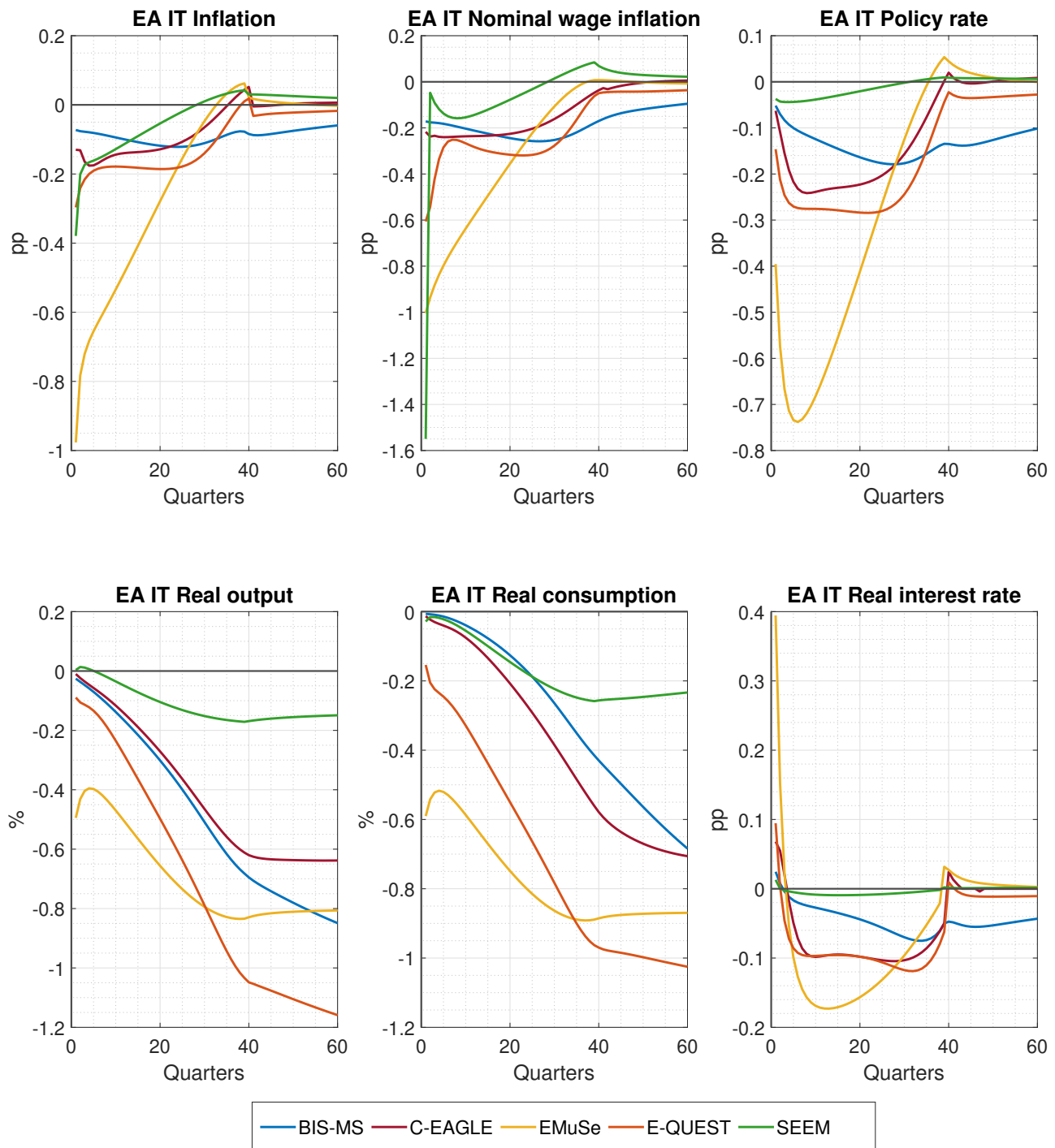
Notably, focusing on the case where the central bank targets deviations of long-run output

Figure 11: Permanent scenario for the euro area; monetary policy targets a long-run trend



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 particular 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

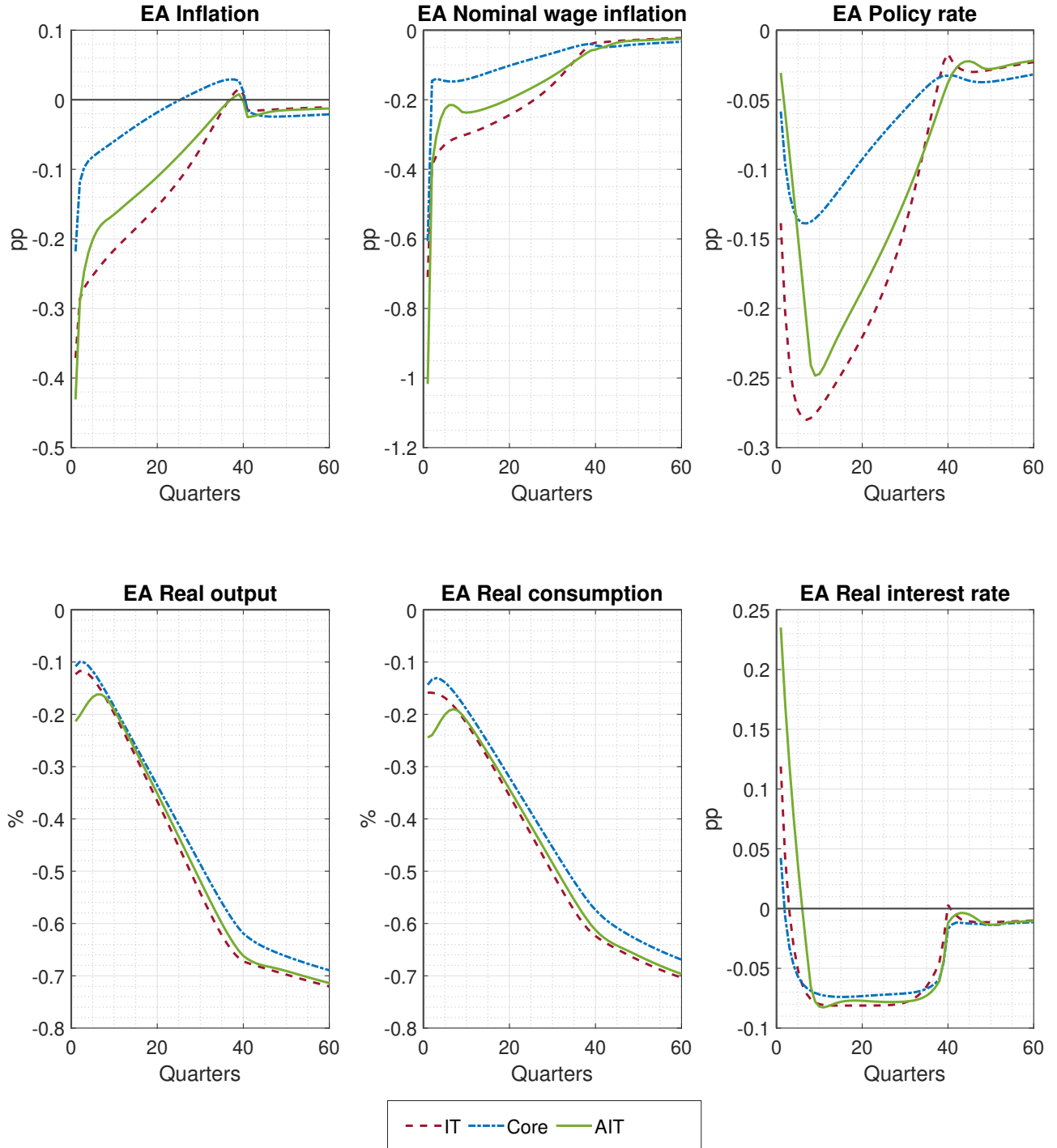
Figure 12: Permanent scenario for the euro area; monetary policy targets long-run output



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 model implies around 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

Figure 13: Permanent scenario: Monetary policy



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

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 strong positive

Box 3: Role of expectations during the transition

The green transition is likely to bring about unprecedented structural changes, accompanied by significant uncertainty. 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 14: Alternative expectations about the permanent scenario

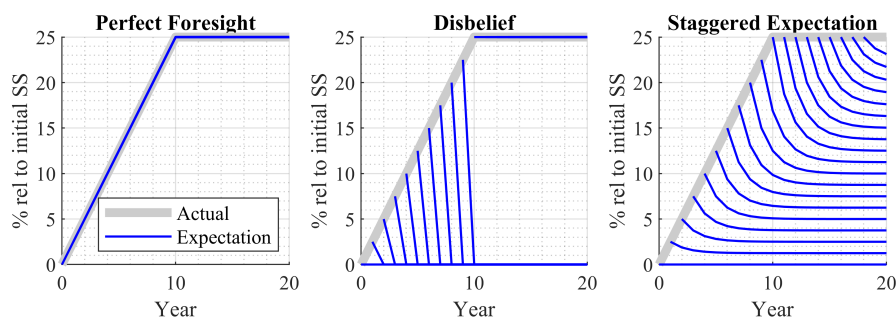
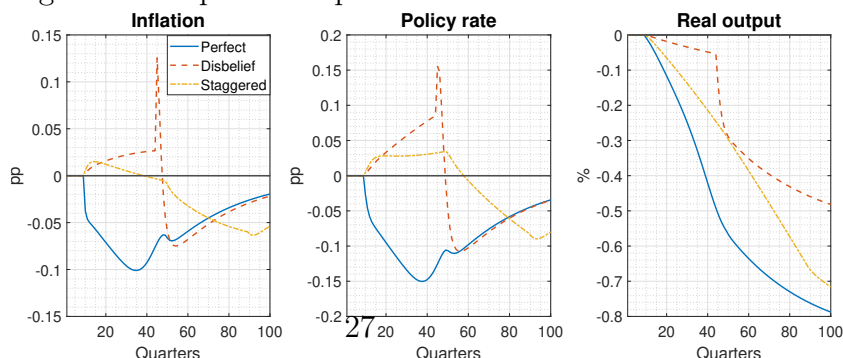


Figure 15 highlights the role alternative expectation formations for the transmission of the permanent scenario, as modelled using the BIS-MS model. First of all, the results demonstrate that the small inflation response is robust across the different expectation formations. Instead, the alternative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

Figure 15: Impact of expectation formation on the transition



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.

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 by close to -1% 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 document has presented a model comparison conducted by a group of institutions engaging in macroeconomic modelling of environmental issues in the context of monetary policy. The document 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., 2025), 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 the case of temporary shocks, alternative monetary policy rules tend to perform rather equally in terms of their responses to 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, in turn depressing economic activity more than for 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.

References

- Adolfson, Malin, Stefan Laséen, Jesper Lindé, and Mattias Villani**, “Bayesian estimation of an open economy DSGE model with incomplete pass-through,” *Journal of International Economics*, 2007, 72 (2), 481–511.
- Airaudó, Florencia S., Evi Pappa, and Hernán D Seoane**, *The green metamorphosis of a small open economy*, Vol. 219, Centre for Economic Policy Research, 2023.
- Annicchiarico, Barbara, Marco Carli, and Francesca Diluiso**, “Climate policies, macroprudential regulation, and the welfare cost of business cycles,” 2023.
- Bartocci, Anna, Alessandro Notarpietro, and Massimiliano Pisani**, “‘Green’ fiscal policy measures and nonstandard monetary policy in the euro area,” *Economic Modelling*, 2024, 136 (C).
- Beltrán, Felipe, Luigi Durand, Mario González-Frugone, and Javier Moreno**, “A preliminary assessment of the economic effects of energy and climate in Chile,” *Latin American Journal of Central Banking*, 2024, p. 100146.
- Blanchard, Olivier Jean and Stanley Fischer**, *Lectures on Macroeconomics*, Vol. 1 of *MIT Press Books*, The MIT Press, December 1989.
- Bryant, Ralph C., Peter Hooper, and Catherine L. Mann, eds**, *Evaluating Policy Regimes: New Research in Empirical Macroeconomics*, The Brookings Institution, 1993.
- Burgert, Matthias, Giulio Cornelli, Burcu Erik, Benoit Mojon, Daniel Rees, and Matthias Rottner**, “The BIS multisector model: a multi-country environment for macroeconomic analysis,” 2025. BIS Working Paper, forthcoming.
- Chafwehé, Boris, Andrea Colciago, and Romanos Priftis**, “Reallocation, productivity, and monetary policy in an energy crisis,” *European Economic Review*, 2025, 173 (C).
- Coenen, Günter, Christopher J. Erceg, Charles Freedman, Davide Furceri, Michael Kumhof, René Lalonde, Douglas Laxton, Jesper Lindé, Annabelle Mourougane, Dirk Muir, Susanna Mursula, Carlos de Resende, John Roberts, Werner Roeger, Stephen Snudden, Mathias Trabandt, and Jan in’t Veld**, “Effects of Fiscal Stimulus in Structural Models,” *American Economic Journal: Macroeconomics*, January 2012, 4 (1), 22–68.

- , **Matija Lozej, and Romanos Priftis**, “Macroeconomic effects of carbon transition policies: An assessment based on the ECB’s New Area-Wide Model with a disaggregated energy sector,” *European Economic Review*, 2024, 167 (C).
- , **Peter McAdam, and Roland Straub**, “Tax reform and labour-market performance in the euro area: a simulation-based analysis using the New Area-Wide Model,” Working Paper Series 747, European Central Bank April 2007.
- Darracq Pariès, Matthieu, Peter Karadi, Christoffer Kok, and Kalin Nikolov**, “The Impact of Capital Requirements on the Macroeconomy: Lessons from Four Macroeconomic Models of the Euro Area,” *International Journal of Central Banking*, December 2022, 18 (5), 1–50.
- Del Negro, Marco, Julian di Giovanni, and Keshav Dogra**, “Is the Green Transition Inflationary?,” Staff Report 1053, Federal Reserve Bank of New York February 2023. Revised December 2023.
- Ernst, Anne, Natascha Hinterlang, Alexander Mahle, and Nikolai Stähler**, “Carbon pricing, border adjustment and climate clubs: Options for international cooperation,” *Journal of International Economics*, 2023, 144 (C).
- Ferrari, Alessandro and Valerio Nispi Landi**, “Will the green transition be inflationary? Expectations matter,” *IMF Economic Review*, 2024, pp. 1–64.
- Gali, Jordi and Tommaso Monacelli**, “Monetary policy and exchange rate volatility in a small open economy,” *The Review of Economic Studies*, 2005, 72 (3), 707–734.
- García, Pablo, Pascal Jacquinot, Crt Lenarcic, Kostas Mavromatis, Niki Papadopoulou, and Edgar Silgado-Gómez**, “Green Transition in the Euro Area: Domestic and Global Factors,” Working Papers 816, DNB October 2024.
- Golosov, Mikhail, John Hassler, Per Krusell, and Aleh Tsyvinski**, “Optimal taxes on fossil fuel in general equilibrium,” *Econometrica*, 2014, 82 (1), 41–88.
- Gomes, Sandra, Pascal Jacquinot, and Massimiliano Pisani**, “The EAGLE. A model for policy analysis of macroeconomic interdependence in the euro area,” *Economic Modelling*, 2012, 29 (5), 1686–1714.
- Hinterlang, Natascha**, “Different effects of carbon pricing and border adjustment in Germany and Spain,” *Economic Modelling*, 2024, 141, 106840.

- , **Anika Martin, Oke Röhe, Nikolai Stähler, and Johannes Strobel**, “Using energy and emissions taxation to finance labor tax reductions in a multi-sector economy,” *Energy Economics*, 2022, 115 (C).
- , —, —, —, —, and —, “The Environmental Multi-Sector DSGE model EMuSe: A technical documentation,” Technical Papers 03/2023, Deutsche Bundesbank 2023.
- Kaldorf, Matthias and Matthias Rottner**, *Climate Minsky moments and endogenous financial crises*, BIS Working Papers 1248, 2025.
- Känzig, Diego R.**, “The unequal economic consequences of carbon pricing,” *NBER Working Paper*, 2023, w31221.
- Laxton, Douglas and Paolo Pesenti**, “Monetary rules for small, open, emerging economies,” *Journal of Monetary Economics*, 2003, 50 (5), 1109–1146.
- McCallum, Bennet T.**, “Robustness properties of a rule for monetary policy,” *Carnegie-Rochester Conference Series on Public Policy*, 1988, 29, 173–203.
- Nakov, Anton and Carlos Thomas**, “Climate-conscious monetary policy,” ECB Working Paper 2845, ECB 2023.
- NGFS**, “Climate change, the macroeconomy and monetary policy,” Technical Report, Network for Greening the Financial System 2024.
- , “Climate macroeconomic modelling handbook,” Technical Report, Network for Greening the Financial System 2024.
- Olovsson, Conny and David Vestin**, “Greenflation?,” Working Paper 420, Sveriges Riksbank May 2023.
- Pasten, Ernesto, Raphael Schoenle, and Michael Weber**, “The propagation of monetary policy shocks in a heterogeneous production economy,” *Journal of Monetary Economics*, 2020, 116, 1–22.
- Priftis, Romanos and Raphael Schoenle**, “Fiscal and macroprudential policies during an energy crisis,” Working Paper Series 3032, European Central Bank February 2025.
- Sahuc, Jean-Guillaume, Frank Smets, and Gauthier Vermandel**, “The New Keynesian Climate Model,” Working Paper 977, Banque de France December 2024.
- Taylor, John B.**, *Monetary Policy Rules* number tayl99-1. In ‘NBER Books.’, National Bureau of Economic Research, Inc, 1999.

- Timmer, Marcel P., Erik Dietzenbacher, Bart Los, Robert Stehrer, and Gaaitzen J. de Vries**, “An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production,” *Review of International Economics*, 2015, 23 (3), 575–605.
- Varga, Janos, Werner Roeger, and Jan in ’t Veld**, “E-QUEST: A multisector dynamic general equilibrium model with energy and a model-based assessment to reach the EU climate targets,” *Economic Modelling*, 2022, 114, 105911.

A Models

A.1 SEEM by Banco Central de Chile

The SEEM (Beltrán et al., 2024) extends the Neo-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 Neo-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 hydro-electricity, 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 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., 2025). 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 country), 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 either be of aggregate or 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. 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 alternative expectation formation mechanism. Burgert et al. (2025) describes the toolbox in more detail.

A.3 EMuSe by Deutsche Bundesbank

The **E**nvironmental **M**ulti-**S**ector 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.¹¹

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.¹² 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).¹³ 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.¹⁴

¹¹The model can also be extended to capture pollution abatement efforts.

¹²See, e.g., Hinterlang et al. (2022), Hinterlang et al. (2023), Ernst et al. (2023) and Hinterlang (2024).

¹³An alternative data source with more recent data are FIGARO tables provided by Eurostat.

¹⁴<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,¹⁵ 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-labour bundle. The energy composite is then utilised 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.

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¹⁵For 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 labour 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.1: Temporary scenario for CL

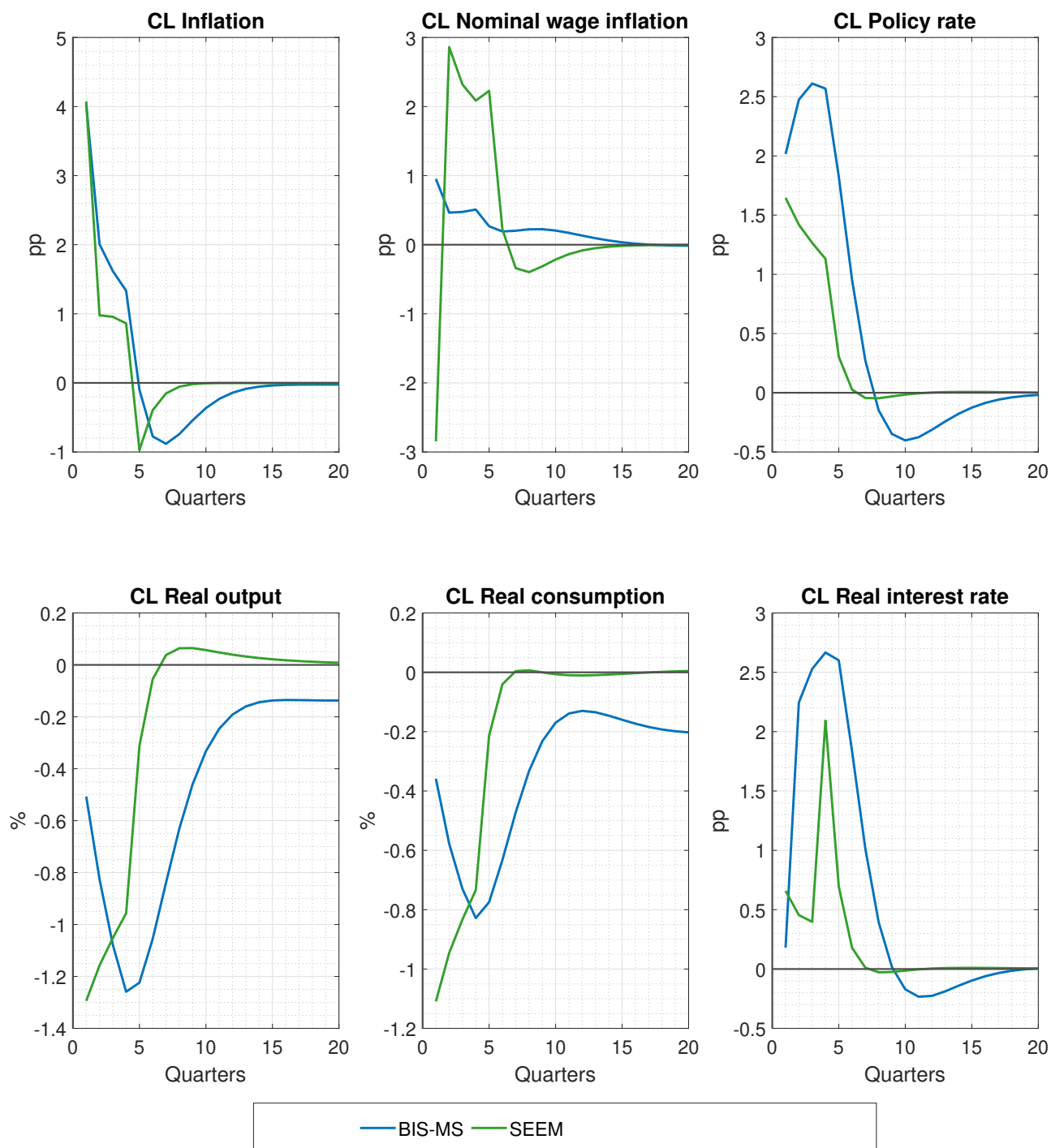
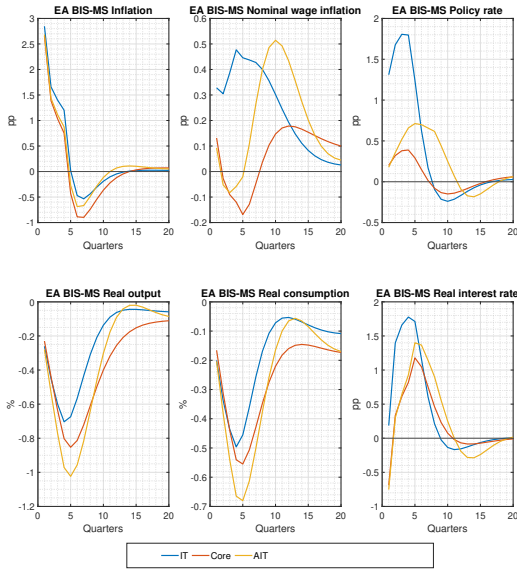
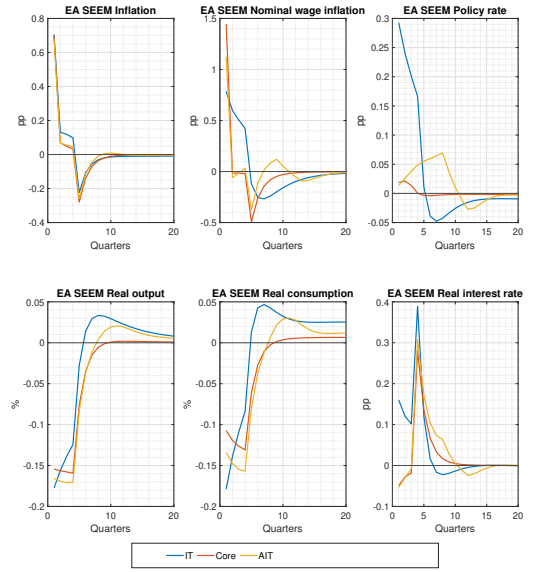


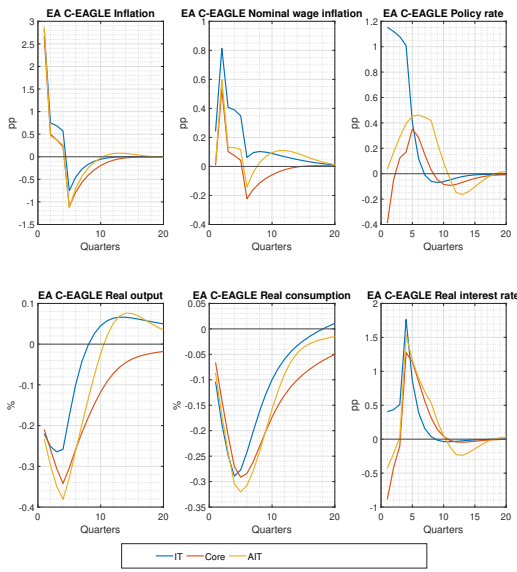
Figure B.2: Temporary scenario - Role of monetary policy for the euro area



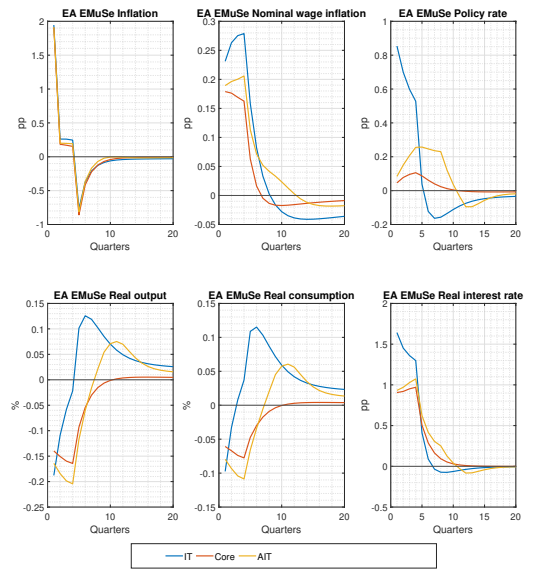
(a) BIS-MS model



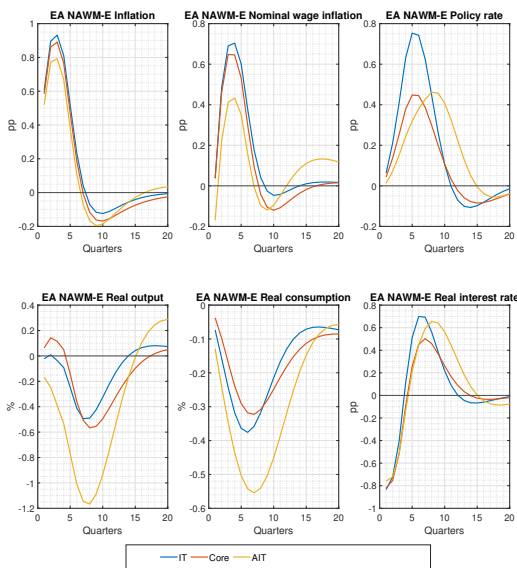
(b) SEEM model



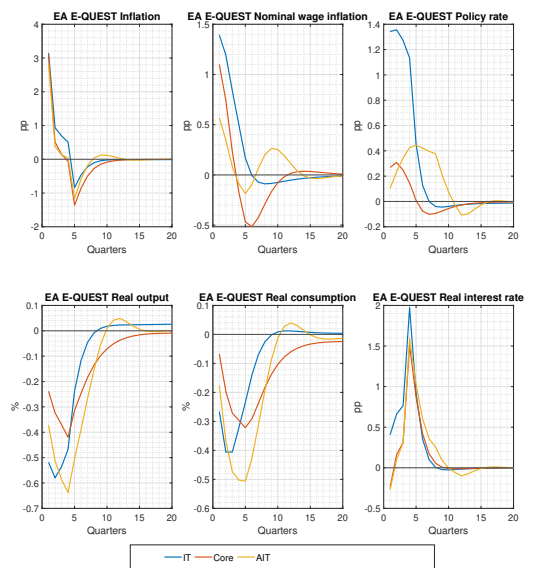
(c) C-EAGLE model



(d) EMuSe model



(e) NAWM-E model



(f) E-QUEST model

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

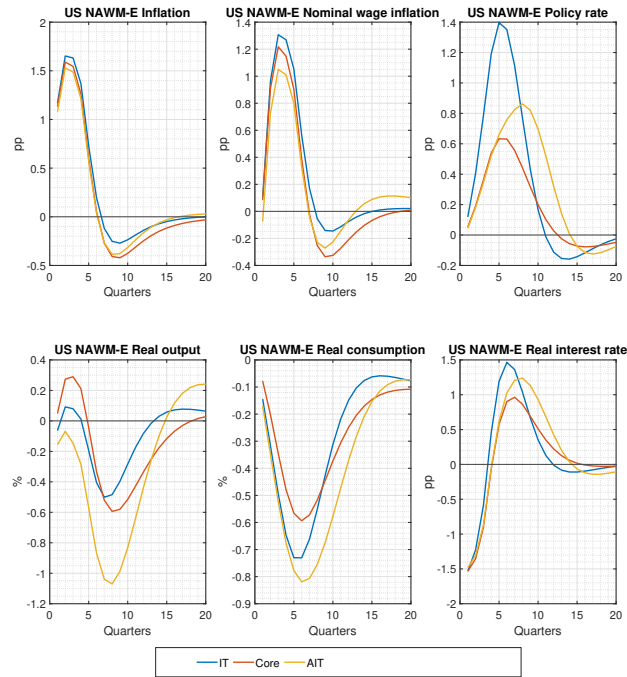
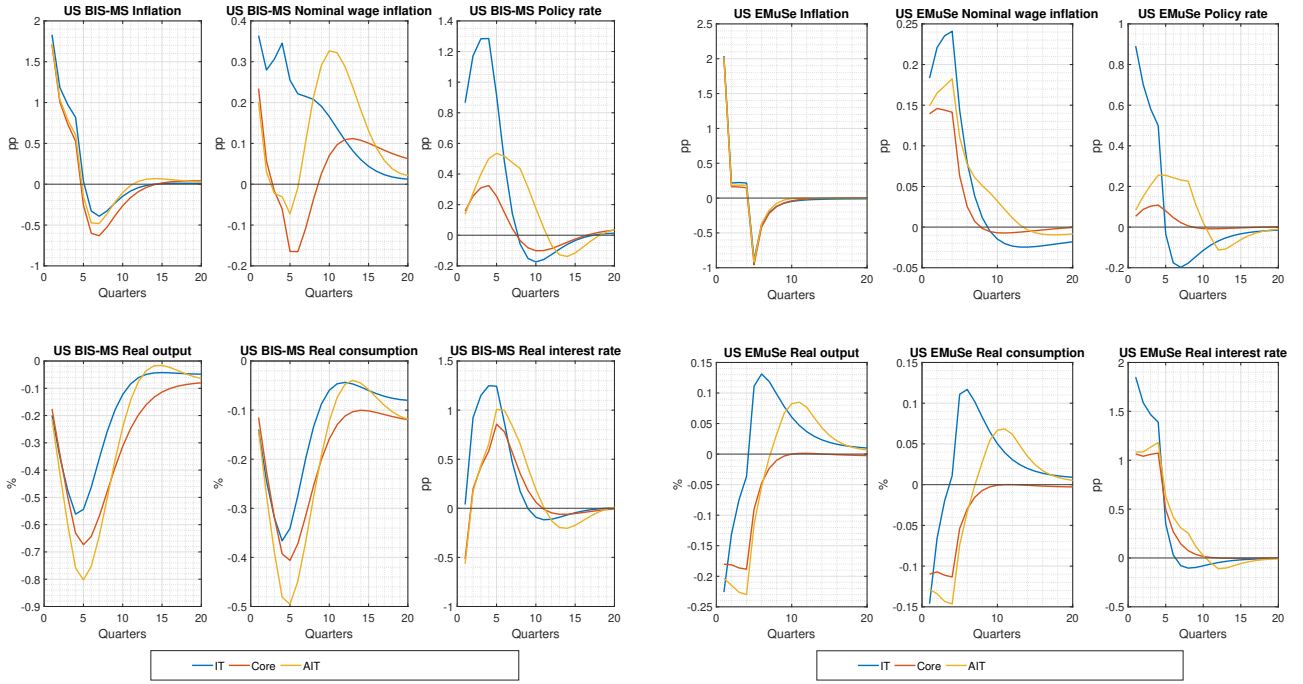


Figure B.4: Temporary scenario - Role of monetary policy for Chile

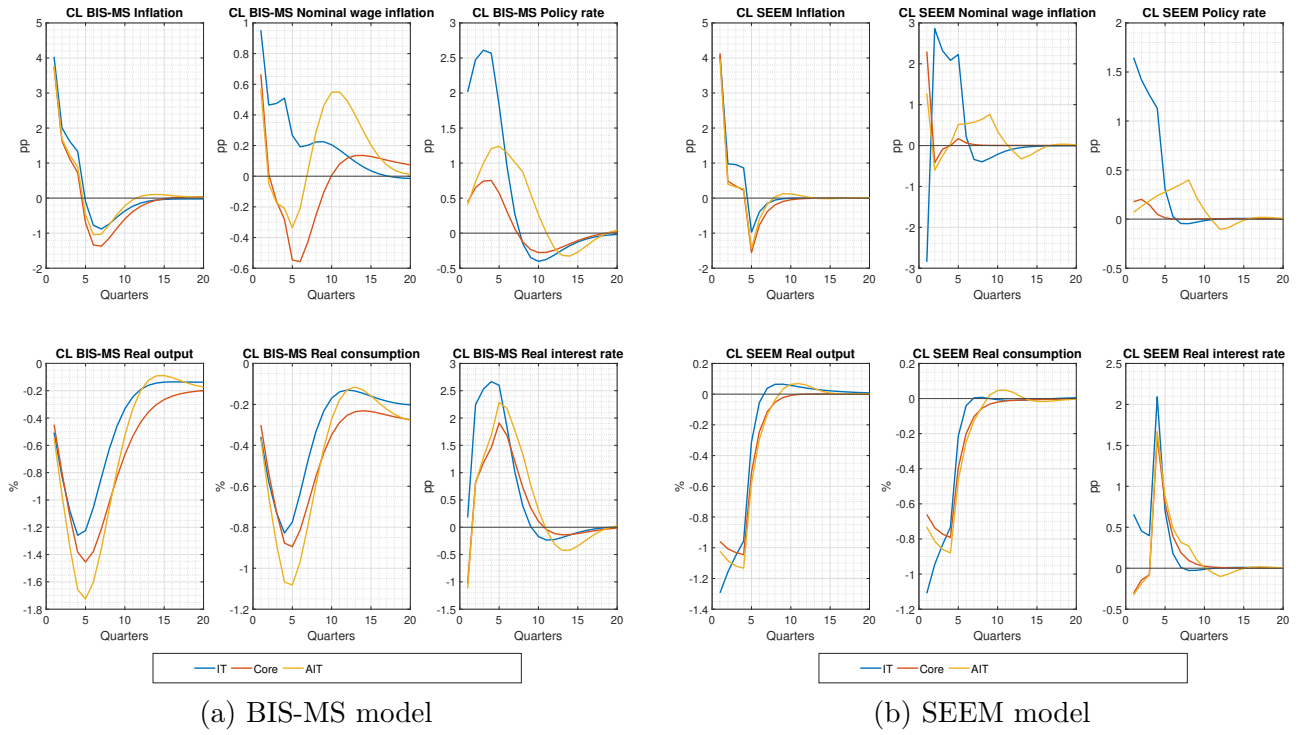
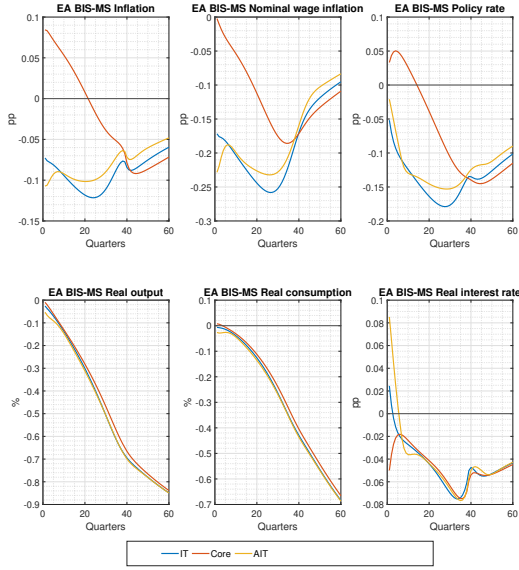
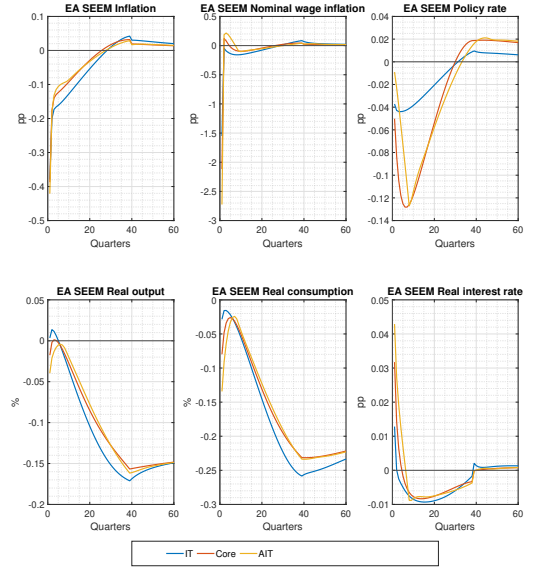


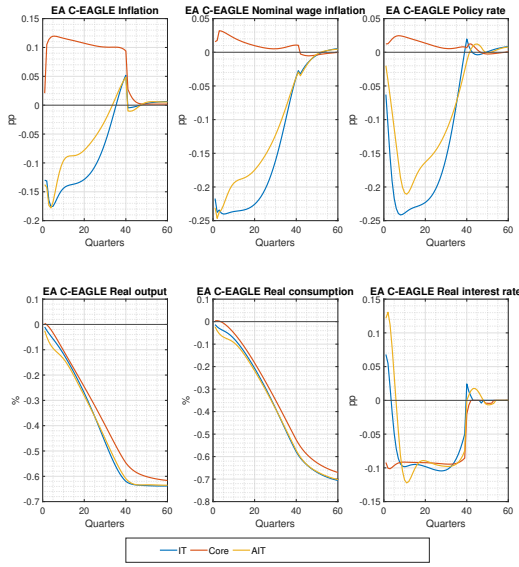
Figure B.5: Permanent scenario - Role of monetary policy for the euro area



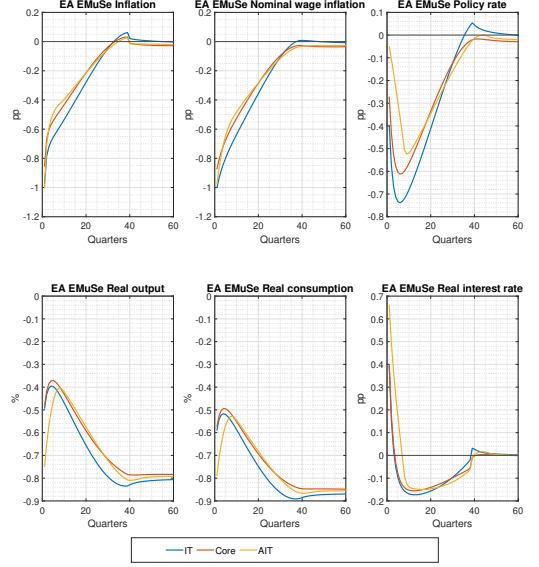
(a) BIS-MS model



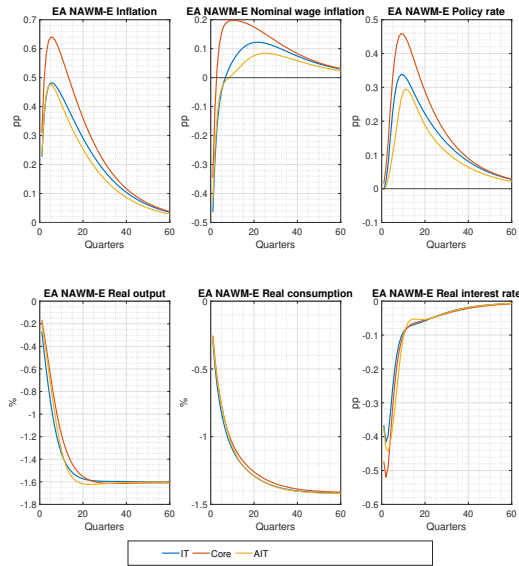
(b) SEEM model



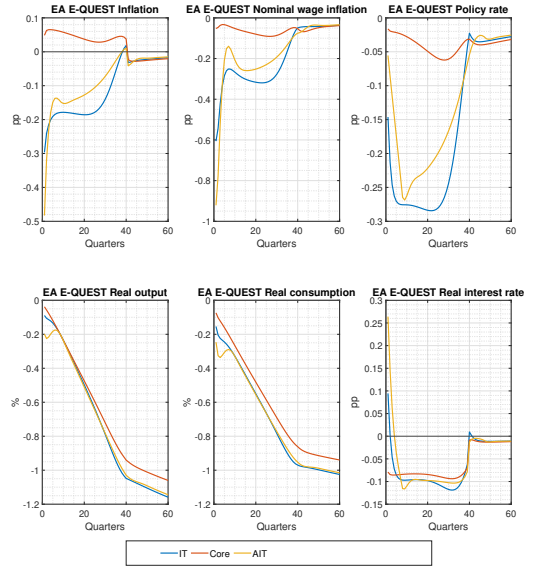
(c) C-EAGLE model



(d) EMuSe model



(e) NAWM-E model



(f) E-QUEST model

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

