USING NiGEM IN UNCERTAIN TIMES: INTRODUCTION AND OVERVIEW OF NiGEM

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This paper introduces a special issue of the *Review* on how the National Institute Global Econometric Model (NiGEM) is being used to navigate uncertain times. NiGEM is the leading global macroeconomic model, used by both policy-makers and the private sector across the globe for economic forecasting, scenario building and stress testing. The paper summarises the main features of NiGEM and describes some standard model simulations to illustrate how the model responds to monetary, fiscal and technology shocks.

Keywords: NiGEM, macroeconomic model, open economy macroeconomics, global structural model, spillovers.

JEL codes: C5, E37, F41, F47.

1. Introduction

Macroeconomic models are intended to provide a useful framework for understanding how economies work. They are particularly important in uncertain times, as it is possible to use them to think through the effects of various identifiable risks and assess the appropriate policy responses. In current circumstances these risks include Brexit, the imposition of US tariffs on imports as well as possible retaliatory tariffs on US exports, abrupt changes in fiscal policy, and sharp movements in exchange rates and other financial market prices.

In a recent special issue of the *Oxford Review of Economic Policy*, Olivier Blanchard argued that different classes of models are needed for different tasks (Blanchard, 2018). He described the purposes of five different classes of macroeconomic models: foundational models, dynamic stochastic general equilibrium (DSGE) models, policy models, toy models and forecasting models.

This special issue is about the National Institute Global Econometric Model (NiGEM) and how it is being used to navigate the uncertain times we are facing. NiGEM is what Olivier Blanchard would describe as a policy model as it is:

> 'aimed at analysing actual macroeconomic policy issues. Models in this class should fit the main characteristics of the data, including dynamics, and allow for policy analysis and counterfactuals. They should be used to think, for example, about the quantitative effects of a slowdown in China on the United States, or the effect of a US fiscal expansion on emerging markets'. (Blanchard, 2018)

This description fits NiGEM like a glove. NiGEM is the leading global macroeconomic model, used by both policy-makers and the private sector across the globe for economic forecasting, scenario building and stress testing. It consists of individual country models for the major economies that are linked through trade in goods and services and integrated capital markets. So, in NiGEM, a slowdown in China, associated with lower imports, would impact on the United States and other countries through the effect of lower exports to China and associated shifts in asset prices. The overall effect would depend on both the underlying source of the shock in China and the policy response in China and other countries.

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The individual country models within NiGEM are 'economy-wide systems of dynamic equations, based around the internationally-accepted national accounting framework, with parameters estimated from aggregate time-series data' (Wallis, 2000). They all have broadly the same New Keynesian structure in that agents in the model are generally assumed to have rational expectations, though this can be amended, and there are nominal rigidities that slow the process of adjustment to external events. Importantly, the individual country models incorporate well-specified supply-side behaviour that underpins the sustainable growth rate of each economy in the medium term. As far as possible the same theoretical structure has been adopted for each of the individual country models, except where clear institutional or other factors prevent this. As a result, variation in the properties of each country model reflects genuine differences emerging from estimation, rather than different theoretical approaches.

One of the benefits of using NiGEM for macroeconomic analysis is that a version of the model has been used regularly for forecasting and policy analysis since it was first developed in 1987; an earlier description of the properties of NiGEM is in Barrell *et al.* (2004). NiGEM has not stayed the same over this period, but has evolved and been improved to incorporate new thinking, evaluate new policies and adapt to new circumstances. Recent changes to incorporate macroprudential instruments into the model are described in Carreras *et al*. (2018). The current structure of NiGEM is described more fully later in this article.

A particular strength is the growing community of NiGEM users that has supported the work of NIESR both financially and by providing an impetus to further model development. This special issue includes contributions from five institutions that use NiGEM and illustrate how the model has been applied to some of the key issues of the day.

Nigel Pain, Elena Rusticelli, Véronique Salins and David Turner (OECD) investigate the potential macroeconomic benefits of increased public sector investment, focusing on the case of the United States. They show that a fiscal expansion that takes the form of an increase in public investment has a more enduring effect on the economy than an equivalent increase in public consumption. This is because extra investment spending raises the capital stock and so adds to productive potential, while an increase in public consumption has no long-lasting impact on capacity. They also use the model to calculate cross-country differences in the effect of equivalent expansions in public investment and show that the effect is smaller in more open economies. They also provide quantitative estimates of the extent to which a coordinated fiscal expansion by the G7 countries would spill over to other countries. Somewhat surprisingly they show that the short-term effect on output in some of the smaller countries arising from the spillovers is larger than the effect in the larger countries that are increasing investment spending. This illustrates how a quantified macroeconomic model like NiGEM can provide interesting insights that are not otherwise available as easily.

Markus Jorra, Andreas Esser and Ulf Slopek (Deutsche Bundesbank) also look at the role of international spillovers. In particular, they examine the wider effects of the recently enacted US tax reform. They also consider the global impact of a hard landing in China. These are exactly the questions that Olivier Blanchard suggested policy models should be used to answer. They show that spillovers are not uniform and that while higher US demand has a positive impact on activity in close trading partners like Mexico and Canada, the effect on countries like Germany and Japan is less clear cut as the effect of higher global real interest rates counteracts the direct demand impact. In carrying out this analysis, the authors show that the results are sensitive to how the model is set up, focusing on the specification of import demand, and suggest important ways in which the model can be improved.

Sophie Haincourt (Banque de France) examines the macroeconomic effects of recent currency fluctuations, emphasising the importance of identifying the source of the movements. She focuses on dollar and euro fluctuations in 2017 and their effect on inflation and activity in the United States and the Euro Area. The sources of currency movements are identified by the contributions of their currency counterparts and attributed to variations in risk premia and monetary policy. She uses this approach to argue using NiGEM that, contrary to popular belief, the depreciation of the US dollar over this period was associated with lower US growth as it was caused partly by a rise in risk premia that were detrimental to US investment.

Ulf Slopek (Deutsche Bundesbank) studies the macroeconomic effects of the imposition of import tariffs by the United States. For illustrative purposes he focuses on the hypothetical case of a US tariff applied on all non-commodity imports, irrespective of what country they come from. The results are sensitive to assumptions about how export prices are affected by tariffs, and how the tariff revenue is spent. But the main case suggests that tariffs act in a similar way to adverse supply shocks and have detrimental effects on activity and prices in the United States and abroad.

Hugo Erken, Raphie Hayat, Carlijn Prins, Marijn Heijmerikx and Inge de Vreede (Rabobank) analyse the effect of Brexit on the UK economy using NiGEM. They estimate that a hard Brexit would reduce cumulative UK GDP growth by 18 percentage points by 2030. These estimates are significantly larger than in other studies, many of which also used NiGEM. The main reason for the difference is that, unlike many other studies, Erken *et al.* analyse the endogenous impact of Brexit on UK productivity using a new empirical model of UK productivity estimated over 1969–2016. This empirical model suggests that UK productivity growth is related to factors such as R&D capital, human capital and the openness of the economy, that might be adversely affected by a hard Brexit. Significant adverse effects of Brexit through these channels account for the larger effects that are estimated.

Thomas Conefrey, Gerard O'Reilly and Graeme Walsh (Central Bank of Ireland) analyse the effect of external shocks, including Brexit, on the Irish economy. They use a two-step approach. First, they use NiGEM to evaluate the effects of the shocks in question on Ireland's main trading partners. Second, they then feed these estimates into a sectoral model of the Irish economy, COSMO. In the case of Brexit, based on previous NIESR research on Brexit that excludes possible productivity effects (Ebell, Hurst and Warren, 2016), Conefrey *et al.* estimate that a hard Brexit would reduce UK GDP by 3 to 4 per cent in the long run. They find a similar impact on the Irish economy arising from a fall in demand for Irish exports, mainly from the UK, and the deterioration in Ireland's relative competitiveness due to the modelled depreciation in sterling.

These papers demonstrate the wide range of issues that may be analysed using NiGEM to provide quantitative insights. Of course, the answers provided by any model are sensitive to the modelling choices made and need to be assessed against a range of other evidence, including the other types of models referred to in Blanchard (2018).

In the remainder of this article we provide a more detailed overview of the NiGEM model. Section 2 summarises the country coverage and the broad structure of the model. Section 3 describes the behaviour of the agents in the model: households, firms, governments and monetary policy authorities. Section 4 outlines the key pricing and trading relationships in the model and how the model is brought into equilibrium. Section 5 sets out some standard model simulations to illustrate how the model responds to monetary policy, fiscal policy and technology shocks.

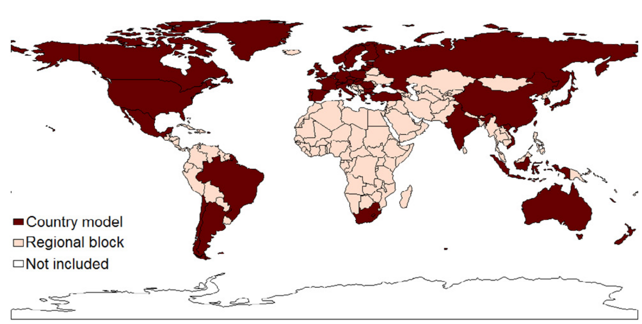
2. Country coverage and broad structure of NiGEM

NiGEM is a global model, and almost all countries in the OECD are modelled individually within it. There are also separate models of Argentina, Chile, China, India, Russia, Hong Kong, Taiwan, Brazil, South Africa, Estonia, Latvia, Lithuania, Slovenia, Romania and Bulgaria, while the rest of the world is modelled through regional blocks. The global coverage of NiGEM is illustrated in the map shown in figure 1.

All country models contain the determinants of domestic demand, export and import volumes, prices, current accounts and net assets. In the long run, output is tied down by factor inputs and technical progress interacting through production functions. In the short run, the dynamic properties of the model are consistent with the data and well-determined.

International linkages come from patterns of trade, the influence of trade prices on domestic prices, the impacts of exchange rates and patterns of asset holding and associated income flows. The structure of the trade block ensures overall global consistency of trade volumes by imposing that the growth of import volumes is equal to the growth of export volumes at the global level. Trade volumes and prices are linked by Armington matrices, based on 2016 trade patterns. The volumes of exports and imports of goods and services are determined by foreign or domestic demand, respectively, and by competitiveness

Figure 1. NiGEM country coverage



Source: NIESR.

as measured by relative prices or relative costs. The export demand variable is constructed as a weighted sum of other countries' imports, which ensures approximate balance, and any discrepancy is allocated to exports in proportion to the country's share of world trade. Import prices depend on a weighted average of global export prices, and this ensures that the ratio of the value of exports to the value of imports remains at around its historical level. It is assumed that exporters compete against others who export to the same market as well as domestic producers via relative prices. Imports depend upon import prices relative to domestic prices and on domestic total final expenditure. The overall current balance depends upon the trade balance and net property income from abroad, which comprises flows of income onto gross foreign assets and outgoings on gross foreign liabilities. World flows of property income balance because all assets are matched by liabilities, revaluations of liabilities match those of assets and income flows match payments.

3. Agents in the model

In this section we describe the behaviour of the key agents in NiGEM: households, firms, governments and monetary authorities. In general, the model can be solved under a number of different assumptions about behaviour: for example, whether expectations are rational or adaptive. In what follows we describe the default behavioural assumptions.

3.1 Households

Households in the model are assumed to choose consumption in accordance with life-cycle considerations as a function of their current and expected future real disposable income as well as wealth from housing and financial assets, all net of taxes. In the long run, consumption depends on a dynamic adjustment path around real disposable income and real wealth, and follows the pattern discussed in Barrell and Davis (2007).

$$\ln C_t = \alpha^C + \beta^C \ln(RHW_t) + \left(1-\beta^C\right)\ln\left(RTW_t + RNW_t\right) \qquad (3.1.1)$$

where C is real consumption, RHW is real human wealth, defined below, RTW is real tangible wealth, mainly housing, and RNW is real net financial wealth.

Human wealth is the forward-looking component in the consumption model and is defined as a function of expectations of future real disposable income as follows:

$$RHW_t = E\left[\sum_{j=0}^{T} \varnothing^j RPDI_{t+j}\right] \qquad (3.1.2)$$

where RPDI is real personal disposable income, $\varnothing$ is the discount factor, determined by the real interest rate.

Real interest rate effects are captured by the $\varnothing$ parameter in equation (3.1.2). Higher interest rates entail lower current consumption as the opportunity cost of giving up savings is higher. This is similar to an Euler equation, which links the optimal intertemporal consumption decision of a representative consumer with rational expectations to a discount factor and the real interest rate.

The dynamics of adjustment to the long run are largely data-based. Differences between countries can be attributed to differences in the relative importance of types of wealth and of liquidity constraints.

The key parameters embedded in the model equations for the G7 countries are reported in table 1. The impact of a change in tangible (housing) wealth on consumption in the short run is about five times stronger than the impact of a change in financial wealth in countries for which data is present.

Table 1. Key consumption equation parameters

	β^C	Δln(RPDI)	Δn(RTW)	Δln(RTW-1)	Δln(RNW)	Δn(RNW-1)
US	0.93	0.15	–	0.15	–	0.03
UK	0.93	0.17	–	0.16	–	0.03
Germany	0.78	0.68	0.02	–		–
France	0.71	0.51	–	–	–	0.04
Italy	0.83	0.14	–	–	0.03	–
Canada	0.93	0.17	–	0.16		0.03

Note: β^c gives the long-run weight on income from equation (3.1.1), the coefficients indicate the short-run response of consumption to changes in real income and wealth.

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The short-run response to changes in real income captures the number of liquidity constrained consumers. In the presence of borrowing constraints, less liquid assets and in particular tangible wealth have a smaller effect on current households' consumption (Byrne and Davis, 2003). When credit constraints are low, households can consume their illiquid wealth to smooth consumption over time. Borrowing allows smoothing out the impacts of fluctuations in income, thereby driving a faster adjustment to the long-run equilibrium consumption. This suggests relatively few borrowing constraints in the US and the UK, with a greater degree of borrowing constraints in Germany and France.

3.2 Firms

Aggregate supply in the individual country models is based around an underlying constant-returns-to-scale CES production function with labour-augmenting technical progress. This is embedded within a Cobb-Douglas relationship to allow the factors of production to interact with oil usage:

$$Q=\gamma^{Q}\{[s^{Q}(K)^{-\rho}+(1-s^{Q})(Le^{\lambda t})^{-\rho}]^{-\frac{1}{\rho}}\}^{\alpha}M^{1-\alpha} \quad (3.2.1)$$

where Q is real output, K is the total capital stock, L is total hours worked, λ is the rate of labour-augmenting technical progress and M is oil input. (We omit time subscripts in this and subsequent equations, unless it is crucial to include them.)

This relationship underpins the factor demand equations in the model, forms the basis for unit total costs and provides a measure of capacity utilisation, which then feeds into the price system. Demand for labour and capital are determined by firms' profit maximisation, implying that the long-run labour–output ratio depends on real wage costs and technical progress, while the long-run capital–output ratio depends on the real user cost of capital

$$lnL=\alpha^{L}+lnY-(1-\sigma)\lambda t-\sigma\ln\left(\frac{w}{p}\right) \quad (3.2.2)$$

$$lnK=\alpha^{K}+lnY-\sigma\ln\left(\frac{c}{p}\right) \quad (3.2.3)$$

where α^L and α^K are constant terms related to the other parameters in the model, *w/p* is the real wage, *c/p* is the real user cost of capital and σ is the elasticity of substitution between capital and labour.

Barrell and Pain (1997) estimate an elasticity of substitution σ of 0.5 from the labour demand equation. The user cost of capital depends on the real long-term interest rate and a risk premium.

Business investment is determined by an error-correction-based relationship between actual and equilibrium capital stocks as below.

$$IB_t=K_t-K_{t-1}*(1-\text{dep}) \quad (3.2.4)$$

where IB is business investment, K is the capital stock, *dep* is the depreciation rate and the long-run equation for the capital stock is (3.2.3).

3.3 Governments

The government budget deficit is:

$$BUD=CED*(GI+GC)+TRAN+GIP \\ -TAX-CTAX-ITAX \quad (3.3.1)$$

where the government budget deficit (BUD) is determined by spending minus revenues. Government spending includes spending on investment (GI) and consumption (GC) rising in line with trend output in the long run, with delayed adjustment to changes in the trend. They are revalued in line with the consumers' expenditure deflator (CED). In addition transfers ($TRAN$) to unemployed and pensioners as well as interest payments (GIP), depending on the size of the accumulated debt and the prevailing interest rate, are identified. The revenues include corporate ($CTAX$) and personal (TAX) direct taxes and indirect taxes ($ITAX$) on spending.

The deficit flows onto the debt stock, which affects interest payments and private sector wealth.

$$DEBT_t=DEBT_{t-1}+BUD_t-\Delta M_t \quad (3.3.2)$$

where ΔM is the change in the money stock, representing possible monetary financing of the deficit.

A default budget rule is included to ensure that governments stay solvent in the long run, i.e. that the deficit and debt stock return to sustainable levels in all scenarios. The budget rule adjusts the aggregate tax rate when the public debt ratio (*gbr*) deviates from its target (*gbrt*) as below:

$$taxr_t=taxr_{t-1}*\left[\frac{0.01*y_{t-1}(p^{y}{}_{t-1}/100)*\left(\beta^{taxr}\left(gbrt_{t-1}-gbr_{t-1}\right)\right)}{pi}\right] \quad (3.3.3)$$

where *taxr* is the tax rate, *y* is GDP and p^y is the GDP deflator and *pi* is personal income. Other solvency rules may be used within the model, including with different speeds of adjustment.

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Table 2. Parameters of two-pillar monetary rule

	γ^i	α^i	β^i
US	0.5	40	0.70
UK	0.5	30	0.95
Euro Area	0.5	40	0.70
Canada	0.5	30	0.95
Japan	0.5	60	0.75

This entails that if the government budget deficit is greater than the target, then the income tax rate adjusts upwards to return the deficit to target in the medium term (a time span of around five years).

3.4 Monetary policy authority

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 a simple feedback rule depending on inflation, the output gap, the price level, and nominal output. Different monetary policy rules are defined, with the two-pillar strategy being the default one.

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.[1]

$$i_t=\gamma^i i_{t-1}+\left(1-\gamma^i\right)*\left[-\alpha^i ln\left(\frac{NOM^*_t}{NOM_t}\right)+\beta^i\left(inf_{t+1}-inf^*_{t+1}\right)\right] \quad (3.4.1)$$

Where i is the short-term nominal interest rate, NOM is nominal output, NOM^* is a specified target for nominal output, inf is inflation expectations ($=\Delta\ln CED_{t+1}$) and inf^* is the inflation target.

4. Prices, trade and equilibrium

This section outlines the key pricing and trading relationships in the model and how the model is brought into equilibrium.

4.1 Prices of goods and services

The prices set by firms depend on the cost of inputs to production. Firms are assumed to choose factors to minimise the cost of production given the production function (3.2.1). Substituting optimal factor input levels ($\bar{L},\bar{K}$) into the cost function (and abstracting from energy inputs into production) yields an expression for total costs:

$$TC = w\bar{L} + r\bar{K} = \frac{Q}{\gamma^Q}\left\{s^{Q\frac{1}{1+\rho}}c^{\frac{\rho}{1+\rho}} + (1-s^Q)^{\frac{1}{1+\rho}}w^{\frac{\rho}{1+\rho}}(e^{-\rho\lambda t})^{\frac{1}{1+\rho}}\right\}^{\frac{1+\rho}{\rho}} \quad (4.1.1)$$

Assuming that firms operate on demand curves for factors in the long run, $\bar{L}$ and $\bar{K}$, we derive an expression for the marginal cost of production:

$$MC = \left(\frac{\bar{L}}{Q}\right)^{1+\rho}\left(\gamma^Q e^{\lambda t}\right)^{\rho}\frac{w}{\left(1-s^Q\right)} \quad (4.1.2)$$

Under imperfect competition, firms charge a mark-up over the marginal cost. The assumed market structure is similar to the standard assumption of monopolistic competition but not identical to it, allowing for more flexibility and institutional differences across countries. To take a demand-dependent mark-up into account, we augment equation (4.1.2) with capacity utilisation to yield an expression for observed total cost per unit:

$$UTC = CU^{\alpha^{UTC}}\left(\frac{\bar{L}}{Q}\right)^{1+\rho}\left(\gamma^Q e^{\lambda t}\right)^{\rho}\frac{w}{\left(1-s^Q\right)} \quad (4.1.3)$$

Parameter α^{UTC} varies across countries to reflect different degrees of product market regulation. The first column of table 3 shows that for countries with less regulated product markets, like the US and the UK, parameter α^{UTC} tends to be lower. Taking logs, we can derive the following linear expression:

$$\ln UTC = \theta^{UTC} + \alpha^{UTC}\ln CU + \ln w + \beta_1^{UTC}\ln\frac{L}{Q} + \beta_2^{UTC}t \quad (4.1.4)$$

where $\beta_1^{UTC} = (1+\rho)$, $\beta_2^{UTC} = \rho\lambda$. The constant term $\theta^{UTC} = \rho\ln\gamma^Q - \ln\left(1-s^Q\right)$ collects parameters of the production function.

Consumer prices in the model are a function of unit total cost and a wedge explained by prices of imported goods and services:

$$\ln CED = \beta^{CED}\ln UTC + (1-\beta^{CED})\ln PM \quad (4.1.5)$$

Parameter β^{CED} captures the sensitivity of consumer prices, and inflation, to price pressure from abroad and depends on the openness of the economy and demand for imports.

Short-term expressions for all price equations are written in error correction form, such that the growth

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Table 3. Selected model parameters reflecting the degree of product and labour market regulation

	UTC equation: elasticity of capacity utilisation (α^{UTC})	Phillips curve: unemployment elasticity ($\beta_1{}^{w}$)	Phillips curve: error correction parameter ($-\delta^{w}$)
Canada	0.083	–0.001	–0.100
China	0.084	–0.002	–0.084
France	0.094	–0.001	–0.095
Germany	0.209	–0.004	–0.167
Italy	0.375	–0.004	–0.150
Japan	0.228	–0.004	–0.114
UK	0.021	–0.002	–0.036
US	0.075	–0.002	–0.149

rate of unit total cost, $\Delta\ln UTC$, also depends on lagged differences of wages and lagged technological change. Consumer price inflation is also a function of lagged unit total cost growth, and import price inflation.

4.2 Wages and unemployment

Wage bargaining

In equilibrium, the level of real wages is determined in a bargaining process between workers and firms. The higher is unemployment, the lower is the bargaining power of workers. We assume a Phillips curve relationship between real wage growth and unemployment. Profit maximisation on behalf of firms also requires wages to move in line with productivity over time. We therefore allow for an error correction of wages to trend labour productivity as well as deviations of actual labour productivity from trend. The productivity-augmented real wage Phillips curve is written as:

$$\Delta\ln\frac{w_t}{CED_t} = \beta_1^w U_{t-1} - \delta^w\left[\ln\frac{w_{t-1}}{UTC_{t-1}} + b_1^w\left(t_{t-1} - \ln\frac{Q_{t-1}}{L_{t-1}}\right) - b_2^w \ln\frac{Q_{t-1}}{L_{t-1}}\right] \quad (4.2.1)$$

$\frac{w_t}{CED_t}$ is the real consumer wage and U_{t-1} the lag of the unemployment rate. $\frac{w_{t-1}}{UTC_{t-1}}$ is the real producer wage, $\ln\frac{Q_{t-1}}{L_{t-1}}$ is realised (log of) output per hour worked, i.e. labour productivity, and $\left(t_{t-1} - \ln\frac{Q_{t-1}}{L_{t-1}}\right)$ the deviation of (log) labour productivity from a long-run productivity trend.

Parameters β_1^w and δ^w vary across countries and reflect differences in labour market institutions that determine the bargaining power of workers relative to firms, such as union density, unemployment insurance, employment protection and minimum wages (table 3).

Expectations

While workers and firms base their economic decisions on real wages, in practice nominal wages are bargained over. Rational agents not only take into account the current price level but also form expectations about the price level in the future. We account for the forward-looking nature of nominal wage setting as follows:

$$\Delta\ln w_t = \alpha_0^w \Delta\ln\frac{w_t}{CED_t} + \alpha_1^w \Delta\ln CED_t + \alpha_2^w E\left[\sum_{b=1}^{H}\Delta\ln CED_{t+b}\right] \quad (4.2.2)$$

w_t is the nominal wage. CED_t is the current price level (consumer expenditure deflator), itself a function of unit total costs of production, consumption tax rates and import prices. $E\left[\sum_{b=1}^{H}\Delta\ln CED_{t+b}\right]$ is expected inflation over H periods. Expectations are consistent with model predictions.

Parameters α_1^w and α_2^w govern the extent to which agents are forward-looking, or 'rational'. $\alpha_2^w=0$ would imply that expectations are formed purely adaptively. In NiGEM, such a parameter setting is optional. $\alpha_1^w \neq 0$ implies that expectations about the price level are sticky and allows us to account for nominal rigidities. This can be compared to approaches in the DSGE literature to model nominal rigidities, such as the concept of Calvo pricing (Calvo, 1983; e.g. Christiano *et al*., 2005). By contrast, our method is more strongly motivated by empirical considerations (fitting the data), and parameters α_1^w and α_2^w vary across countries. Similar to DSGE-type models, nominal rigidities in NiGEM ensure that monetary policy has real effects.

Equilibrium rate of unemployment

Using the optimal demand for labour $\bar{L}$ (equation (3.2.2)), the price setting equation (4.1.5) and the wage setting equation (4.2.2), the equilibrium rate of unemployment can be derived. In equilibrium, actual inflation equals expected inflation and capacity utilisation will settle at an equilibrium. In addition, actual labour productivity and labour-augmenting technological progress should grow at the same rate. The equilibrium rate of unemployment can then be written as a function only of structural parameters, the terms of trade (export relative to import prices, $\frac{PX}{PM}$) and domestic producer price inflation relative to imported inflation to allow for global current account imbalances in the long run

$$U^* = \alpha_1^U + \alpha_2^U \Delta\ln\frac{PX}{PM} + \alpha_3^U \Delta\ln\frac{UTC}{PM} \quad (4.2.3)$$

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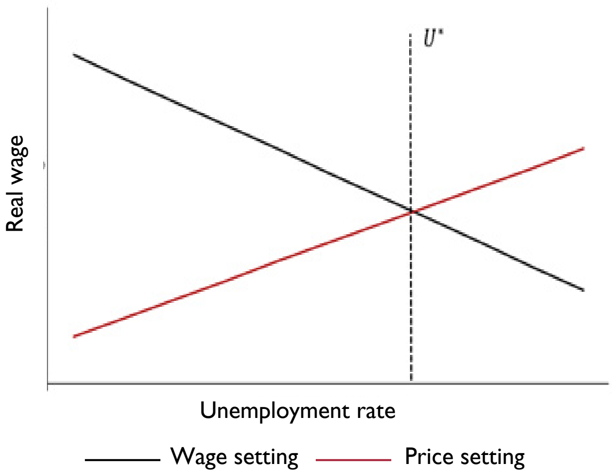
Figure 2. Labour market equilibrium



Source: Illustration based on Giavazzi *et al.* (2010).

where α_1^U captures the parameters associated with product and labour market institutions in the price and wage setting equations. If α_3^U was zero, this would imply that the equilibrium unemployment rate would only be determined by structural factors and the terms of trade.

U^* can also be interpreted as the non-accelerating inflation rate of unemployment (NAIRU): it indicates the level of unemployment below which inflation would be expected to rise relative to expectations. Figure 2 above summarises the labour market equilibrium graphically. The price setting relationship is upwards sloping in unemployment as a result of decreasing returns to labour input into the production function (equation 3.2.1 above): as unemployment decreases, or employment increases, the marginal cost of production would increase with the effect that firms will charge higher prices. In that sense, the price setting equation could be thought of as a labour demand equation. *Vice versa*, the wage setting relationship, according to which wages are negatively related to unemployment, would correspond to a labour supply curve in a standard analysis of the labour market.

From the equilibrium rate of unemployment, the equilibrium level of employment can be derived:

$$L^* = LF(1 - U^*) \qquad (4.2.4)$$

where LF is the labour force. The size of the labour force depends on demographics, migration and participation rates. We take it as exogenously given, using projections from official sources. With respect to employment, we further distinguish between employees in employment and the self-employed. Only the former are assumed to be relevant for the wage and price setting process.

4.3 International trade

NiGEM is a globally closed model in that all income and asset flows into one country are matched by outflows from other countries. International trade is driven by demand such that no country exports unless there is demand from other countries. Import demand is modelled as a function of total final expenditure and import price competitiveness:

$$\Delta \ln M_t = \beta_0^M + \beta_1^M \Delta \ln TFE_t - \beta_2^M \Delta \ln \frac{PM_t}{CED_t} - \delta^M \left[\ln M_{t-1} - b_1^M \ln TFE_{t-1} + b_2^M \ln \frac{PM_{t-1}}{CED_{t-1}} \right] \qquad (4.3.1)$$

Total final expenditure TFE_t is defined as domestic demand less imports. The paper by Jorra *et al.* (2018) in this *Review* augments the import demand function to account for differences in the import content of expenditure components. The authors show that this can have implications for the magnitude of international spillovers. In the long run, a demand elasticity $b_1^M > 1$ is imposed to allow for a continued rise in the share of trade in world output, i.e. globalisation. Import price competitiveness is defined as the ratio of import prices to domestic consumer prices: the higher the price of imports relative to prices at home, the lower import demand. Import prices are a weighted average of prices for commodity and non-commodity imports

$$PM = \alpha^{PM} PM^{COM} + \left(1 - \alpha^{PM}\right) PM^{NCOM} \qquad (4.3.2)$$

Commodity import prices PM^{COM} are exogenously given prices for metal, agricultural raw material, food, beverages and fossil fuel. In the long run, the growth rate of these prices is determined by the growth rate of non-commodity prices. α^{PM} is a country's share of commodity exports in total exports. Non-commodity import prices PM^{NCOM} of country i are a weighted average of other countries' export prices PX_j^{NCOM}

$$PM_i^{NCOM} = \sum_{j=1}^{J} wt_j PX_j^{NCOM} \qquad (4.3.3)$$

where weight wt_j is the share of country j's exports in all imports of country i and J is the number of trading partners.

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Non-commodity export prices are written in error correction form to converge to an equilibrium defined by competitors' export prices and the domestic price level:

$$\Delta \ln PX_{it}^{NCOM} = \beta_0^{PXN} - \delta^{PXN} * \left[\ln PX_{it-1}^{NCOM} - b_1^{PXN} \ln CPX_{it-1}^{NCOM} - b_2^{PXN} \ln \frac{CED_{t-1}}{RX_{t-1}} \right] + \beta_1^{PXN} \Delta \ln \frac{CED_t}{RX_t} + \beta_3^{PXN} \Delta \ln DPX_{it}^{NCOM} \tag{4.3.4}$$

Competitors' export price level is defined as the average of export prices of competitors l in a particular market, weighted by the presence of competitors in that market v_l:

$$CPX_i^{NCOM} = \sum_{l=1}^{L} v_l PX_l^{NCOM} \tag{4.3.5}$$

In the short run, export prices not only depend on domestic price inflation but also export competitors' domestic prices. These are defined as average domestic prices weighted by exports from country i to country m relative to total exports from country i

$$DPX_i^{NCOM} = \sum_{m=1}^{M} u_m \frac{CED_m}{RX_m} \tag{4.3.6}$$

Putting import demand and relative price levels together allows us to write the dynamic export equation as follows:

$$\Delta \ln X_{it} = \beta_0^X - \delta^X * \left[\ln X_{it-1} - \sum_{n=1}^{N} r_m \ln M_{mt-1} - b_1^X \ln \frac{PX_{it-1}^{NCOM}}{CPX_{it-1}^{NCOM}} - b_2^X \ln \frac{PX_{it-1}^{NCOM}}{DPX_{it-1}^{NCOM}} \right] + \beta_1^X \Delta \sum_{n=1}^{N} r_m \ln M_{mt} + \beta_2^X \Delta \ln \frac{PX_{it}^{NCOM}}{CPX_{it}^{NCOM}} + \beta_3^X \Delta \ln \frac{PX_{it}^{NCOM}}{DPX_{it}^{NCOM}} \tag{4.3.7}$$

In the long run, export volumes are tied down by foreign demand and the competitiveness of export prices relative to export prices of competitors and trading partners' domestic prices, with short-run adjustments made with respect to changes in the same variables. Slopek (2018, this *Review*) explores the role of tariffs in shaping the relationship between export prices and foreign demand for exports. He finds that assumptions made about the adjustment of export prices can have important implications for the adjustment of the economy to the introduction of tariffs.

The trade balance is calculated as export volumes less import volumes

$$TB_t = \frac{X_t}{RX^b} \frac{PX_t}{PX^b} - \frac{M_t}{RX_t} \frac{PM_t}{PM^b} \tag{4.3.8}$$

where superscript b indicates a variable's base year value.

4.4 Financial market prices

Like product markets, international financial markets clear such that global liabilities equal global assets. A country's net income from interest payments, profits and dividends (IPD) can be written as the difference between income credits and debits:

$$\left(IPDC_t - IPDD_t\right) = \left[ROR_t \left(GA_{t-1} - \beta_1^{IPD} GL_{t-1}\right) + i_t^* \beta_2^{IPD} GL_{t-1}\right] - \left[\beta_3^{IPD} \left(PROF_t - TAX_t^c\right) + \left(1 - \frac{0.2}{debt_t^{gov} / y_t}\right) INT_t^{gov} + \frac{GL_{t-1} RX_{t-1} - \left(1 - \frac{0.2}{debt_t^{gov} / y_t}\right) debt_{t-1}^{gov} - \beta_4^{IPD} EQCAP_{t-1} EQPR_t}{RX_t} \right] \tag{4.4.1}$$

The terms in the first bracket represent credit with the rest of the world. GA are gross assets held, and GL are gross liabilities, which are both assumed to be a proportion of nominal GDP. ROR is the rate of return on foreign assets, which error-corrects in world debit. i^*_t is the short-term interest rate earned on liabilities in the rest of the world. We assume it to be identical to the US risk-free rate (policy rate).

The second bracket contains debit with the rest of the world. It is written as a function of profits less corporate taxes, interest payments on government debt and private and government debt as well as stock market returns expressed in domestic currency.

The current account balance is the sum of the trade balance (TB), net foreign income (IPDC less IPDD) and balance of payments transfers (BPT), the latter defined as being proportional to nominal GDP in foreign currency terms $BPT_t = \beta_1^{BPT} \frac{y_t p_t^y}{RX_t}$ with p_t^y being the GDP deflator:

$$CB_t = TB_t + \left(IPDC_t - IPDD_t\right) + BPT_t \tag{4.4.2}$$

Prices on international financial markets, i.e. long-term interest rates, exchange rates and equity prices, adjust in a forward-looking manner while allowing for (small) deviations from a standard no-arbitrage condition.

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Short-term interest rates i_t are determined by the monetary policy rules described in section 3.4 thereby responding endogenously to the state of the economy. Long-term interest rates LR_t result from a 10-year forward convolution of short-term rates plus a term premium (TPREM), which may capture risks associated with uncertainty about future monetary policy, bond market liquidity, or sovereign default:

$$(1+LR_t)=\prod_{b=0}^{10}(1+i_{t+b})+TPREM_t \quad (4.4.3)$$

The bilateral exchange rate RX_t, is defined as domestic currency per unit of foreign currency. It is forward-looking in that it jumps in response to news about the expected path of interest rates, solving an uncovered interest parity condition:

$$RX_t = RX_{t+1}\left(\frac{1+i_t}{1+i_t^*}\right) \quad (4.4.4)$$

The article by Haincourt (2018) in this *Review* studies the effect of unexpected shocks to the exchange rate on the macroeconomy. Finally, equity prices move with discounted future values of profits relative to private sector capital stock *KP* plus a premium:

$$EQP_t = \frac{PROF_t - TAX_t^c}{KP_t} + \frac{EQP_{t+1}KP_{t+1}}{(1+i_t)(1+EQPREM_t)KP_t} \quad (4.4.5)$$

The equity risk premium drives a wedge between returns on equity and returns on interest-bearing debt.

4.6 Estimation, calibration and solution method

Data used in the model is quarterly and mainly based on the internationally agreed national accounting framework. Model parameters are determined primarily through estimation and calibration. Model equations are regularly re-estimated to pick up changes to the structure of the economy. We employ standard time series and panel estimation methods to obtain robust estimates.

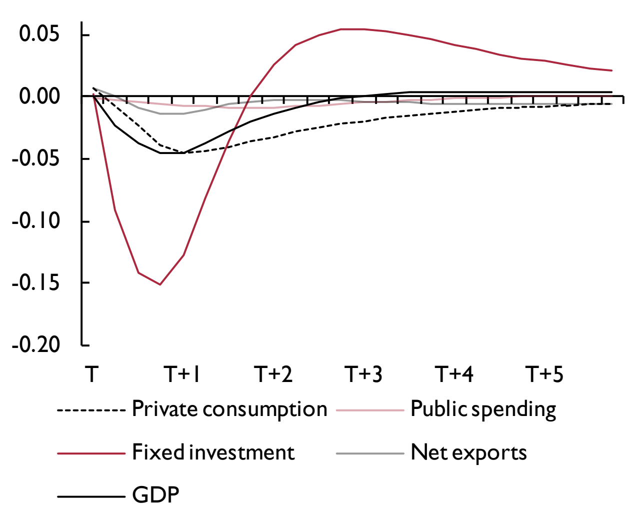
The model is solved using the Extended Path method for non-linear equations (Fair and Taylor, 1993, 1990). The default setting is that agents in the model have rational expectations in that their expectations are consistent with model predictions. In other words, the variance of future shocks does not affect agents' current expectations. In practice this implies that iterating along the solution path expectations are recalculated until convergence is achieved (see also Barrell *et al*., 2003). The model may also be solved in backward-looking mode using alternative equations that do not contain forward looking terms.

5. Forecasting, stress testing and policy analysis

The NiGEM model is primarily used for forecasting, stress testing and policy analysis. The global forecasts produced using the model are described elsewhere in this *Review*. While, for brevity, these are mainly presented as point forecasts, stochastic simulations of the model are also carried out to produce distributions around these point forecasts. These are illustrated in the fan-charts shown in the UK chapter of this *Review*, for example, that provide estimates of the risks around the main forecast.

The model is also used to produce different scenarios whose likelihood can be assessed by reference to the fan charts. Assessing risks is critical in decision-making and macroeconomic scenarios are increasingly important for risk assessment at banks and other financial institutions. The new IFRS9 standard requires institutions to use a range of possible economic scenarios to estimate an expected credit loss. Scenarios are also required for various regulator-driven and internal stress testing exercises. Some of these scenarios are known to be extremely unlikely to materialise, but still absolutely vital to consider in the proper management of risk.

Figure 3. Impact on Euro Area expenditure components from monetary policy shock (per cent difference from baseline)



Source: NiGEM simulations.
Note: The time unit is one year.

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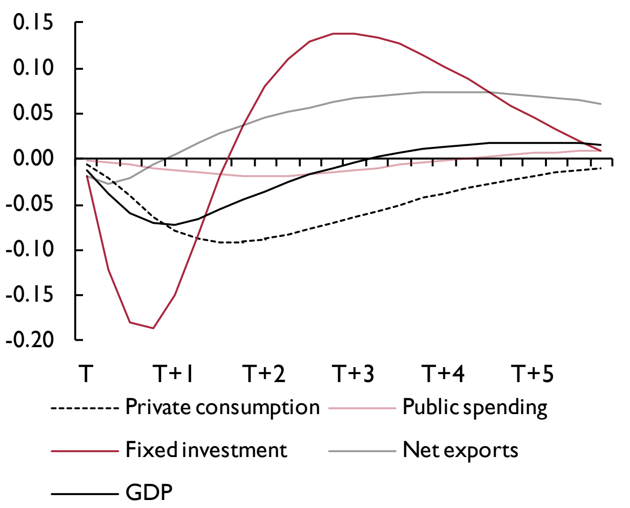
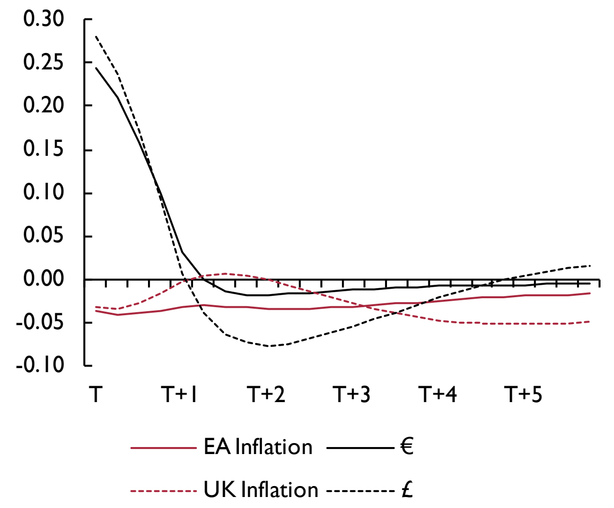
Figure 4. Impact on UK expenditure components from monetary policy shock (per cent difference from baseline)



Source: NiGEM simulations.

Figure 5. Impact on respective currencies and inflation from monetary policy shocks



Source: NiGEM simulations.
Notes: Exchange rates – per cent difference from baseline. Inflation – percentage point difference from baseline.

In the rest of this section we present some building blocks to scenario analysis, showing how the model can be used to assess the effects of simple shocks to monetary policy, fiscal policy and productivity. Besides showcasing the flexibility of NiGEM, the objective is to confirm that the model produces dynamics that are in line with the macroeconomic literature.

5.1 Monetary policy shock

We first describe the response of the model to shocks to short-term interest rates. Because interest rates are determined in the model by feedback rules, we assume that they are changed because of a short-term (one year) change in the nominal GDP target.

Higher Euro Area interest rates

The first case we consider is an increase in the Euro Area nominal interest rate of 25 basis points.

A contractionary monetary policy shock reduces overall domestic demand through the effects of higher interest rates on consumption and investment (figure 4). Higher rates reduce consumption through the wealth effect depending on the number of liquidity-constrained consumers that varies across Euro Area countries. Investment decreases immediately after the shock as higher rates increase the user cost of capital, which is a function of real long rates. The effect of the shock on the trade balance is small as the fall in import volumes on the back of lower demand is offset by a decline in exports, driven by an appreciation of the euro. As domestic prices adjust over time, there is no long-run impact on real variables: GDP is about 0.05 per cent lower after one year, but returns to base values after about three years.

Inflation is lower by 0.04 pp immediately after the shock for both domestic and external reasons. This is a little smaller than the effect estimated for the UK by Cloyne and Hürtgen (2016). The rise in the unemployment rate due to the fall in demand drives down wages as they are determined by a Phillips curve relationship (see section 4.2). The consequent fall in unit total costs drives lower inflationary pressures. Also, the appreciation of the euro driven by higher yields decreases import prices, contributing to the deflationary effect.

Higher UK interest rates

We now consider an equivalent shock that increases the nominal interest rate by 25 basis points in the UK. The effects are shown in figure 4. The exchange rate and price channel govern the different dynamics that arise in the UK relative to the Euro Area following a monetary policy shock. Being a small open-economy, the UK has greater labour market flexibility and lower price rigidity. Monetary policy in the model has therefore a faster price adjustment than in the Euro Area.

The reaction of domestic demand is similar to the Euro Area. The most notable difference is for the trade balance,

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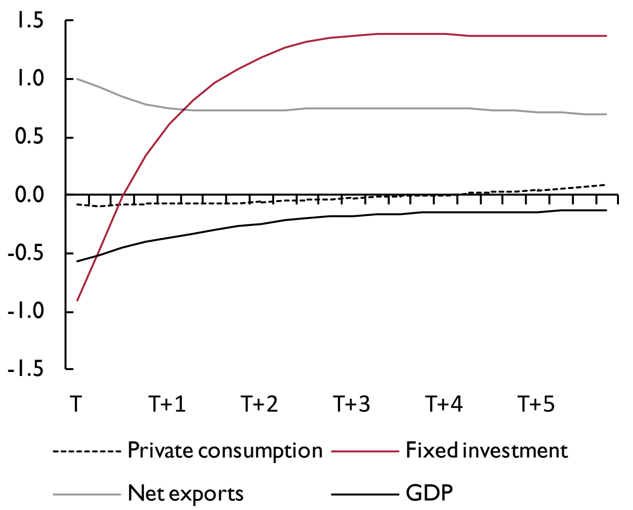
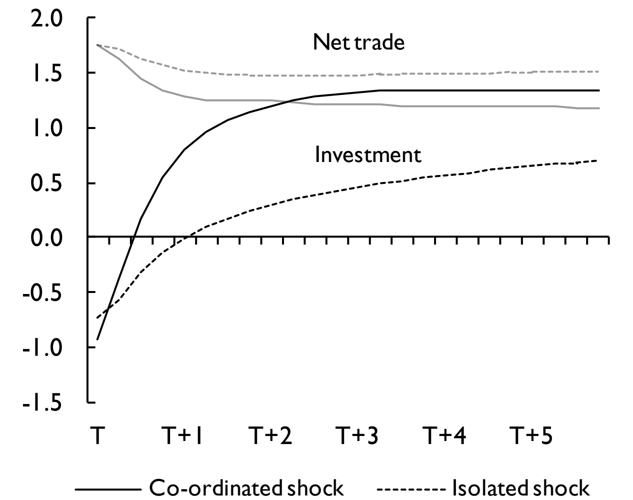
Figure 6. Impact on Euro Area expenditure components from a reduction in public consumption in four Euro Area major economies (per cent difference from baseline)



Source: NiGEM simulations.

Figure 7. Impact on German fixed investment and net trade from co-ordinated and the isolated shock to public consumption (per cent difference from baseline)



Source: NiGEM simulations.

which in the UK is significantly above base one year after the temporary monetary policy shock. After the immediate currency appreciation and decline in inflation, the subsequent sterling depreciation makes exports more competitive while import volumes remain lower than base. This improves the trade balance to a significantly greater extent than in the previous Euro Area shock.

Figure 5 compares the responses of exchange rates and inflation rates to monetary tightenings in the Euro Area and in the UK. In both cases, the exchange rate appreciates by about 0.25 per cent on impact, but then reverts over time to base values. Partly driven by the exchange rate's appreciation, inflation falls immediately by about 0.04 percentage points. In the UK, inflation reverts to base one year after the shock as import prices are higher, determining a faster price adjustment than in the Euro Area.

5.2 Fiscal policy shock

The fiscal shock considered is a permanent reduction in government consumption equivalent to 1 per cent of GDP.

Co-ordinated fiscal contraction in the Euro Area

A co-ordinated shock to public consumption by the four major Euro Area economies reduces GDP by around 0.5 per cent in the first year. Table 4 displays the changing contributions of the expenditure components to the change in output expressed as a percentage of baseline GDP following the shock.

Table 4. Euro Area expenditure components after the co-ordinated fiscal policy shock by the four major economies of the Euro Area (percentage points contribution)

	GDP	Private consumption	Fixed investment	Net exports	Public consumption
T+1	–0.48	–0.05	–0.05	0.37	–0.76
T+2	–0.31	–0.04	0.16	0.33	–0.76
T+3	–0.21	–0.03	0.23	0.34	–0.76
T+4	–0.16	–0.01	0.25	0.35	–0.76
T+5	–0.15	0.01	0.25	0.34	–0.75

Source: NiGEM simulations.

The assumed fiscal shock to the four major Euro Area major economies contributes to a fall in government spending for the Euro Area as a whole of almost 0.8 percentage points of GDP. The first-year GDP multiplier effect is around half, although this fades over time as private investment responds to a lower cost of capital (figure 5).

The immediate responses to the shock are of lower domestic demand. Unemployment increases and puts downward pressures on wages, feeding disinflationary pressures and encouraging a relaxation of monetary policy. The real interest rate declines with the accompanying deflation and investment is permanently higher. Lower interest rates also lead to a euro depreciation which, together with a fall in domestic demand, improves the trade position. Over time GDP returns towards its initial equilibrium with the composition of demand having switched from government consumption to private investment.

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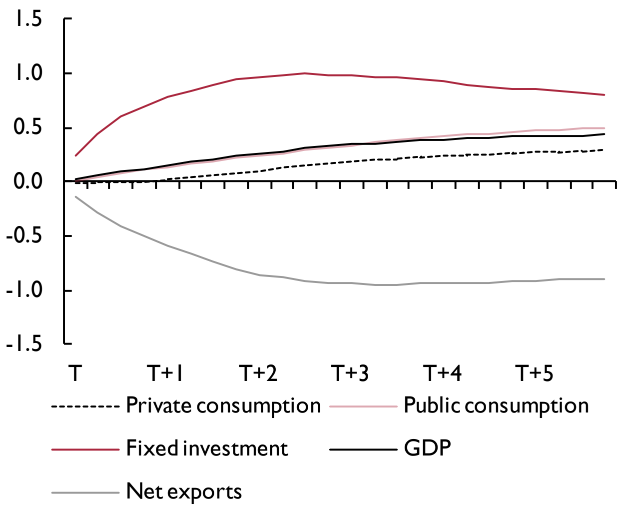
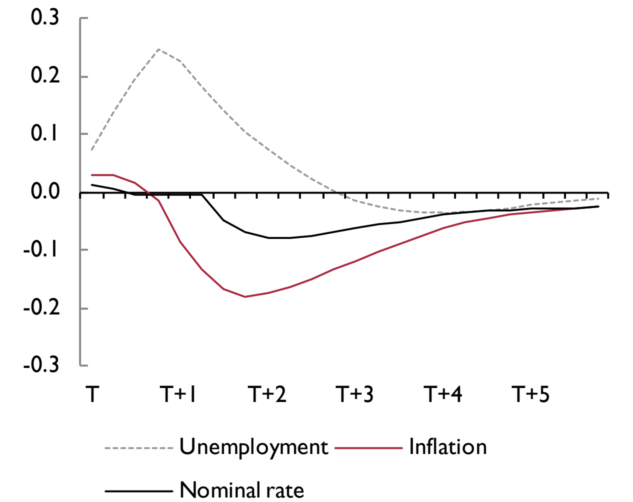
Figure 8. Impact on Euro Area expenditure components following synchronised productivity shock (per cent difference from baseline)



Source: NiGEM simulations.

Figure 9. Impact on Euro Area unemployment, inflation and nominal interest rate after the co-ordinated productivity shock (percentage point difference from baseline)



Source: NiGEM simulations.

Fiscal contraction in Germany alone

An isolated shock reducing fiscal spending in Germany has smaller effects for the Euro Area as a whole and for Germany itself than is the case for a co-ordinated fiscal expansion as spillovers from abroad are reduced in absence of direct fiscal shocks to the other countries (figure 7). Consumption and overall output react similarly to the isolated shock and to the co-ordinated one. The key difference is the reaction of investment and the trade position. The co-ordinated shock negatively impacts the demand for German exports by the other European countries that have been shocked directly. Investment increases by more in the co-ordinated case due to the larger decline in the user cost of capital induced by the greater monetary policy response. Therefore, in the co-ordinated exercise, the effective exchange rate of the euro declines by significantly more than in the isolated case.

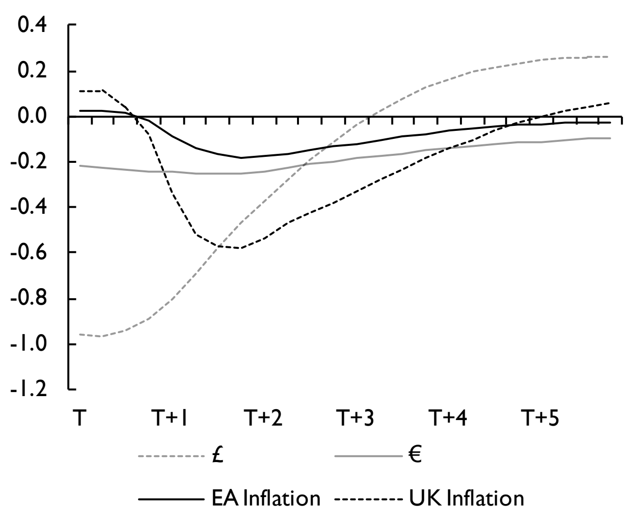
5.3 Productivity shock

We implement a permanent positive shock to labour-augmenting productivity of 1 per cent of GDP simultaneously in four major Euro Area economies, as well as an isolated improvement in the UK.

Synchronised improvement in productivity in the Euro Area

Productivity enters the production function and impacts potential output directly, with the speed of adjustment differing across countries. Euro Area potential output

Figure 10. Difference between the effect of the co-ordinated Euro Area and the UK productivity shocks on their respective currencies and inflation (difference from baseline)



Source: NiGEM simulations.

Note: Exchange rates – per cent difference from baseline. Inflation – percentage point difference from baseline.

permanently increases with the shock and drives actual output higher in the long run. The negative output gap emerging from the temporary wedge between potential and actual output puts downward pressures on prices in the short term.

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Lower prices increase real disposable income supporting consumption; the accommodative monetary policy reaction feeds through the user cost of capital on the back of lower long real rates, which encourages investment. Higher capacity stimulates government expenditures. The trade balance represents a drag on output as imports increase by more than exports with the increase in output (figure 8).

The fall in the capacity utilisation rate following the shock drives a temporary rise in unemployment, consistent with the evidence presented in Galí (1999) and Francis and Ramey (2003). This further induces lower price pressures as the wage bargaining process is hindered. Monetary policy reacts after one year to the deflationary shock by decreasing nominal short rates, and returning inflation back to base (figure 9).

Improvement in productivity in the UK alone

A permanent shock to labour augmenting technological progress permanently increases actual output and potential output in the UK similarly to the previous case. Different responses arise due to the faster price adjustment mechanism and stronger exchange rate effects in the UK (figure 10). The faster price adjustment mechanism in the UK drives a greater fall in prices as the technology shock induces spare capacity in the economy. Immediately after the shock, unemployment rises and puts downward pressure on wages. Likewise, the exchange rate channel is more responsive in the UK and determines a greater depreciation of sterling than the shock in the Euro Area to the euro. Finally, monetary policy response is more accommodative in the UK than in the Euro Area and responds to the deflationary shock by decreasing the nominal rate.

Looking at the reaction of the expenditure components to the shock in the UK, investment rises to a greater extent than in the Euro Area, as the monetary policy reaction is more accommodative and leads to a greater fall in the user cost of capital. The steep depreciation of sterling drives greater export competitiveness, such that the trade balance is not significantly different from base following the shock, unlike in the Euro Area.

NOTE

1 Nominal GDP is determined by the GDP deflator by default, but it is also possible to use a consumer expenditure deflator.

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