

THE EFFECTS OF MONETARY AND TECHNOLOGY SHOCKS IN THREE DIFFERENT MODELS OF THE EURO AREA*

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1. INTRODUCTION

The purpose of this study is to analyse the dynamic response of a set of euro area macroeconomic variables to monetary policy and technology shocks. We do so by conducting simulations on three different models of the euro area. The first modelling approach corresponds to structural VAR models (SVAR), the second approach uses the NiGEM multi-country model developed by the National Institute of Economic and Social Research (NIESR) and the third approach is a slightly modified version of the Smets and Wouters (2003) Dynamic Stochastic General Equilibrium (DSGE) model.

Economic models are mathematical representations of the economy that are designed to be simplifications of a complex reality. Models are used by economists to help them understand the functioning of the economy, to identify the main economic mechanisms at work, to forecast its future behaviour and to make counterfactual policy analysis. However, no model is capable of perfectly capturing reality. A more robust approach may thus be gained by analysing the results of different models. In this study we use three modelling approaches which differ both in terms of the theoretical underpinnings and the empirical specification. This implies that the results should be compared mainly in qualitative terms and not in terms of the quantitative effect.

One useful way to express the notion that any model implies some compromise is that proposed by Pagan (2003), who considers that there is usually a trade-off between the degree of theoretical coherence of a model and its degree of empirical coherence. Theoretical coherence refers to the extent to which the models reflect the current state of knowledge concerning the way the economy works. Empirical coherence refers to the ability of the model to fit the patterns of the variables of interest seen in a historical data set. The need to establish a trade-off between the two types of coherence arises because theory may not provide sufficient guidance to explain certain patterns seen in the data (e.g. how many autoregressive terms should be included in a model) or because certain features of empirical models may be theoretically implausible (for instance non-stationary nominal interest rates).

Within the commonly used macro-models, VAR models are generally regarded as being the most coherent empirically as they only contain a minimal set of theoretical restrictions and are able to fit the data well. The SVAR model used in this paper has some theoretical adherence to the extent that the restrictions imposed on the VAR are those implied by a theoretical model (see Alves *et al.*, 2006a), but otherwise is quite flexible in reproducing the data.

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The NiGEM follows a more traditional modelling approach. It is a multi-country macroeconomic model where for each country or region there is a description of the supply side, the labour market, consumption behaviour, financial markets and government sector. As a global model, NiGEM describes trade in goods and services, the structure of foreign assets and liabilities, and the links between these and the rest of the model. The NiGEM has hundreds of equations and allows for a very detailed simulation of a wide range of shocks and variables. Even though it allows for some theoretically desirable features (such as forward-looking behaviour), the model includes several ad-hoc features that reduce its theoretical coherence. As a result, it can be argued that the NiGEM is vulnerable to the Lucas critique (see Lucas, 1976), namely that the parameters of the model are a mixture of the so-called “deep parameters”, describing preferences and technology, and expectational parameters which by definition do not remain stable when there are changes in the policy regime.

The third model used in this study is a DSGE model. DSGE models are micro-founded and can be considered to have the closest adherence to economic theory, albeit at a cost of simplification relative to models such as the NiGEM. DSGE models are founded on the real-business-cycle (RBC) literature that started in the 1980s.¹ In RBC models, prices were flexible and markets continuously cleared, and consequently there was little scope for monetary policy. In the 1990s, a new generation of models appeared, the so-called DSGE models, which were based on the RBC methodology and extended it to address a broader range of macroeconomic issues. By including nominal rigidities, monetary policy becomes relevant in these models. Since DSGE models include the optimising behaviour of economic agents in their structure, they are, in principle, immune to the Lucas critique. The possibility to join together the theoretical consistency of such models with their ability to fit economic data well makes them an important tool in policy analysis.²

This study is organised as follows. In section 2 we provide a brief description of the models used in the simulation exercises. In section 3 we define the simulation experiments and in section 4 we present the simulation results. Section 5 concludes.

2. BRIEF DESCRIPTION OF THE MODELS

2.1. The Structural VAR

The SVAR model used in this study was estimated in Alves *et al.* (2006 a, b) for the euro area which in turn is largely based on the models of Altig *et al.* (2005) for the US.³ The VAR includes measures of labour productivity, hours worked (per capita), inflation, consumption, investment, capacity utilization, real wages, interest rates and monetary aggregates (see Appendix). Let Y_t be the vector of endogenous variables. The VAR in structural form is then given by:

$$A_0 Y_t = A(L) Y_{t-1} + e_t$$

where e_t is the vector of structural shocks and A_0 and $A(L)$ are parameter matrices and L is the lag operator. The structural shocks, e_t , which are unobservable, are assumed to be mutually independ-

(1) The first application of this methodology was by Kydland and Prescott (1982).

(2) Some recent studies have shown that DSGE models are able to fit the data reasonably well (see Smets and Wouters, 2003, 2004). In fact, several central banks have already replaced their traditional macro-econometric models with DSGE models in policy advice and in the forecasting process (for example the Bank of England, the Bank of Finland and the Bank of Canada).

(3) Previous work on structural VARs in the context of the euro area includes Peersman and Smets (2001) who, however, only estimate technology shocks, and Peersman and Straub (2004) who estimate both monetary and technology shocks using model-based sign restrictions.

ent. It should be noted that the above equation cannot be estimated without imposing some restrictions on the matrix A_0 . In fact, the model is first estimated in its reduced form:

$$Y_t = B(L)Y_{t-1} + u_t.$$

The structural shocks are related linearly to the one-step-ahead forecast errors, u_t :

$$u_t = Ce_t, \quad E(e_t e_t') = I$$

and the parameters of the structural form are linked to those of the reduced form by:

$$C = A_0^{-1}, \quad B(L) = A_0^{-1}A(L).$$

In order to uniquely identify monetary policy and technology shocks it is necessary to impose restrictions on the matrices A_0 and $A(1)$ (see Alves *et al.*, 2006 a,b and section 3 below).

2.2. The NiGEM

NiGEM is an estimated multi-country model of the world economy.⁴ In NiGEM a large number of economies are linked through the effects on trade as well as financial markets. NiGEM includes nominal rigidities that slow the process of adjustment to shocks and typically a dynamic error correction framework is adopted for key behavioural equations.

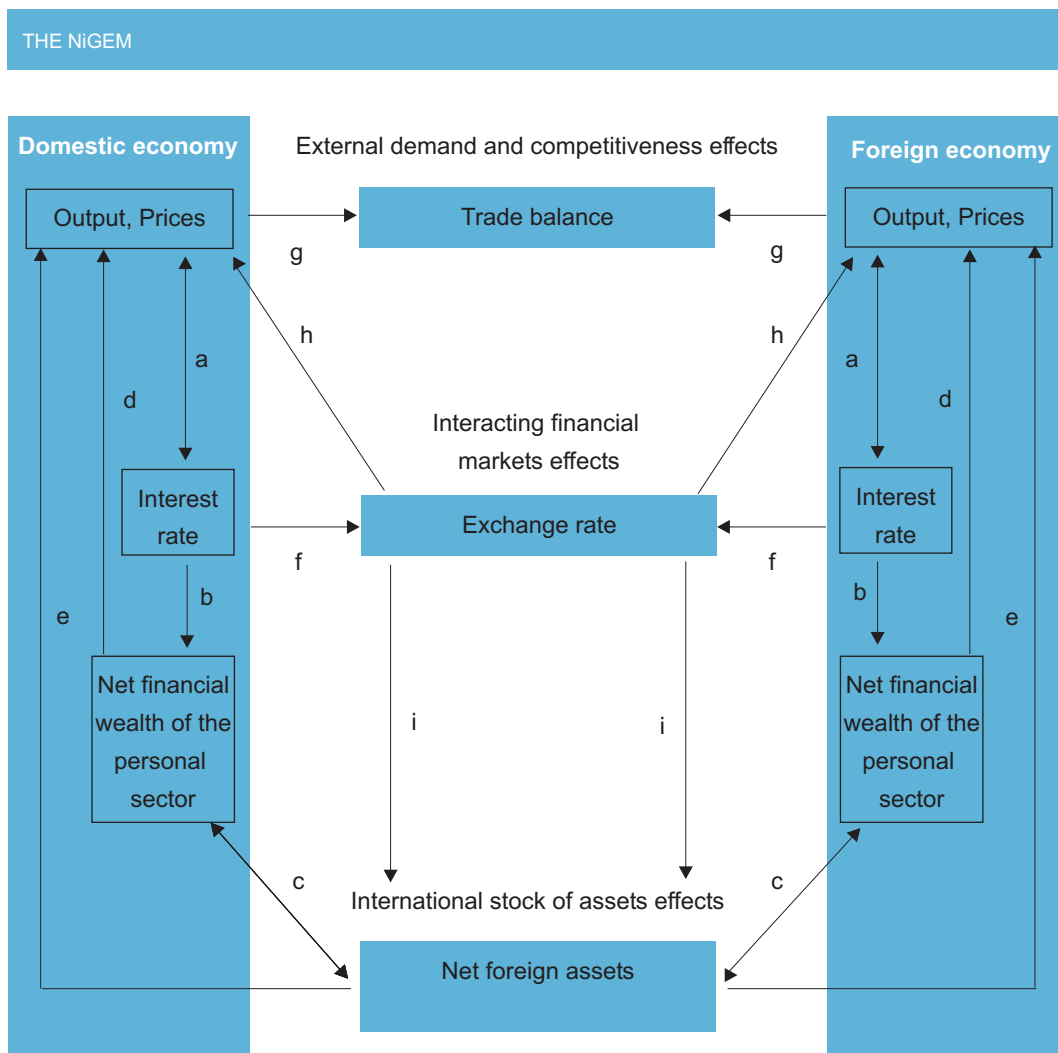
NiGEM provides us with a quite detailed picture of different economic effects of policy simulations. According to Pagan's approach, a structural model like NiGEM may be seen as middle ground between SVAR and DSGE models. In SVAR models, the use of theoretical priors is scarce and the system cannot include a large number of variables. On the other hand, NiGEM is not so well theoretically founded as DSGE models, but has a much greater richness in terms of the features of the model. It should be noted, however, that NiGEM can be run with either forward or backward looking expectations. Among the models used in this article, it is the only one that considers international linkages (Chart 1).

In NiGEM almost all economies belonging to the Organisation for Economic Co-operation and Development (OECD) are included as separate blocks but with a common underlying structure. The euro area is not modelled as a whole, but results from the aggregation of individual countries that are modelled separately. Nevertheless, it is possible to run the model in a way that is consistent with a monetary union in the euro area and thereby ensure common interest rate and exchange rate paths for countries within the euro area.

Each country model has complete demand and supply sides and full asset structures. On the supply side, NiGEM is a one sector model. The quantity of output supplied in each country depends on the aggregate production function and the equilibrium in the labour market. International factors affect supply only through real interest rates, except in some countries where the rate of technical progress depends on the stock of foreign direct investment. Prices are strongly related to the cost function implied by the production function as well as to the measure of capacity utilisation. In the labour market there is a set of equations that determine the levels of employment, unemployment, average hours worked and hourly wages in equilibrium. In the long run, real wages rise in line with productivity, all else equal. In the short to medium-term, unemployment imposes a stabilising feedback mechanism in the model putting downward pressure on real wages.

(4) For a detailed description see "The NiGEM Model", NIESR, document available at <http://www.niesr.ac.uk/pdf/nigem2.pdf>.

Chart 1



Note: Type of effect: a - Monetary policy; b - Asset price changes in financial markets; c - Revaluations of foreign assets; d - Wealth effects; e - Income balance; f - Interest rate parity; g - Trade; h - Import and export prices; i - Valuation effects.

Demand is generated both domestically, some of which spills over into imports of goods and services, and externally, that is demand for exports of goods and services. Consumption depends on income (the sum of wages, profits and interest income plus transfers and net of taxes) and wealth. The change in the capital stock adjusted for depreciation determines investment. External trade of goods and services depends upon demand and relative competitiveness effects.

In NiGEM each country has a stock of foreign assets and a stock of foreign liabilities. Therefore, changes in exchange rates and in both domestic and foreign equity prices and interest rates will generate wealth and income effects.

Each country has a model for the public sector which includes taxes and government spending. Fiscal policy is set using taxes and levels of spending. In addition, there is an automatic solvency rule, which is implemented by an increase in the direct tax rate. This simple feedback rule ensures that governments remain solvent in the long run by returning the budget deficit and debt stock to sustainable levels. In the long run, Ricardian equivalence is fulfilled.

Financial markets are crucial in NiGEM as they determine long-term interest rates, exchange rates and equity prices. They may be backward looking or forward looking. Nominal short-term interest rates are determined by monetary policy rules. Long-term interest rates are a forward convolution of expected short-term interest rates. Forward looking exchange rates are ruled by an Uncovered Interest Rate Parity condition which means that in each period the expected change in the forward looking exchange rate is equal to an interest premium. Equity prices are solved out from the discounted sum of expected profits.

2.3. The DSGE model

The DSGE model used in this study is a slightly modified version of the model in Smets and Wouters (2003) that we re-estimated with euro area data (see Appendix). This is a closed economy model where there are two types of optimising agents: households and firms. Households optimise utility (which is a function of consumption and leisure) subject to their budget constraint and firms maximise profits. The government sector is modelled as being totally exogenous and the behaviour of the monetary authority is assumed to be well described by a Taylor-type rule where the interest rate is assumed to react to the output gap and deviations of inflation from target. The structure of the model is summarised in Chart 2.

Households want to keep their lifetime consumption as smooth as possible. In addition, households display external habit formation,⁵ which introduces persistence in the consumption process, a feature of the data. As regards savings, the model assumes that agents can invest in one-period bonds, which yield a return. The interest rate on these bonds is the same as the policy rate of the central bank.

Households also decide on how much time to devote to work or to leisure and they set their wage in the labour market. It should be noted that this model rules out the existence of unemployment.⁶ Each household offers a differentiated type of labour to a labour aggregator that transforms it into a homogeneous input. Wages are sticky à la Calvo (1983), which means that there is a constant and exogenous probability of households being able to reoptimise wages in each period. The fraction of households that cannot reoptimise wages partially updates their previous period wages with previous period inflation. The households that are allowed to reoptimise their wages set the wage so that the present value of the marginal return to working is a markup over the present value of the marginal cost of working (i.e. the disutility of working). This implies that the aggregate real wage is a function of expected and past real wages and expected, current and past inflation.

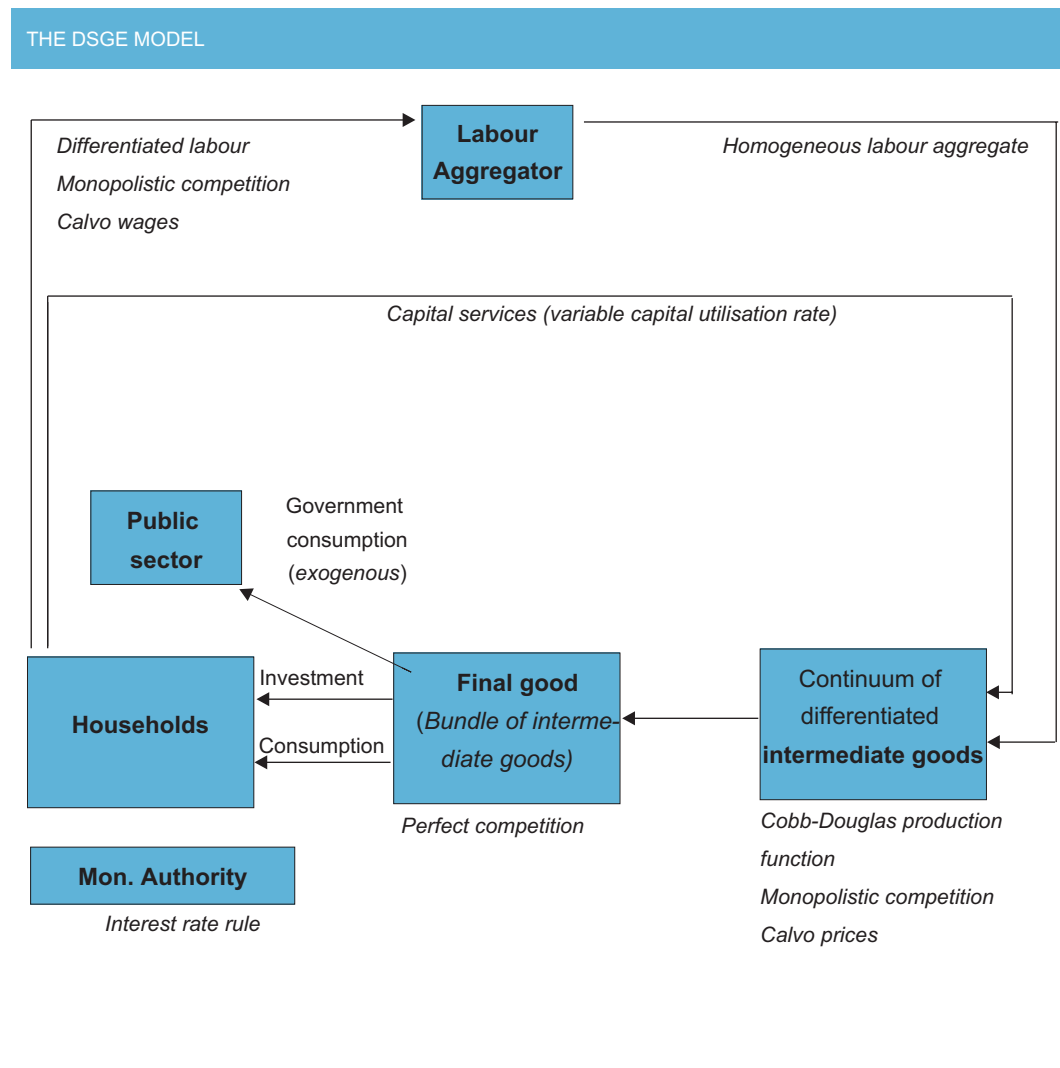
The model assumes that capital is owned by households who rent it to firms. Households can change their capital stock by investing in new capital, taking into account that there are adjustment costs.⁷ They can also change the degree of utilisation of the capital stock (i.e. the level of capital services that are rented). When households rent out capital to firms they receive a remuneration, the rental rate of capital. As the rental rate of capital goes up, the capital stock can be used more intensively according to a cost schedule (following King and Rebelo, 2000). The real value of installed capital depends positively on its expected future value (taking into account the depreciation rate) and on the expected val-

(5) Under habit formation, an increase in current consumption lowers the marginal utility of consumption in the current period and increases it in the next period. The fact that habits are considered external means that the habit formation depends on past aggregate consumption and not on the individual consumer's past consumption.

(6) For a recent example of an estimated DSGE model which allows for unemployment, see Christoffel, Kuester and Linzert (2006).

(7) These costs, that are a function of the change in investment, are useful in capturing the hump shaped response of investment to various shocks as discussed by Christiano, Eichenbaum and Evans (2005).

Chart 2



ues for the real rental rate and the rate of capital utilization (net of the expected cost of using capital).⁸ Households choose the utilization rate that equals the cost of higher utilization to the real rental rate of capital services. The introduction of variable capital utilisation tends to smooth the adjustment of the rental rate of capital in response to changes in output.

Focusing now on the product markets, this economy produces one final good and a continuum of intermediate goods. The final good is just a bundle of the continuum of intermediate goods and its market is in perfect competition. The final good can be used for consumption (either private or public) and investment purposes. The intermediate goods are differentiated, so there is monopolistic competition in the markets for these goods. Each intermediate good is produced by a single firm via a Cobb-Douglas production function with capital and labour.

Firms decide on the combination of production inputs (by minimising costs) and then they decide on the price they charge. Firms are not allowed to choose prices optimally in every period. As in Calvo (1983), in each period only an (exogenous) fixed proportion of the firms get to reoptimise. The other

(8) We use a different timing assumption regarding the stock of capital evolution equation, because Smets and Wouters (2003) assume that investment takes one period to be installed and we assume that it is installed immediately.

firms partially update their previous period prices by means of the previous period aggregate inflation (following Christiano, Eichenbaum and Evans, 2005). As a result of the maximisation of profits, firms set the new prices as a markup over current and expected marginal costs. This implies that current aggregate inflation will depend on past and expected inflation and on the marginal cost.

All markets have to clear. This implies that the final good production (net of the costs of changing the capital utilisation) has to equal its demand, namely for consumption purposes (both private and public) and investment purposes. Additionally, the capital rental market is in equilibrium when the demand for capital by the intermediate goods producers equals the supply by the households and the labour market is in equilibrium when the firms' demand for labour equals labour supply at the wage set by the households.

3. DEFINITION OF THE SIMULATION EXPERIMENTS

3.1 Monetary policy shock

Following Christiano, Eichenbaum and Evans (1999), we identify monetary policy shocks as deviations of the interest rate from a policy rule that the central bank is assumed to follow.

In the SVAR model, the identification of the monetary policy shock is achieved by assuming that the only date t variables in the monetary authority's information set are productivity, measures of economic activity (hours, capacity utilization), wages and inflation (see Alves *et al.* 2006a, b).

In the DSGE and the NiGEM models the monetary policy shock is the additive random term in the Taylor rule where the central bank adjusts the short-term interest rate as a reaction to past levels of the rate (interest rate smoothing), the output gap and differences between the inflation rate and its objective. Note, however, that there are differences in the way that the rule is implemented. In fact, in the NiGEM the rule for the short-term interest rate (R_t) is defined in terms of the level of the variables:

$$R_t = \rho R_{t-1} + r^* + \gamma_y (y_t - \bar{y}_t) + \gamma_\pi (\pi_t - \pi^*_t) + \varepsilon_t$$

where $y_t - \bar{y}_t$ is the output gap, $\pi_t - \pi^*_t$ is the deviation between the inflation rate and the central bank's inflation target, and r^* is the long run equilibrium nominal interest rate which is set equal to 4.0 per cent. In the DSGE model we use the rule:⁹

$$\hat{R}_t = \rho \hat{R}_{t-1} + \gamma_y \hat{y}_t + \gamma_\pi (\hat{\pi}_t - \hat{\pi}^*_t) + \gamma_{\Delta y} (\hat{y}_t - \hat{y}_{t-1}) + \gamma_{\Delta \pi} (\hat{\pi}_t - \hat{\pi}_{t-1}) + \varepsilon_t$$

where the hat (^) means that the variables are measured in deviations from the steady state. In the DSGE model ρ is estimated to be equal to 0.89, γ_π is equal to 1.5 and, γ_y , $\gamma_{\Delta y}$ and $\gamma_{\Delta \pi}$ are all equal to 0.1. In NiGEM we assume further that the parameter ρ is equal to 0.8, γ_y equal to 0.5 and γ_π equal to 1.5.

In the simulations described below, the monetary policy shock involves a temporary and exogenous increase in the stochastic term of the euro area monetary policy rule (i.e. an increase in ε_t), so that the short-term interest rate rises by 25 basis points in the period the shock hits the economy.

(9) In the Smets and Wouters (2003) model the interest rate rule is defined in terms of the deviation of output from potential, which is defined as the level of output that would prevail under flexible prices and wages in the absence of cost-push shocks.

3.2. Technology shock

The identification approach of the technology shock implies some differences in terms of the way it is implemented in each of the models. In the case of the SVAR models, to identify the technology shocks we follow much of related literature by imposing the restriction that these are the only shocks that can affect labour productivity in the long run. In implementing it, we pursue the methodology advocated by Shapiro and Watson (1988). We assume, as is standard in the literature, that in the short-run real economic activity and prices do not react to monetary policy shocks or to shocks to money velocity. In the NiGEM model, the technological shock consisted of temporarily increasing labour-augmenting technical progress in all euro area countries in the Constant Elasticity of Substitution production function. In the DSGE model the shock is implemented as an exogenous increase in total factor productivity in a Cobb-Douglas production function. In all three models, the magnitude is calibrated such that it has - not necessarily on impact - a maximum effect on euro area output of 1 percent.

4. RESULTS

In this section, we report the responses of macroeconomic variables to a monetary policy shock and a technology shock as described in the previous section. In the following description of the results, we concentrate on the first 20 quarters after the occurrence of each shock.

4.1. Impulse responses to a monetary policy shock

4.1.1. SVAR

The responses of the variables to the monetary shock are shown in Chart 3.¹⁰ After a monetary policy shock the interest rate shows a hump-shaped increase. Output, consumption, investment and hours worked per capita all exhibit hump-shaped falls that take approximately one-and-half to two years to get to the trough. As expected, investment responds in a quantitatively stronger fashion than consumption. The short-run reaction of inflation is an increase. This result is common in VAR studies and constitutes what has been called the “price puzzle”¹¹. Surprisingly, the short run reaction of real wages is to increase and that is in spite of inflation rising in the same time frame. That effect is reversed thereafter so that the real wages’ response eventually goes into negative territory.

4.1.2. NiGEM

In NiGEM after a monetary policy shock there is a prompt response of financial markets. The positive interest rate differential between the euro area and other economies created by the shock generates an expectation of euro depreciation in the periods ahead.¹² Forward-looking exchange rates immedi-

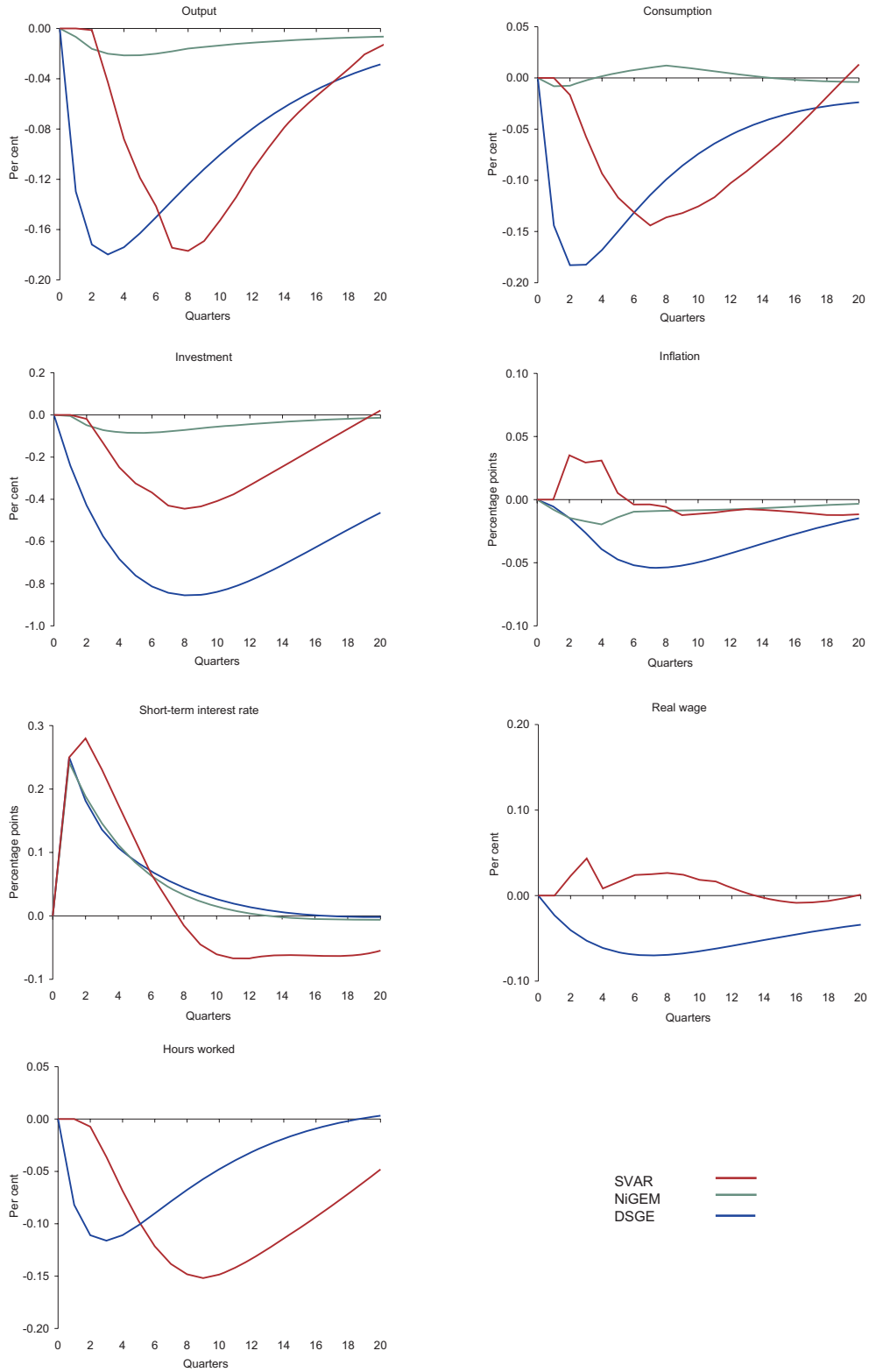
(10) The responses of all variables are measured in percentages, except the interest and inflation rates, which are measured in percentage points.

(11) In the literature there are several explanations for this result. One explanation is that the price puzzle is the result of the central bank reacting to leading indicators of inflationary pressures (such as commodity prices). As there are lags in the effects of monetary policy, inflation rises in a first stage at the same time that interest rates are also rising. In the medium term, inflation eventually declines as the delayed effects of monetary policy are transmitted to the economy. Another explanation for the price puzzle is that the increase in interest rates raises the costs of firms which are, in the very short-term, transmitted to consumer prices.

(12) The responses are in percentage deviations from baseline, except for the interest and inflation rates, which are in percentage point deviations from the baseline.

Chart 3

IMPULSE RESPONSES TO A MONETARY POLICY SHOCK^(a)

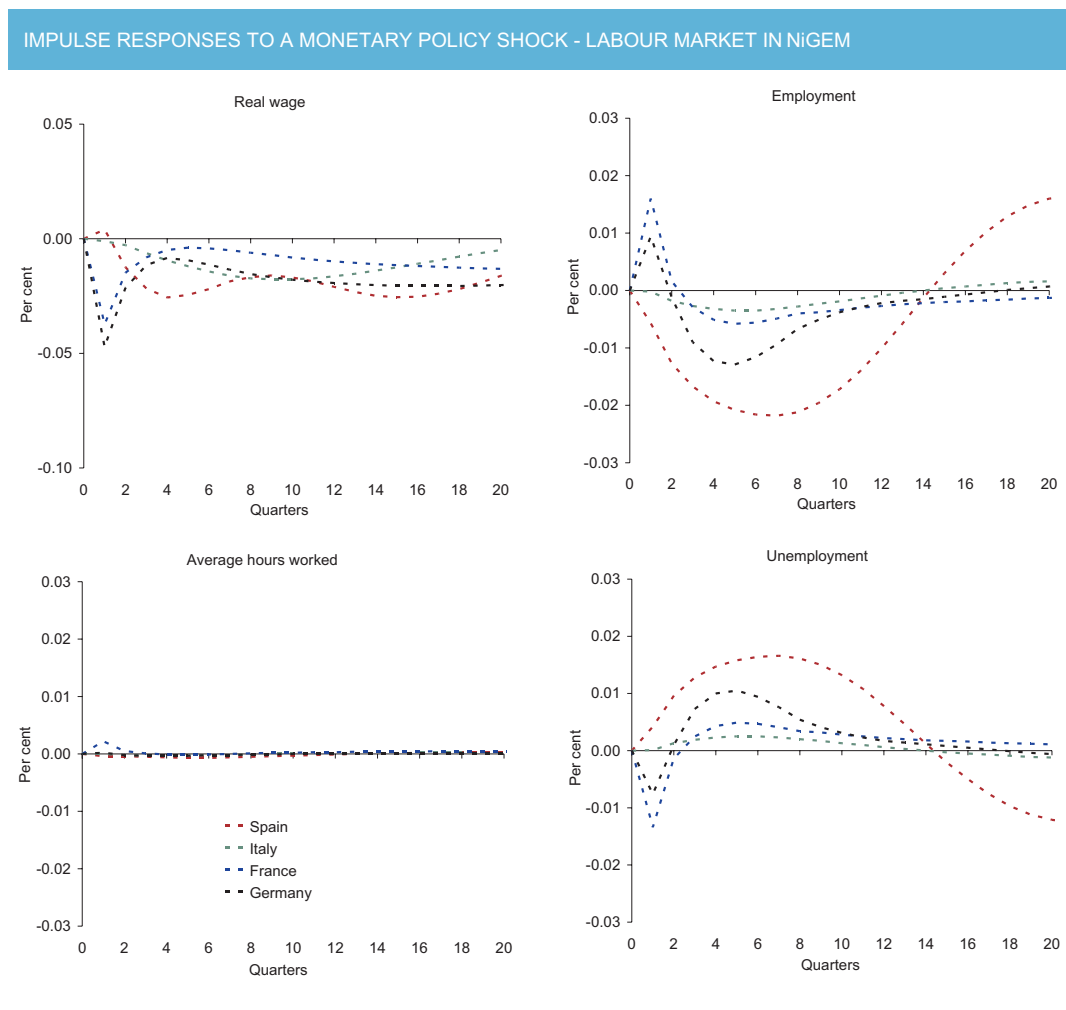


Note: (a) For the NIGEM no aggregation for the whole euro area is available in the case of real wage and total hours worked.

ately respond with a movement in the opposite direction, which means an instantaneous nominal effective appreciation of the euro relative to the baseline. In line with the evolution in short-term interest rates, long-term interest rates rise. Higher interest rates lead to a decline in both financial asset and housing prices in comparison to the baseline.

The initial shock and the financial markets' reaction transmit gradually to product and labour markets through the deceleration in demand and prices (Chart 3). The real appreciation of the exchange rate reduces net external demand. In particular, real exports drop. The rise in the user cost of capital influenced by the increase in the forward-looking real long-term rate (i.e., considering forward-looking expectations of inflation) diminishes the desired capital stock and real investment. Though more moderately, real private consumption also declines relative to the baseline influenced primarily by the decrease in real wealth. The decrease in demand feeds directly into the capacity utilization equation and generates a downward pressure on domestic prices. In addition, the exchange rate appreciation reduces import prices which pass-through to domestic prices. As a result, consumer price inflation declines relative to the baseline.¹³

Chart 4



(13) The reduction in inflation will moderate though not impeding the increase in the forward-looking real long-term rate, the real appreciation of the currency and the decrease in real wealth.

The labour market adjusts to the reduction in demand and in the largest euro area economies there is generally a reduction in employment and an increase in unemployment in comparison to the baseline (Chart 4). The increase in unemployment, in conjunction with the decline in inflation and the forward-looking behaviour in labour market, leads to a gradual decline in the nominal wage relative to the baseline. Real wages also decline, though in a more mitigated amount, influenced by the decline in inflation.

For some years after the shock, real disposable income is sustained though it eventually falls in the context of diminishing labour compensation. Two factors contribute to the positive behaviour in real personal income for some time: first, the fall in inflation exerts a favourable effect and second, the increase in the domestic interest income and the improvement in the balance of income from abroad. The behaviour of real disposable income explains why real consumption does not decline much in response to a monetary policy shock and even moves slightly above baseline in the second and third years after the shock.

4.1.3. DSGE model

In the DSGE model, the transitory monetary policy shock implies that the nominal interest rate increases which leads to a hump-shaped fall in output, consumption and investment (Chart 3).¹⁴ The maximum effect occurs in the two first years after the shock. Higher interest rates make savings more attractive and therefore households substitute consumption today for consumption in the future, which partly explains the decline in consumption. A higher interest rate increases the cost of investment which induces investment to fall. The maximum effect on investment is around 3 to 4 times larger than that on consumption. The decrease in demand for final goods makes firms produce less and demand less factor inputs, so employment falls. Lower demand for labour puts downward pressure on nominal wages and given the small decline in inflation, real wages also fall. The decline in labour and the real wage reinforce the fall in consumption.

4.2. Impulse responses to a technology shock

4.2.1. SVAR

The responses of the variables to the technology shock for the SVAR are shown in Chart 5. The impact of a positive technology shock is to generate a steady increase in output that takes about 20 quarters to reach one percent. Consumption and investment also rise in line with output. Hours worked and real wages rise.¹⁵ It is still worth noting that the impact on inflation is negligible and interest rates increase slightly.

4.2.2. NiGEM

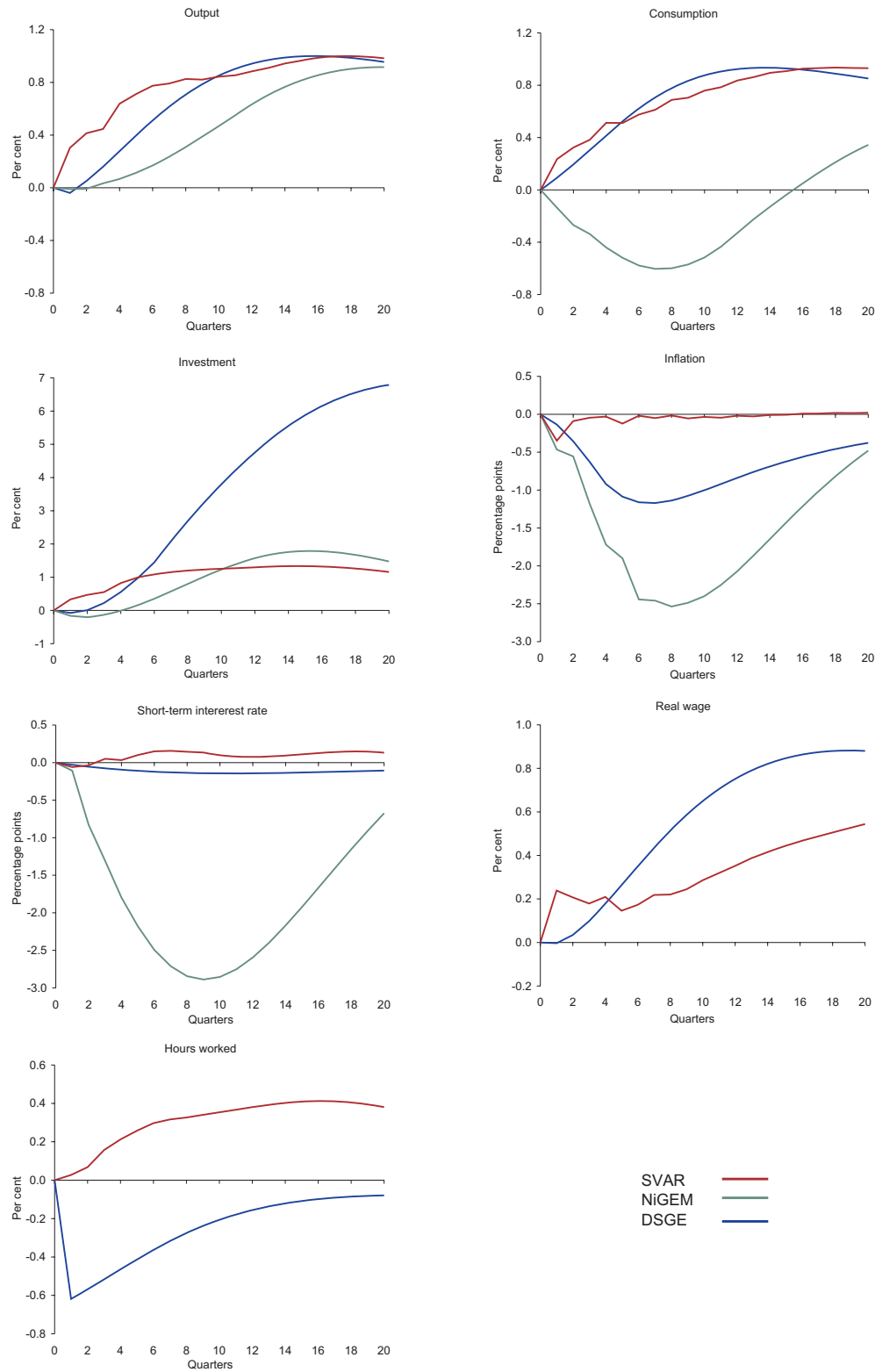
The increase in exogenous technical progress feeds directly into the capacity utilization equation and there is an immediate downward pressure on prices as a result of the increase in economic capacity. Inflation declines immediately relative to the baseline (Chart 5). In a framework where the monetary

⁽¹⁴⁾ The responses are in percent deviations from the steady-state, except for the interest rate which is in deviations from the steady-state.

⁽¹⁵⁾ Note, however, that this result hinges crucially on the assumption of stationarity of hours. If one considers hours to be non-stationary then hours worked would fall in response to a positive technological shock (see Alves, *et. al* 2006 a, b).

Chart 5

IMPULSE RESPONSES TO A TECHNOLOGY SHOCK^(a)



Note: (a) For the NiGEM no aggregation for the euro area is available in the case of the real wage and total hours worked.

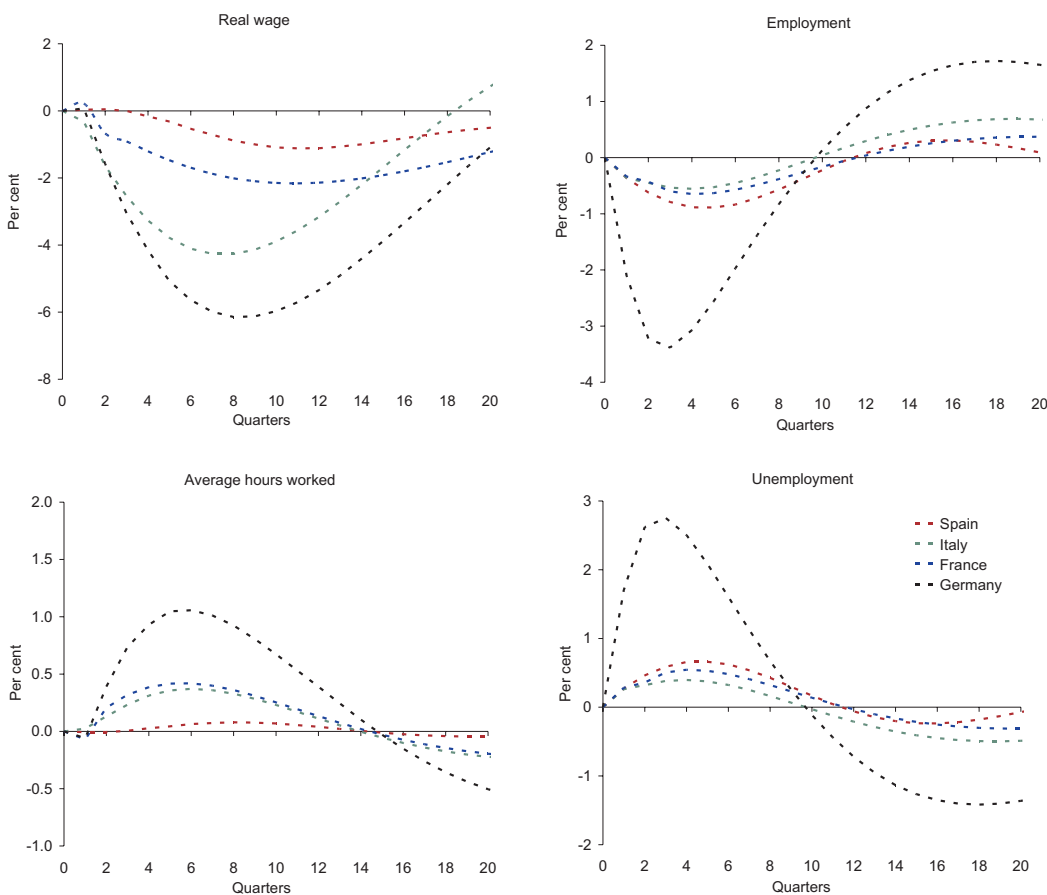
authority follows a Taylor rule, the decline in inflation in a first stage leads to a fall in interest rates. In parallel, forward-looking exchange rates will react in the first period in anticipation to the expectation of lower interest rates which means an instantaneous nominal effective depreciation of the euro relative to the baseline. This factor together with declining inflation implies evidently a real effective depreciation of the euro, i.e. euro area competitiveness increases.

The changes in financial markets feed into real economic activity in particular via stimulating investment and external demand. The user cost of capital declines after the shock, influenced by the fall in the forward-looking real long-term rate and, consequently, the desired capital stock and real investment rise. In turn, the real exchange rate depreciation diminishes the price of exports and fuel external demand. The positive effect on investment and net exports contribute to the increase in real GDP.

For some periods after the shock, there is a reduction in employment and an increase in unemployment in comparison to the baseline (Chart 6). This follows immediately from the shock that leads to a reduction in labour demand for each level of output and real wages. The response of average hours is relatively symmetric to the employment response and is mainly explained by the short-run dynamics in real wages and GDP. As the response of average hours is smaller than that of employment, total hours worked decline. The increase in unemployment, in conjunction with the decline in inflation and the forward-looking behaviour in the labour market, leads to a strong decline in the nominal wage, which con-

Chart 6

IMPULSE RESPONSES TO A TECHNOLOGY SHOCK - LABOUR MARKET IN NiGEM



tributes to diminish labour compensation and personal income relative to the baseline. In the first years after the shock, the decrease in nominal wage and income may be greater than the one observed in prices, which in general leads to a decline in real wages and real disposable income in the biggest euro area countries. These factors contribute to dampen real private consumption for some time after the shock.

Eventually, the expansion of real activity becomes more broadly balanced as private consumption gains momentum. As mentioned before, besides income, consumption depends also on wealth. In this context, it should be noted that real financial wealth increases after the shock, benefiting to a great extent from the lower level of prices and in part from a temporary increase in nominal wealth resulting from the rise in equity and bond prices following the interest rate decline. On the other hand, over time, the ongoing activity expansion will reverse the labour market situation, implying a decrease in unemployment, a recovery in real wage and higher real disposable income.

4.2.3. DSGE model

After a positive technology shock, the increased productivity temporarily expands the economy's production frontier and lowers firms' marginal costs. As a result, output, consumption and investment rise (Chart 5). The response of the variables occurs with some delay, which is shorter in the case of consumption, and is quite persistent, with the effects of the shock being significant for over five years. The real wage increases steadily, which is also reflected in increased consumption though with some delay due to the presence of habit formation.

Given lower marginal costs, firms adjust their prices downward and therefore inflation falls. The decline in inflation is gradual, due to the existence of stickiness in price adjustment, peaking in the second year after the shock. Despite the rise in output, the monetary authority responds with a decrease in interest rates as the effect of the fall in inflation dominates in the Taylor rule. Since workers are more productive, firms need less labour to produce the same amount of output. This leads to a fall in the number of hours worked. Since this is a general equilibrium outcome, it should be noted that the reduction in hours worked is also the desired response of workers.

The responses of labour market variables should be treated with some caution as this sector is quite stylised in this model. It should also be noted that the response of hours worked is not a built-in feature of the model. One possible interpretation of the fall in hours (although not shown in the charts, the response of employment is similar to the one of hours worked) is that the technology shock allows households to work less (and therefore have more leisure which increases their utility) while at the same time having a higher real wage and a higher level of consumption.

5. CONCLUSIONS

This study has characterised the responses of euro area macroeconomic aggregates to monetary policy shocks and technology shocks using three different models. The analysis has allowed the identification of similarities in terms of the responses of some macroeconomic variables but also some striking differences between the models have been uncovered. In all models, the monetary policy shock that consists of a rise in interest rates has a contractionary impact on economic activity. However, in the case of the NiGEM, the response of consumption is more muted. This seems to be linked to effects coming from the external sector, which is excluded from the other models where the euro area is treated as a closed economy. In terms of the inflation response, both the NiGEM and the DSGE models respond as expected, with a contractionary monetary policy leading to lower inflation. In the

SVAR model, however, inflation rises in the short-term, declining only in the medium-to longer term. This puzzle is a feature common to other VAR studies. As for the positive technology shock, the three models show rather similar responses in terms of increased output and investment. However, consumption declines in the case of NiGEM while in the other models it rises. The negligible impact on inflation in the SVAR model differs from that in the DSGE and the NiGEM models where the technology shock has a strong deflationary impact. In the NiGEM this deflationary impact leads to a real depreciation of the euro and to an improvement in exports, which explains why output increases despite the fall in consumption. Another striking difference has to do with the response of labour market variables. In the DSGE and the NiGEM models the labour input declines after a technology shock while in the SVAR it increases. In the DSGE model this is the outcome of the optimising behaviour of households and firms. In the case of the NiGEM more detail on the labour market is available. The responses show that employment declines and unemployment increases in the shorter-term. This may be explained by the fact that demand reacts sluggishly to the increase in the expansion of production capabilities and therefore less labour input is needed to satisfy such demand. The increase in unemployment in NiGEM has negative feedback effects on wages and, consequently, on disposable income and consumption.

In sum, the above results highlight the importance of models as a disciplinary device for analysing the effect of shocks on the economy. The heterogeneity found in the results advises for the use of a broad set of models, to gain robustness in the answers provided. In particular, the modelling of the labour market and the inclusion of open economy features seem crucial in the response of euro area variables to shocks. Such features are usually included in traditional models but are often absent from DSGE models which have been increasingly used in recent years. Our analysis therefore supports the efforts underway to improve these blocks in micro-founded models, an area of active research.

Appendix. Taking the models to the data

The parameters of each of the three models used in this study are obtained with different procedures. While the SVAR model is estimated, the NiGEM and DSGE models involve both estimation and calibration. Starting with the SVAR, we have used a model estimated in Alves *et al.* (2006a, b). The data refer to twelve euro area member states for the period from the first quarter of 1970 to the third quarter of 2004. The variables included are real GDP, consumption, investment, capacity utilization, wages, per capita hours, the short-term interest rate, the GDP deflator and the monetary aggregate M1. For periods after 1999, the data correspond to an aggregation of the available country series using, as far as possible, official statistical sources, such as the Eurostat, the ECB, the European Commission and the OECD. However, euro area series at a quarterly frequency are often available only for a relatively short time-span and we had to backdate a number of series. To do this we relied mostly on the database by Fagan *et al.* (2001), hereafter Area-Wide Model (AWM) database (see Alves *et al.*, 2006). The short-term interest rate series used is the three-month Euribor provided by Bloomberg and for periods before 1999 we used data from the AWM database. The series for hours worked is the one constructed in Alves *et al.* (2006a, b) which is obtained by multiplying average hours per employee by the total number of employees and then dividing by working age population. Inflation is measured as annualised quarterly changes in the logarithm of the GDP deflator. All variables are in logarithms, except for the short-term interest rate.

The NiGEM model used in this article is estimated and calibrated by the NIESR and corresponds to the version V4.06 released in October 2006. The estimation period of the model equations is not identical across equations and is dependent on structural stability (the earliest start date is the first quarter of 1961). The baseline scenario used in simulations corresponds to the results obtained from the NIESR

forecasting exercise in October 2006, which is based upon a quarterly database containing all the information released up to that date.

In which respects the DSGE, following Smets and Wouters (2003), we estimated the log-linearised version¹⁶ of the model using Bayesian techniques, keeping however some parameters fixed. The model is estimated using data for seven observed variables, namely real GDP, consumption, investment, GDP deflator, real wage, employment and the nominal short-term interest rate. We used a slightly different and updated quarterly dataset than the one of Smets and Wouters (2003) (namely data for the period from the first quarter of 1980 to the fourth quarter of 2006). Given that the model implies that all variables must be used in terms of differences from the steady state level, all series used must be stationary. The series were stationarized by removing linear trends as in Smets and Wouters (2003).

While the theoretical model would call for the use of hours worked for the labour input, in the estimation Smets and Wouters used data on employment because no official series for euro area average hours worked was available. This implies that one has to use an auxiliary equation which relates employment (the observed variable) with hours worked (the variable in the model but that is unobserved). Given that employment is likely to respond more slowly to macroeconomic shocks than total hours worked, it is assumed that in any given period only a constant fraction of firms is able to adjust employment to its desired total labour input. The difference is taken up by (unobserved) hours worked per employee (that are completely flexible). We followed the same procedure and used the employment series in the estimation, but we used a slightly different version of this auxiliary equation.

(16) We take a log-linear approximation of the equilibrium equations around the steady-state.

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