Climate Scenarios Sensitivity Analysis to Macroeconomic Policy Assumptions

Technical document

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This document was prepared by:

Matthieu Darracq-Pariès[1], Stéphane Dees[2], Ian Hurst[3], and Iana Liadze[3]

1 European Central Bank
2 Banque de France
3 National Institute for Economic and Social Research (NIESR), London, United Kingdom

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Contents

Acknowledgements 2

Executive summary 3

1. Macroeconomic Policy Assumptions in NGFS Scenarios-Phase III 4

1.1. Main issues and options available 4

1.2. Comparison of alternative options through selected simulations 5

1.3. Key features of policy assumptions in shock implementation 6

2. Sensitivity Analysis to Fiscal Policy Assumptions 7

2.1. Comparison of alternative recycling options through selected simulations 7

2.2. Comparison across selected countries 8

3. Sensitivity Analysis to Monetary Policy Assumptions 10

3.1. Monetary policy constraints in adjusting its stance 10

3.2. Alternative output – inflation trade-offs reflected in monetary policy interest rate rules 11

3.3. Monetary policy rule comparison across other selected countries 12

3.4. Exploring the role of exchange rate flexibility 13

Appendix: Fiscal and Monetary Policy Setting in NiGEM 16

Bibliography 18

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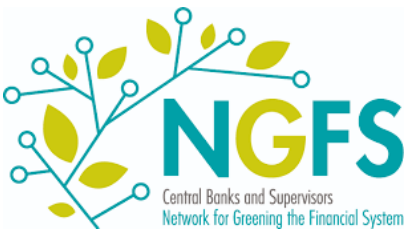


Executive summary

Mandate and scope of the analysis: NIESR started developing the climate module of NiGEM in 2018, with an aim of understanding the interactions between the macroeconomy and climate-related shocks and climate-related policy. In 2021, NIESR joined the Network for Greening the Financial System (NGFS), to contribute to the NGFS Climate Scenarios (Bertram et al., 2021). In particular, in Phase II, NiGEM has complemented the detailed energy modelling of the Integrated Assessment Models (IAMs) used by the NGFS to provide greater macroeconomic detail and to elaborate the macroeconomic policy channels (for more details about NiGEM, see Hantzsche, 2018).

The role of macroeconomic policy assumptions in NGFS scenarios has attracted a lot of attention, as they are part of the narratives which conditions the climate scenarios. The set of policy settings has therefore been carefully explored in order to design the policy conditionality of the Phase III scenarios. Moreover, to assess the sensitivity of the results to assumptions related to fiscal and monetary policy, this document also reports an analysis conducted through the lens of the NiGEM model (using REMIND-MAgPIE inputs), giving alternative scenarios according to different policy options.

Revisiting the policy settings for the macroeconomic scenarios in phase III: Reviewing the policy conditionality of the scenarios has led us to change its model-based implementation. The main findings of this review are:

- ✓ *Policy environment continues to play an important role in scenario setup and interpretation of the impact of climate change shocks on the economies.*
- ✓ *There is always a trade-off between inflation and GDP from any carbon tax recycling program and the recycling option chosen should reflect the narrative for the climate scenario under consideration*
- ✓ *As in Phase II, climate change transition shocks are split into transition only and fiscal policy shocks. However, in Phase III, we improved the consistency of implementing the various carbon tax recycling options available as well as providing greater standardisation of the transition only shocks.*

Sensitivity analysis on stabilization policies: The second objective of the exercise has led us to design a conceptual and analytical roadmap for the sensitivity analysis regarding fiscal and monetary policy. This document therefore includes several simulations including some features of selected scenarios under alternative fiscal as well as monetary policy conduct, and focusing on relevant regional effects. The sensitivity analysis is undertaken around the Phase II shocks for net zero scenario.

The main findings of these simulation exercises are:

- ✓ *Different ways of carbon tax revenue recycling have different impact on the economic variables both in the short and the long term*
- ✓ *Depending on the type of monetary policy environment chosen, it can mitigate as well as amplify the effects of fiscal policy*

This document is structured as follows: Section 1 presents the macroeconomic policy assumptions in the NGFS scenarios. Section 2 provides a sensitivity analysis to fiscal assumptions chosen. Section 3 analyses the sensitivity of scenarios to monetary policy assumptions.

1. Macroeconomic Policy Assumptions in NGFS Scenarios Phase III

This section reviews the main issues identified during Phase II and how they have been accounted for in Phase III.

1.1. Main issues and options available

The option used in Phase II considered the output from the transition as a full combination of the carbon price shock (introduced as a carbon tax in NiGEM) along with a fiscal shock. In this option, labelled "Linked", all energy effects are provided by the carbon price only and the budget position is driven by the recycling option. All recycling choices share a common environment (i.e. the same set of key simulation options, regarding for instance expectations or monetary policy rules) and can be implemented, together with the carbon price increase, in a single shock. In Phase II shock implementation, energy sector changes due to transition shock come only from input derived from IAM models (see Bertram et al., 2021, for technical details about the implementation), and the resulting carbon tax revenue recycling is run with adaptive expectations. Finally, it was chosen to exogenise monetary policy so that the fiscal impact remain unaffected by central bank's reaction (i.e. the central bank does not react to the fiscal shock).

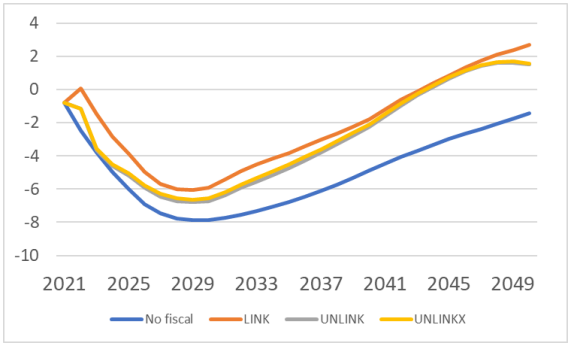
The policy setting retained for Phase II featured a number of issues. First, the exogenisation of monetary policy creates persistent increases in inflation that are not compatible with central banks' mandates. As an alternative, monetary policy could be left endogenous, somewhat mitigating the inflationary impact of the fiscal shock. However, using adaptive expectations as well as shock implementation in one environment, which restricts availability of instruments per shock, leads to continually deteriorating budget position and unsustainably large budget deficits. Finally, a last issue concerned the behaviour of short and long-term interest rates, whose non-stationary dynamics were difficult to justify on economic grounds.

For Phase III, an alternative option, labelled "Unlinked", has been considered and implemented. In this option, the carbon tax increase and its recycling are considered as distinct, separate shocks but the link between them remains based on revenue provided by the tax. Simulating the scenarios with distinct shocks enables to identify the contribution of each shock separately, disentangling for example the role of the transition shock independently from the alternative tax recycling options. Moreover, in order to ensure that the link to IAM output is maintained, the energy sector in NiGEM, which by default is endogenous, has been set exogenous, therefore fully reflecting changes in energy mix coming from IAMs. In the new setting, the carbon tax revenue recycling is treated as rational, meaning that – unlike Phase II simulation output – NiGEM has been used with its forward-looking mode based on model-consistent expectations. Finally, monetary policy has been kept endogenous, coping with issues related to inflation persistence and unrealistic interest rate path as previously identified.

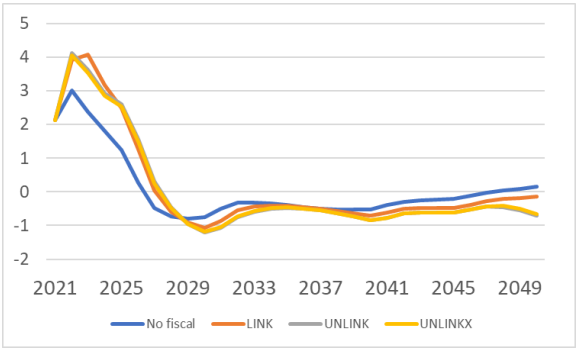
Although the "Unlinked" option increases the solution time (due to the use of the model in its rational expectation mode), it offers a greater flexibility of the policy shock applied and, from the use of the model, a setting which is more "standard" for NiGEM with all channels working within the model. This improves the tractability of implementing recycling options from the carbon tax revenues across various combinations of fiscal instruments.

Figure 1: Implications of alternative options for the US economy under the Net Zero 2050 scenario (all revenues are recycled through public investment)

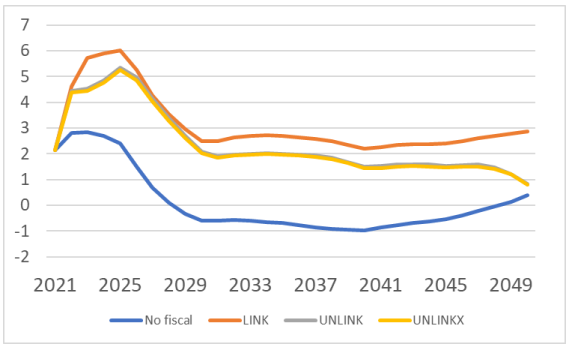
GDP (% deviation from baseline)



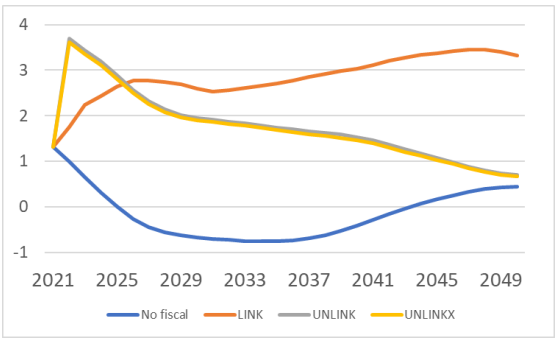
Inflation (p.p. deviation from baseline)



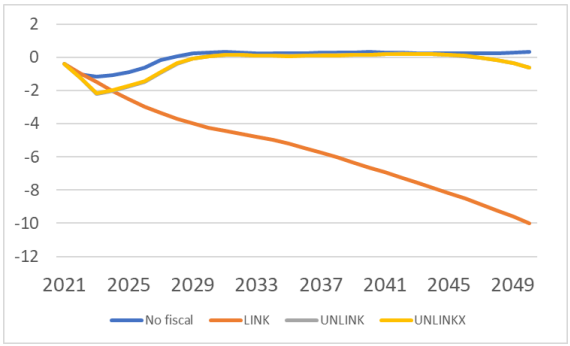
Short-term interest rate (p.p. deviation from baseline)



Long-term interest rate (p.p. deviation from baseline)



Budget position (p.p. deviation from baseline)



Note: the following options are simulated:
No Fiscal: reference shock - carbon price only
LINK: adaptive expectations, monetary policy endogenous
UNLINK: rational expectations, energy sector endogenous
UNLINKX: rational expectations, energy sector exogenous (OFF)
The results are reported in deviation from a baseline scenario which is a combination of the NiGEM v1.22 and IAM starting values for GDP and population. It also includes IAM current policy projections for energy. No transition or physical climate risks are included in this baseline forecast.

1.2. Comparison of alternative options through selected simulations

To assess how the two alternative options ("Linked" and "Unlinked") impact the final results, we have tested them using the NetZero 2050 scenario. Concerning the "Unlinked" option, we consider both the case where the energy sector remains endogenous in NiGEM ("UNLINK") and the case where we exogenise it by sticking to IAM output as far as energy input is concerned ("UNLINKX"). The latter case is the one that have been retained in Phase III final results. The purpose of this exercise is to check the sensitivity of the main variables to the various options and investigate whether the undesirable results observed with Phase II output have disappeared. To complete the comparison, we also include the scenario results without the fiscal recycling shock ("No fiscal"). The simulations are conducted using the Phase II shocks for net zero scenario (in particular, carbon price, fossil fuel consumption and useful energy shocks).

On GDP and inflation, no large discrepancy can be observed (see Figure 1). Assuming that all revenues are recycled through public investment, the NetZero 2050 yields a decline in GDP and an increase in inflation. Note that – unlike Phase II output – monetary policy has been assumed endogenous in all cases, which explains why the inflationary response is not persistent and returns to baseline after 5-7 years. The impact on GDP is reduced over time and returns at a slightly positive level by mid-2040s. The response of monetary policy is slightly more restrictive in the case of the "Unlinked" options with respect to the "Linked" one.

More importantly, the "Unlinked" setting features more satisfactory results as regards to long-term interest rates and the budget position. With the "Linked" option, long-term interest rates increase permanently and the budget position deteriorates further without any adjustment towards an equilibrium. By contrast, the "Unlinked" options all feature a more appropriate behaviour of long-term interest rates and budget positions with some stabilization of both variables in the long term.

1.3. Key features of policy assumptions in shock implementation

To sum up, among the various options described above, Phase III scenarios all include the following features regarding the use of NiGEM:

The macroeconomic results have been used with the "Unlinked" option with energy sector exogenous. Carbon tax increase and its recycling are therefore considered as distinct, separate shocks but the link between them remains based on revenue provided by the tax. Other final specifications of the model include the following options:

- Endogenous monetary policy, implying more realistic output-inflation paths
- Exogenous energy sector, which does not significantly affect the main variables of interest, while maintaining a close link with the energy components simulated with the IAMs
- Fiscal revenues are assumed – as in Phase II – to be recycled with higher government investment (for 50%) and public debt reimbursement (for 50%) in the Net Zero 2050 scenario. Different recycling options are chosen for disorderly scenarios (see main document for details).
- Use of rational expectations, giving a greater congruence of the policy environment used and allowing to take into account exchange rate movement

As shown above, this option has the advantage to activate monetary policy reaction without the undesirable effects on budget position and long-term interest rates observed in Phase II scenarios (which was mainly related to the inconsistent use of rational versus adaptive expectations across the scenarios and simulation legs).

2. Sensitivity Analysis to Fiscal Policy Assumptions

The sensitivity analysis is undertaken around the Phase II shocks for net zero scenario (in particular, carbon price, fossil fuel consumption and useful energy shocks). In this section, we propose a sensitivity analysis according to the fiscal revenue recycling options, thereby discussing the available options within NiGEM and providing a greater in-depth review than available under Phase II. We first compare the impact of the various options on key macroeconomic variables before showing how such effects differ across countries.

2.1. Comparison of alternative recycling options through selected simulations

Four different options are considered to recycle carbon tax revenues. To correctly differentiate the impact of recycling choices, we assume in this sensitivity analysis that, for each variant, 100% of carbon tax revenues are used to finance each of the four fiscal policy choices:

- an increase in public investment
- a cut in taxes applied to private sector agents
- an increase in transfers to households
- the reimbursement of public debt

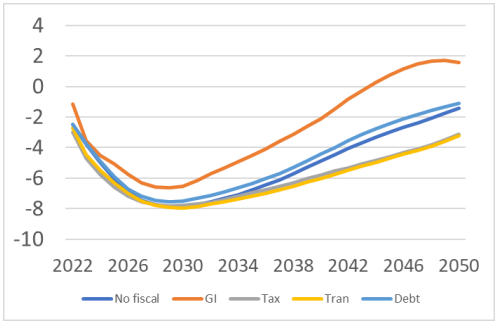
The policy conditionality for the simulations follows the "Unlinked" option (with exogenous energy sector), as presented above. In particular, NiGEM is used assuming rational expectations and endogenous monetary policy. Moreover, solvency rules are activated except for public debt, which implies that the debt-to-GDP ratio may permanently deviate from its initial position. For the sake of comparison, the reference shock, the increase in carbon price, without the corresponding fiscal shock is also included in the analysis ("no fiscal").

Figure 2 shows the sensitivity of the Net Zero 2050 scenario to fiscal policy options for key macroeconomic variables. The results shown focus on the U.S. economy (comparison with other economies is presented below). Overall, we can notice relatively limited differences across recycling options. The shock triggers negative effects on activity and positive effects on inflation in the short term. However, the monetary policy reaction differs according to the fiscal policy choice underlying that the need for macroeconomic stabilisation is somehow differentiated. More precisely, among the four options, a full recycling through higher public investment leads to the most beneficial effects on GDP, which become positive around 2040, while the other options cannot fully absorb the negative shock coming from higher carbon prices. Among the fiscal instruments considered, government investment has indeed the stronger output multipliers as it directly affects final expenditures. It also affects long-run potential output through higher capital stock (although without direct impact on technological progress). As a result, in the short term, the inflationary impact is also the strongest, with a 4 percentage point increase from baseline. All the other options lead to a rise in inflation (around 3 p.p.) but, in all cases, inflation returns to baseline within a 5-year period following the carbon price increase.

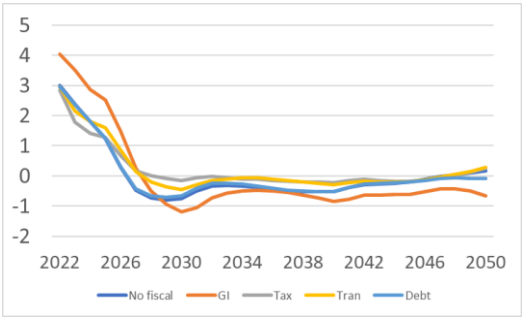
The inflationary pattern, which seems reasonable, can be explained by the monetary policy reaction. Figure 2 shows that the recycling option matters as far as the tightening degree is concerned. When recycling is conducted only through higher public investment – i.e. the option with the largest stimulus – the increase in short-term interest rates is the largest, by around 400 to 500 basis points. Moreover, such a policy stance remains tight until the end of the horizon. By contrast, the other options, while all requiring interest rates hikes (by around 200 basis points), yields less tightening. With the option to recycle revenues by reimbursing public debt, interest rates return to baseline quickly (after 5 years), while for the options implying higher transfers or tax cuts, interest rates remain permanently higher (by around 50 basis points). The patterns observed for short-term interest rates also explain the differences across recycling options concerning long-term interest rates.

Figure 2: Implications of alternative Fiscal revenue cycling options for the US economy

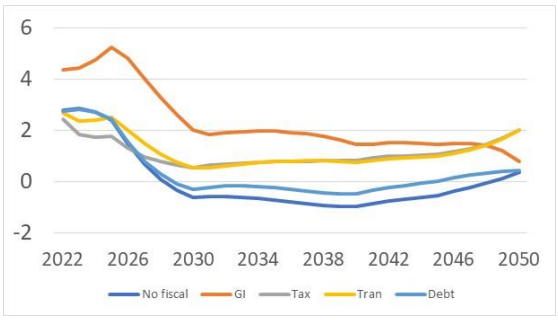
GDP (% deviation from baseline)



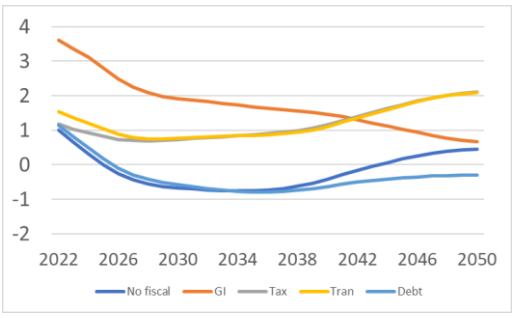
Inflation (p.p. deviation from baseline)



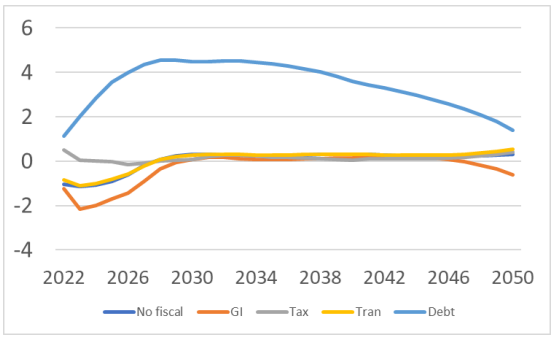
Short-term interest rate (p.p. deviation from baseline)



Long-term interest rate (p.p. deviation from baseline)



Budget position (p.p. deviation from baseline)



Note: **No Fiscal**: reference shock - carbon price only; **GI**: recycling through public investment; **Tax**: recycling through income taxes; **Tran**: recycling through transfers; **Debt**: paying off debt.

The results are reported in deviation from a baseline scenario (Fig.1 notes for details).

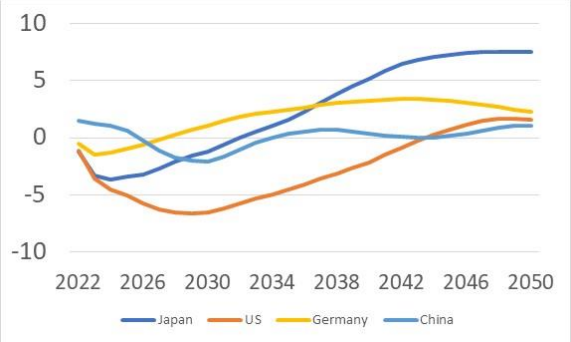
Finally, regarding the budget position, we observe the largest deterioration when the revenues are recycled through higher public investment, followed by the option involving transfer increases. The recycling through tax cuts keeps budget neutrality. It is worth mentioning that the impact on the budget results both from the exogenous shock based on carbon tax revenues and from the endogenous (model-based) reaction on taxes from the deteriorating economic environment following transition shocks (automatic stabilisers).

2.2. Comparison across selected countries

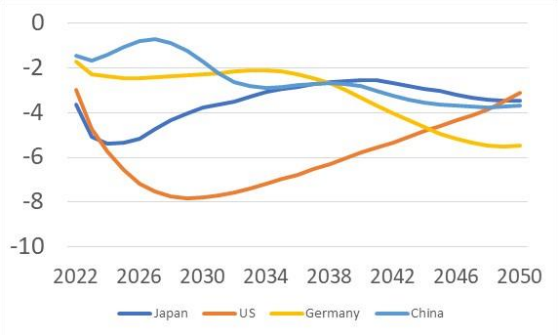
Figures 3 offers a comparison of our sensitivity analysis across selected countries. In addition to the U.S., we also include the results for Germany, Japan and China. We focus here on the impacts on GDP only. In terms of GDP, the US appears more negatively affected relative to the other three countries. Such a heterogeneity across countries may be explained inter alia by the degrees of energy intensity or lower carbon price levels. All recycling options, except public investment, leads to negative effects in the short to medium term, gradually converging to neutral impacts by 2050. Notice that Fiscal revenues available for recycling generally peak around 2030 and by the end of the simulation horizon, get close to zero, in line with the profile of the scenario design.

Figure 3: GDP impact of various fiscal revenue cycling options for selected economies (% deviation from baseline)

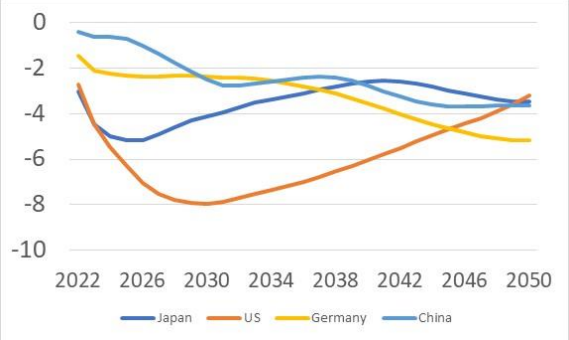
Public investment



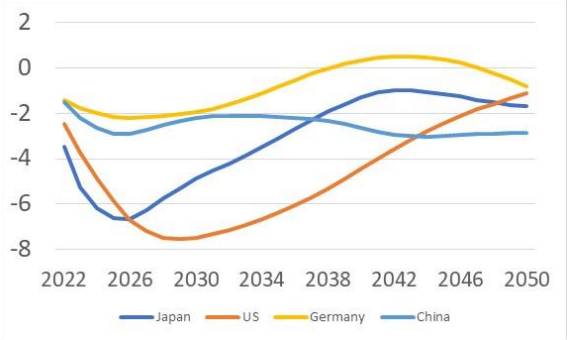
Tax cut



Transfers



Debt reduction (no recycling)



Recycling through public investment brings the strongest stimulus to economic activity. Such an option yields even positive impacts on GDP for Germany and Japan, where the shock leads in the latter case to a 7% increase in GDP by 2050 compared to baseline. In the cases of tax cuts or transfers, despite different short- to medium-term dynamics, the long-term impact is rather similar across countries with a permanent decline in GDP by around 3-4% compared to baseline. In the case of China and Germany, the short-term reaction is rather muted while it exhibits strongest negative changes for the U.S. and, to a lesser extent, Japan. Finally, using carbon tax revenues to reduce public debt yields to broadly neutral impacts in the long-term, especially in the case of Germany and the U.S. where the impact of the shock on GDP gradually disappears over time.

3. Sensitivity Analysis to Monetary Policy Assumptions

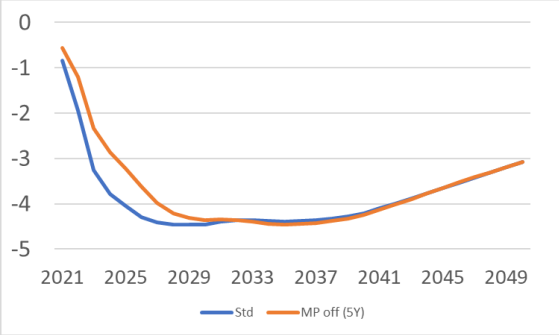
In this section, we analyse the sensitivity of the scenario results to monetary policy assumptions. As earlier, we use the "Unlinked" simulation setting, combining two independent shocks: a carbon price increase, simulated with rational expectations and by deactivating fiscal solvency rules or revenue recycling; and a fiscal shock, corresponding to the effects of fiscal revenue recycling, with rational expectations and exogenous energy sector. Moreover, we assume in this sensitivity exercise equal shares of recycling between tax, transfers, govt. investment and debt.

3.1. Monetary policy constraints in adjusting its stance

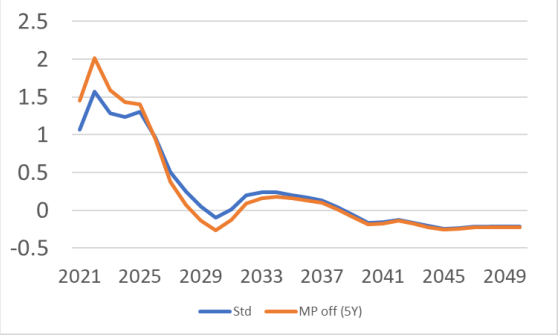
We first consider that the policy interest rate is kept at its baseline level for the first 5 years of the scenario. The 2-pillar monetary policy rule (standard rule in NiGEM) is assumed for (most) countries. The 2-pillar strategy sets the short-term interest rate as a function of the ratio of the nominal GDP target to nominal GDP and the difference between inflation expectations and the inflation target (see also the Appendix for further detail). The carbon price and fiscal shocks use the same MP environment.

Figure 4: Implications of a temporary exogenisation of the policy interest rate for the US economy

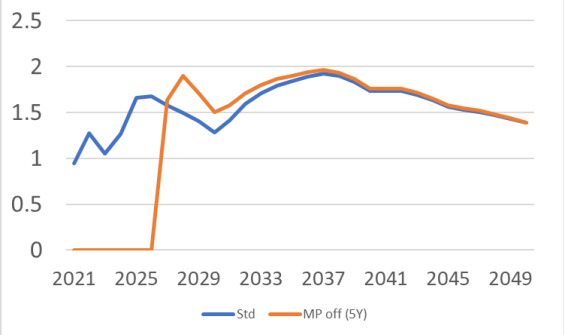
GDP (% deviation from baseline)



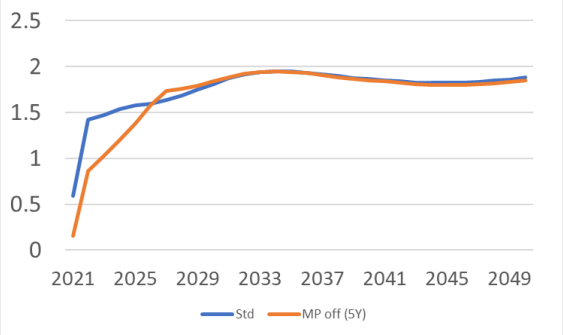
Inflation (p.p. deviation from baseline)



Short-term interest rate (p.p. deviation from baseline)



Long-term interest rate (p.p. deviation from baseline)



Note:
Std: **2-pillar monetary policy interest rate rule (except for the economies that are pegged to the US dollar)**
MP off (5Y): the monetary policy rate is assumed to remain at its baseline level for the first 5 years of the simulation

The temporary exogenisation of the monetary policy rate reduces slightly the negative effects of the carbon price shock to GDP (by 1 percentage point at most) before converging to the fully endogenous case at the end of the 5-year period. Similarly, the increase in inflation in the short-term is slightly stronger with this temporary exogenisation of monetary policy. The relatively limited differences between the standard and the temporarily exogenous monetary policy simulations are mainly explained by the rational expectation assumptions that lead agents to anticipate the further tightening action, five years after the shock. This expectation effect can be noticed

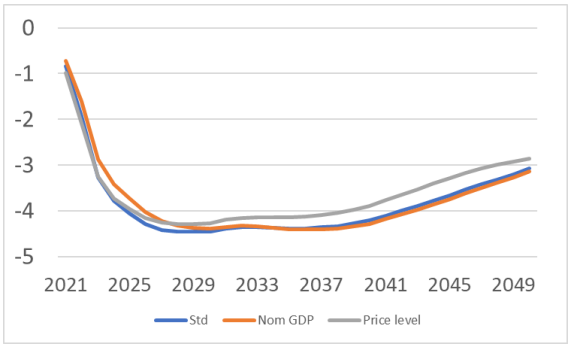
for instance in the reaction of long-term interest rates that increases right after the shock, although to a lesser extent than in the standard case.

3.2. Alternative output – inflation trade-offs reflected in monetary policy interest rate rules

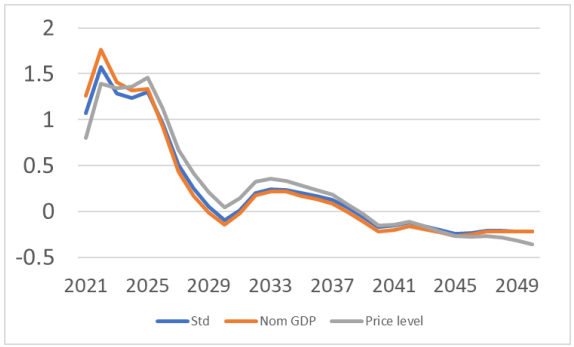
The second sensitivity analysis considers alternative monetary policy interest rate rules. The standard 2-pillar rule is compared to nominal GDP targeting and price level targeting.

Figure 5: Implications of alternative monetary policy rules for the US economy

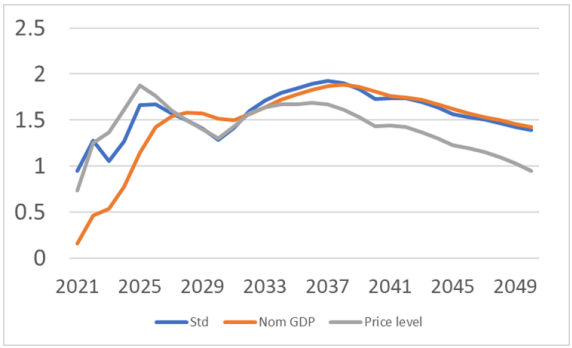
GDP (% deviation from baseline)



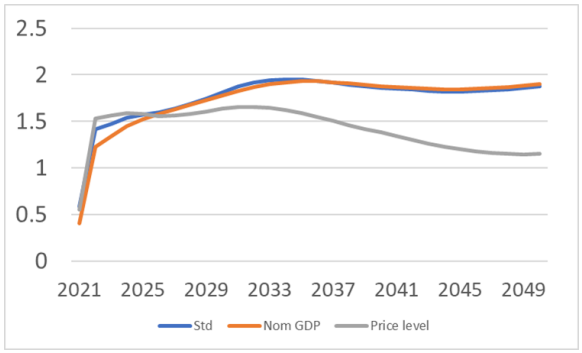
Inflation (p.p. deviation from baseline)



Short-term interest rate (p.p. deviation from baseline)



Long-term interest rate (p.p. deviation from baseline)



Note:
Std: 2-pillar monetary policy interest rate rule
Nom GDP: monetary policy interest rate rule targeting nominal GDP
Price level: monetary policy interest rate rule targeting the price level

On GDP and inflation, the differences remain overall marginal, with the price level targeting being slightly less negative on activity in the medium to long run at the expense of a slightly higher inflation response. Larger differences can be observed on interest rates though. The 2-pillar strategy and the price level targeting leads to the strongest reaction in short-term interest rates in the first 5 years, while nominal GDP targeting leads to more gradual monetary policy reaction. In the long-term however, the nominal GDP targeting reaction converges towards the standard one, whereas price level targeting implies a slightly lower interest rate increase. Similar reactions can be observed on long-term interest rates.

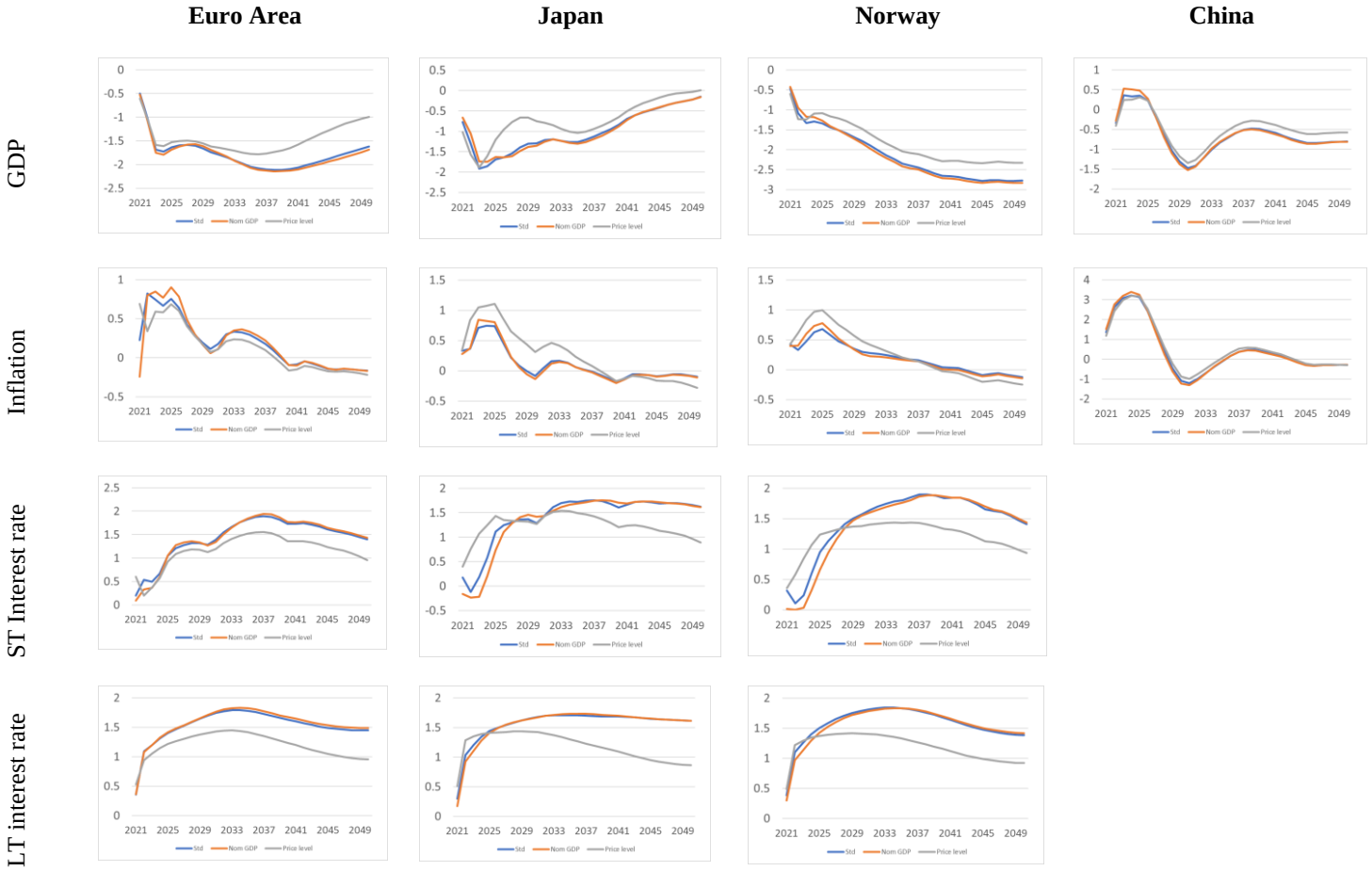
3.3. Monetary policy rule comparison across other selected countries

To complement the previous results that focused the sensitivity analysis on the U.S. economy only, we consider here similar exercises for four additional countries or zones, namely the euro area, Japan, Norway and China. The parameters for the alternative monetary policy rules are calibrated with country-specific values, in line with the benchmark 2-pillar policy rules of NiGEM. The results include the following assumptions:

- EMU – aggregate of full and reduced country models with a common MP, floating exchange rates
- Japan – full country model outside EMU, floating country-specific exchange rates
- Norway – reduced country model, outside EMU, oil exporter and floating exchange rates
- China – full country model outside EMU, pegged to the US by default

As for the U.S., the price-level targeting option leads to slightly less negative impacts on GDP while being slightly more inflationary over the first half of the simulation horizon, which is the most noticeable in the case of Japan and Norway (Figure 6). In these two counties, short-term interest rates increase faster when the central bank target price levels in the first years, while the reaction tends to be more muted over time. For the euro area, the price-level targeting rule delivers both higher GDP and lower inflation than under the alternative policy rules: this is mainly due to the nominal exchange rate adjustment, whereby the euro relative appreciation compared with the other policy rules is more pronounced than for the other countries. More generally, with the standard and the nominal targeting rules, short-term interest rates tend to increase more gradually but reach higher levels in the long term (between 150 and 200 basis points). The same applies to long-term interest rates reactions. Finally, China is not sensitive to the choice of monetary policy rules as the Chinese currency is assumed to be pegged to the US dollar. We relax this assumption in the next subsection.

Figure 6: Implications of alternative monetary policy rules for other selected economies



Note:
GDP - % diff. from base; Inflation and interest rates – percentage point diff. from base
Std: 2-pillar monetary policy interest rate rule
Nom GDP: monetary policy interest rate rule targeting nominal GDP
Price level: monetary policy interest rate rule targeting the price level

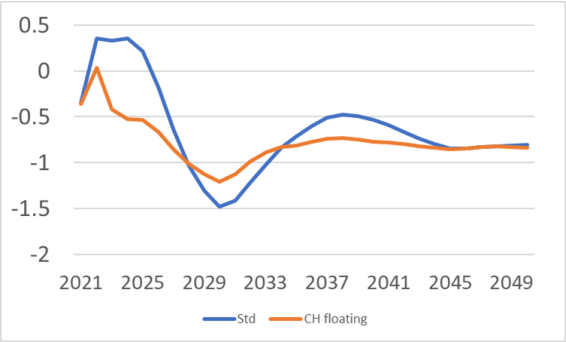
3.4. Exploring the role of exchange rate flexibility

In our last experiment, we explore the role of exchange rate flexibility on the scenario results. We first consider that the Chinese exchange rate is either pegged to the US dollar (default) or uses the 2-pillar rule (floating exchange rate). The 2-pillar monetary policy rules (standard) is also assumed for (most) countries. As in previous exercises, the carbon price and the fiscal shocks use the same monetary policy environment.

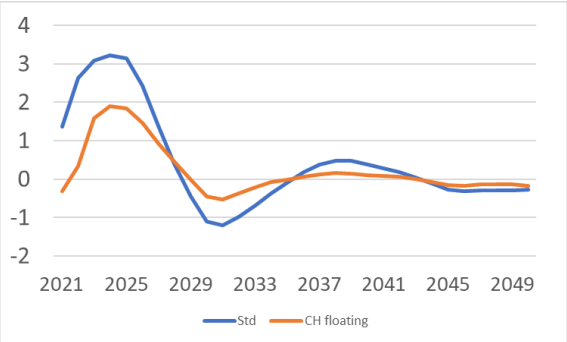
Letting the Chinese currency to float leads to more muted reactions of GDP and inflation to the carbon price and fiscal shocks. As expected, the exchange rate movement acts therefore as a shock absorber. However, in the long term, the impact of the shocks is similar whatever exchange rate regime chosen. By contrast, the exchange rate flexibility implies stronger reaction of China's monetary policy. Short-term interest rates have to be tightened more aggressively, though in a rather gradual manner compared to the standard case, over almost 10 years. Long-term interest rates share a similar pattern.

Figure 7: Implications of exchange rate flexibility for the Chinese economy

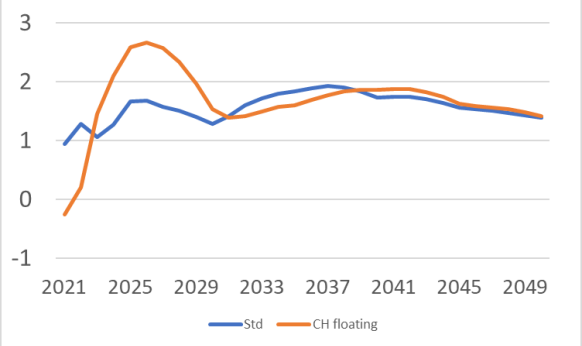
GDP (% deviation from baseline)



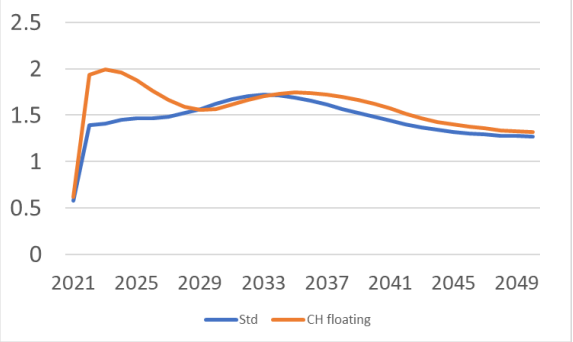
Inflation (p.p. deviation from baseline)



Short-term interest rate (p.p. deviation from baseline)



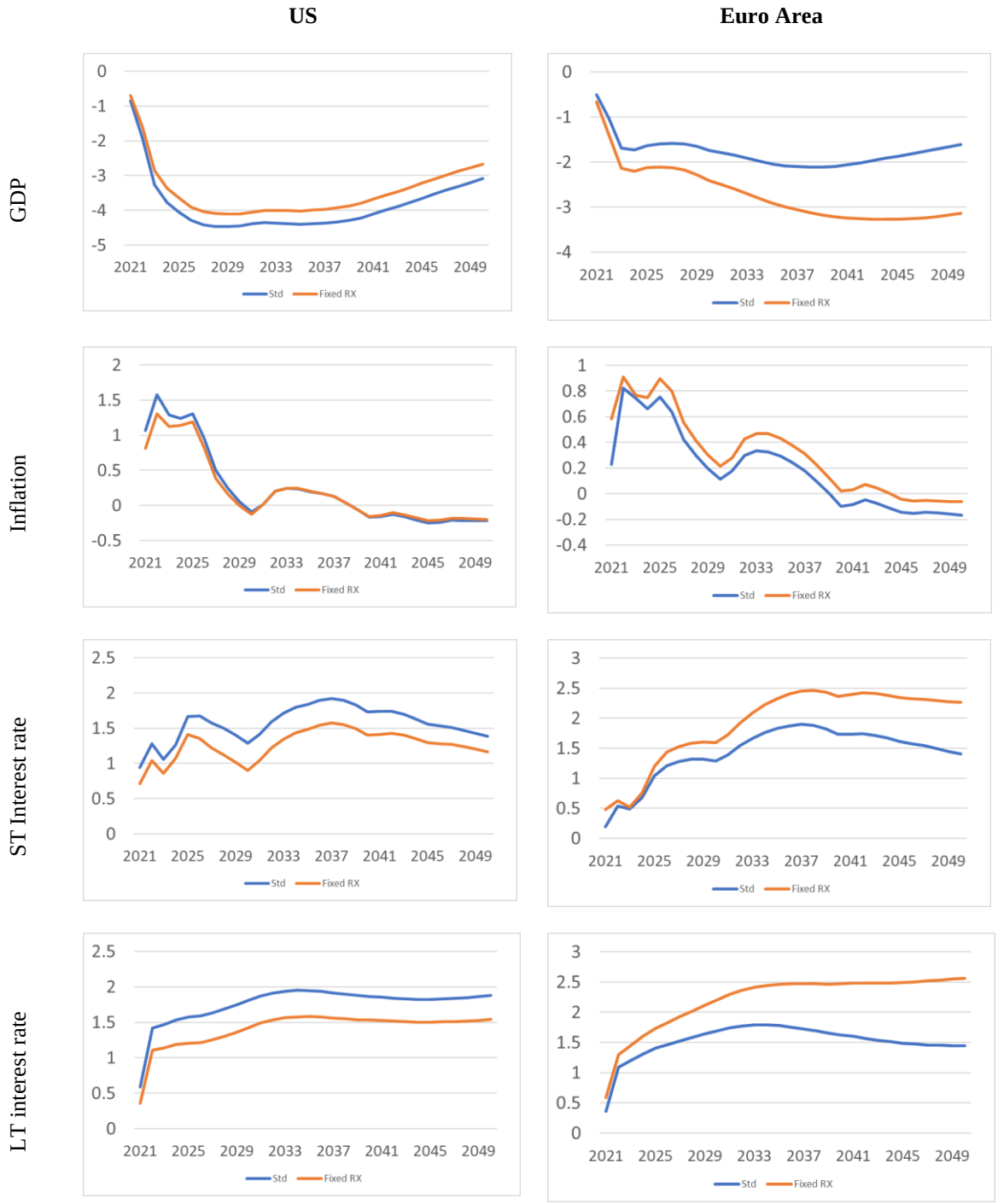
Long-term interest rate (p.p. deviation from baseline)



Note:
Std: exchange regime pegged to the US dollar
CH floating: 2-pillar monetary policy interest rate rule and exchange rate flexibility

Finally, we also contrast floating versus fixed exchange regimes for the US and the euro area (Figure 8). In this last exercise, we use the standard (2-pillar) monetary policy rules for monetary policy reaction. A fixed exchange rate regime seems to limit the negative effects of the carbon price increase to economic activity in the U.S. while it deteriorates further GDP in the euro area case. By 2050, euro area real GDP is lower by more than 1.5 percent in the fixed exchange rate regime compared to the floating one. On inflation, exchange rate flexibility has very marginal impact in the U.S. case, while it tends to be less inflationary for the euro area. These contrasting results between the two areas is explained by the appreciation of the euro against the U.S. dollar that tends to limit the inflationary pressures of the carbon price increase. Economic activity in the euro area benefits relatively from the EUR/USD exchange movements mainly as short-term interest rates react less in the case of the floating regime compared to the fixed one.

Figure 8: Implications of bilateral exchange rate flexibility between the US and the euro area



Note:
GDP - % diff. from base; Inflation and interest rates – percentage point diff. from base
All exchange rates are vis-a-vis US dollar
Std: the euro exchange rate follows the UIP condition
Fixed RX: No movement in the exchange rate (fixed on base)

Appendix: Fiscal and Monetary Policy Setting in NiGEM

Every simulation in NiGEM runs conditional on the scenario space that is defined by the user. This includes the monetary and fiscal policy regimes in each country and region, including the exchange rate regime, and the formation of expectations by consumers, firms, wage setters or financial markets. Policy rules for interest rates and the government sector are essential for the operation of a coherent model of the economy.

Fiscal policy options in NiGEM

Full country models include a well-specified government sector, where the fiscal deficit flows onto the stock of government debt. Barrell and Sefton (1996) demonstrate that the existence of an equilibrium in a forward-looking model requires that debt stocks do not explode. This requires a fiscal solvency rule, to ensure that the deficit and debt stock return to sustainable levels.

The fiscal solvency rule is introduced through the income tax rate, so that a deviation of the deficit or debt stock from their specified targets initiates an endogenous shift in the tax rate. This pulls the deficit and debt stock back towards targeted sustainable levels.

$$TAXR_t = TAXR_{t-1} + \left[\frac{0.01 * NOM_{t-1} * \{\beta_1 * (GBRT_{t-1} - GBR_{t-1}) + \beta_2 * (GDRT_{t-1} - GDR_{t-1})\}}{PI}\right]$$

TAXR: income tax rate
NOM: nominal GDP
GBRT: government deficit target (% GDP)
GBR: government deficit (% GDP)
GDRT: government debt target (% GDP)
GDR: government debt (% GDP)
PI: personal income (income tax base)

By default, the solvency rule operates through the deficit target, with β_2 set to 0. Model users can turn the solvency condition off temporarily or permanently for specific scenario studies.

In the standard model, two main fiscal options are available which can be applied to the carbon price shock itself.

- The solvency rule is maintained such that an additional tax burden is placed on households to maintain the budget position
- The solvency rule is off and the burden feeds into the debt position

When reviewing the recycling of the carbon tax revenue, several options are available

- Lowering tax burden for households. As a result, improved real disposable income supports private consumption and hence GDP.
- Reducing government debt stock. Revenue from carbon taxes can be used to lower fiscal deficit and hence the debt stock (including associated debt interest payments).
- Increase in transfers to households, operates in a similar manner to lowering taxes for consumers.
- Increase in government investment, which has direct positive impact on GDP as well as trend capacity output of the economy.
- VAT can be reduced, based on the implicit carbon tax revenue and personal income to mitigate inflation effects which will improve the disposable income of households and facilitate higher corporate profits. This instrument was left out of the scope of the Fiscal sensitivity analysis of section 2.
- Combination of the above

In all cases, budget neutrality is assumed.

Monetary policy options in NiGEM

The monetary policy authority in the model operates predominantly through the setting of the short-term nominal interest rate. This is done with reference to simple policy feedback rules that depend on targets such as inflation, the output gap, the price level, and nominal output. The interest rate reaction function responds to "gaps" between observed and targeted values of inflation, etc. The target values are set to the baseline values of the relevant variable, so that a shock that delivers a deviation in GDP, inflation or the price level from baseline values will initiate an endogenous reaction in interest rates, depending on the rule selected. All rules include a lagged interest rate, which allows for a degree of inertia in interest rate setting, which will converge to a country-specific steady state rate over time. The default rule in NiGEM follows a 'two-pillar' strategy.

The two-pillar strategy sets the short-term interest rate as a function of the ratio of the nominal GDP target to nominal GDP and the difference between inflation expectations and the inflation target. This policy brings current nominal GDP back to its target level.

$$INT_t = \gamma * INT_{t-1} + (1-\gamma) * \left[\alpha * ln\left(\frac{NOMT_t}{NOM_t}\right) + \beta * (INFL_{t+i} - INFTS_{t+i})\right]$$

INT: nominal short-rate
NOM: nominal GDP, defined with the GDP deflator by default
NOMT: nominal GDP target
INFL: expected inflation, defined with the consumer expenditure deflator
INFTS: inflation target

Model users can turn monetary policy reaction off temporarily for specific scenario studies.

The country-specific impacts of climate change shocks depend on a multitude of factors including the reaction and interaction of monetary and fiscal policies. In principle, the monetary policy rule implies interest rate changes to counteract the economic impact from higher carbon taxes as well as from the fiscal interventions recycling the carbon tax revenues. If monetary policy is assumed to be unchanged and therefore short-term interest rate fixed, then the full pass through to the economy from the various shocks is allowed.

Rational and adaptive expectations

The Lucas critique – based on Lucas (1976) – cast doubt on the performance of early macroeconomic models, as they rested on the assumption that the estimated parameters based on historical behavioural patterns were invariant to the policy environment. Rational expectations or forward-looking models evolved as a reaction to this criticism, and NiGEM incorporates many of the key features of these types of models.

NiGEM allows users to experiment with different types of expectation formation in a range of markets. Rational, or model-consistent expectations, are assumed by default in simulations for monetary policy rules and financial markets, including exchange rates, long-term interest rates and equity prices. Wage bargains are also assumed to be settled based on a country-specific degree of rational expectations. By default, consumers are assumed to be myopic, as the evidence of forward-looking behaviour is less clear, but react to changes in their (forward looking) financial wealth. The housing market is also treated as adaptive by default. But users can modify the defaults to run any scenario with forward-looking or adaptive expectations in any of these markets.

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