NATIONAL INSTITUTE OF ECONOMIC AND SOCIAL RESEARCH

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Discussion paper no.160

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International Monetary Policy Coordination An Evaluation of Cooperative Strategies using a large Econometric Model

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Abstract
Given the increase in world economic integration we wish to examine whether there is a case for coordinating monetary policy across some of the major economies. In late 1998 and early 1999, US monetary policy responded to global economic conditions and interest rates were cut in response to the crisis in Asia. But Europe could have also played an important role in helping to boost world demand given a serious economic downturn. We undertake stochastic simulations on the National Institute's World econometric model, NiGEM, in order to evaluate independently set monetary policy where domestic considerations remain the prime objective and a coordinated policy where domestic interest rates react to conditions outside the national border.

Key Words: International Policy Coordination, Macro-economic Stability, Stochastic Simulations, Policy Rules.

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[1] The support of the ESRC under grant R022250166 Do small differences matter? is gratefully acknowledged. We would like to thank Andrew Hughes Hallet and Stephen Hall for many helpful comments on this paper. All errors remain ours.

1. *Introduction*

The rationale for policy coordination stems from the potential spillover effects that independent domestic policy can have on other countries. These spillover effects may result in adverse economic consequences for other nations. For example a tightening of monetary policy in one country to reduce inflation will result in an appreciation of the exchange rate which can adversely affect the inflation prospects of other countries as imports become more expensive. The issue of spillover effects has become more prominent as the world economy becomes ever more integrated through the reduction of trade barriers, increases in technology and increased cross-border movements of capital and labour. Independent monetary policy does not take into account the externalities of a country's policies on other countries and internalising these in the national decision making process of individual countries may be beneficial.

Increased integration also results in a more rapid transmission of macroeconomic shocks across world economies. Events such as the Asian crisis and the effects it has had across the world have highlighted the important role that international policy coordination may be able to play in helping to keep world demand afloat. The risks facing the current global economic environment may strengthen the case for international policy coordination. These risks include a number of possible scenarios with a negative impact, such as a possible over valuation of the US stock market and the potential downturn in the US that a stock market correction may bring. There are still risks emanating from Asia, recovery is being led by strong growth in their exports but their major market, Japan, is suffering from a depressed economy. Europe too is experiencing low growth and high unemployment. Inflation is very low in both economies, but while nominal interest rates are low in both, Japan's rate are very close to the floor given by zero returns.

Game theoretic models show that in the presence of significant spillover effects, cooperative behaviour can lead to a Pareto-optimal outcome. One of the first applications of game theory to the study of international policy coordination can be found in Hamada (1974, 1976, 1979), where a coordinated game is defined as one in which governments maximise a weighted average of their welfare functions. An uncoordinated game is one where governments optimise their own welfare function

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and take the actions of other governments as given. The simple static game can be set out as follows:

$$Min\, L_j = w_j(x_j, u_j, u_i)$$

subject to

$$x_j = f(x_j, u_j, u_i)$$

where x is a vector of state variables

u is a vector of control variables or policy instruments

In the uncooperative equilibrium, where the policy makers are Nash players, each policy maker minimises his loss function taking as given the other policy makers instrument. The equilibrium can be obtained by solving the first order conditions:

$$\frac{dL_j}{du_j} = 0 \quad \text{for all } j$$

Assuming all countries are symetric we can assume they will choose the same path for the policy instrument and so setting $u_j = u_i$ in the first order conditions yields the Nash equilibrium. By substituting this into the loss function the Nash losses can be calculated. Under the cooperative equilibrium each country will act as if they delegate their sovereignty over domestic policy to one single 'policy maker' who is assumed to have a utilitarian social welfare function. The 'policy maker' will minimise a weighted sum of their loss functions. That is the policy instrument will satisfy the following first order conditions:

$$\frac{dL_j}{du_j} + \sum_{i \neq j} \frac{dL_i}{du_i} = 0$$

Again substituting $u_j = u_i$ in the first order conditions yields the efficient equilibrium and substituting this into the loss function yields the efficient losses. The efficient equilibrium can only be attained if the policy makers can commit themselves to a binding agreement. In this simple framework it can be shown that each player's loss function is lower under the cooperative solution than in the Nash equilibrium.[2]

There have been a number of other authors such as Miller and Salmon (1985), Currie and Levine (1985) and Oudiz and Sachs (1985) who have all drawn attention to the possibility that policy coordination can bring about a solution that is superior to those generated when all parties act independently. Another strand of analysis in this area has attempted to apply the policy game to large econometric models to quantify the potential gains in moving from an uncooperative Nash equilibrium to a coordinated policy. Work in this area has tended to find low potential gains from policy coordination, (for example Hughes Hallett (1986, 1987) and Masson (1992). Currie, Levine and Vidalis (1987) show that a government's reputation is important and could lead to much larger gains and increase the relative value of coordination. However, there may be no benefits to policy coordination without reputation. This strand of work is based on the use of fully optimal policies to measure the size of potential gains where the full information set available to the policy maker is used. This can lead to outcomes that are model specific and as Hall and Nixon (1997) point out such rules can exploit unrealistic model properties. Also Holtham and Hughes Hallett (1987) have shown that the optimal policy rules derived from 10 econometric models are not robust in that the gains from policy coordination do not hold across models.

A further strand of the literature has been to use simple policy rules where only a limited amount of information is taken from the model and thereby the complexity of the rule is reduced considerably. It is generally found that these simple rules are much more robust across models, and are often close to optimal. Most of the literature has focused on targeting exchange rates and stems from the work of Williamson and Miller (1987) who proposed the use of monetary policy to stabilise exchange rates around their Fundamental Equilibrium levels, (FEERs) so that current accounts are in equilibrium in the long run. Hence the exchange rate is in fact an intermediate target. Williamson and Miller (1987), analysed the coordinated use of monetary policies at a global level in order to achieve the FEERs between the cooperating countries. From this the Extended Target Zone (ETZ) scheme developed, where monetary policy is used to target a set of target zones for exchange rates, and fiscal policy is used to target nominal domestic demand. This should then limit the destabilising properties of exchange rate targeting on domestic inflation.

Work in this area has included Currie and Wren-Lewis (1989, 1990) who used a version of NiGEM to empirically assess the ETZ scheme. Two rules were assessed; The ETZ scheme where monetary policy targets FEERs and fiscal policy controls domestic demand, and an alternative scheme which uses fiscal policy to target the current account and monetary policy to stabilise domestic demand. Optimal

[2] See Canzoneri and Henderson for an example of this approach. Also see Morales and Padilla (1995)

parameters were determined for both regimes using optimal control techniques. They find that both schemes improve welfare compared to actual policy behaviour over the period 1975-86. However, the ETZ scheme proved superior to the alternative scheme over this period.

Another paper that has used an earlier version of NiGEM to estimate gains from coordination is Christodoulakis, Currie and Garatt (1996) who evaluated 4 alternative proposals for G3 policy coordination; the ETZ scheme; Explicit Current Account Targeting (ECT) where monetary policy directly targets the current account; an Alternative Assignment where fiscal policy targets the current account and monetary policy targets domestic demand and a reversed assignment where monetary policy targets the current account in the short run and then switches to targeting nominal demand in the long run, fiscal policy does the reverse. Conclusions from this paper suggest if exchange rate volatility matters, then ETZ scheme is superior. However, if exchange rate volatility is not included in the welfare criterion then this scheme is no longer superior. The gains were also found to be unevenly distributed over the G3 implying some problems with the incentive structure of such schemes.

Other work in this area, such as Fenkel, Goldstein and Masson (1989) who use Multimod, analyses uncoordinated policy schemes where monetary policy is used to target the domestic monetary base or nominal income, and coordinated policies where monetary policy targets the exchange rate. Stochastic simulations were used to evaluate the performance of the rules but there were no clear findings in terms of welfare improving schemes. As Christodoulakis, Currie and Garatt (1996) show, the exchange rate targets are achieved by very a high degree of fiscal activism to prevent domestic output and inflation from deviating from target levels. Of course the use of fiscal policy may be constrained in practice. The agreements of the Stability Pact are likely to prevent Euro land countries using such fiscal activism to stabilise domestic economies.

In this paper we want to build on the previous empirical work done on large macro-economic models to undertake a quantitative empirical evaluation and comparison of simple policy rules for international policy coordination. International experience demonstrates that exchange rate targeting has some serious flaws, especially where it implies that there is a one way speculative bet on devaluation, as in the closing stages of the wider ERM in 1992. For the purposes of this paper we aim to explore a different set of policy rules in the context of international policy coordination. The objective of coordination, at least in late 1998, appears to be to stabilise world output to avoid recession. Hence, we do not target the exchange rate explicitly but rather use monetary policy to target some measure of world output in addition to the usual set of domestic variables.

In order to evaluate policy rules we have to have a formal framework, and preferably one that is a reasonable empirical representation of the world it discusses. In this paper we build on the previous work done on NiGEM by using stochastic simulation on the National Institute's Global Econometric Model, NiGEM. This model has forward looking behaviour in financial markets and labour markets and full working models of all European countries. It is therefore an appropriate tool for answering detailed questions about international policy coordination.

The best way to evaluate the stabilisation properties of the rules is to apply a sequence of random shocks to the model. Analysing policy rules using deterministic shocks is useful as it can give a clear comparison of the effects under a very specific shock to the economy (Barrell, Dury and Pain (1998)). However, the overall performance of a policy rule will depend on its ability to stabilise economic variables given a variety of shocks. To conclude that one rule is superior to another, we must apply a number of random shocks to the model and measure its overall performance, and hence the most effective way to evaluate rules is to use stochastic simulation techniques.

We present results in terms Root mean square deviations (RMSD) of main economic variables and welfare losses under each rule. A policy that reduces the variability of these economic variables will be judged to be more effective. We assess each rule against a benchmark rule which is taken to be a standard Taylor rule for each country where nominal interest rates react to domestic conditions (i.e deviations of domestic output and inflation from desired levels). We concentrate on the use of various simple policy rules as opposed to complex optimal rules. One of the main reasons for their considerable use on large-macro-economic models is that they are much easier to understand and interpret and a high degree of transparency gives them a considerable advantage. Advocates of the simple policy rules argue that they are helpful in monitoring the performance of the authorities (see, for instance, Taylor (1985) and (1999)), and this argument carries considerable force in the international context.

The structure of the paper is as follows; Section 2 presents the policy feedback rules we intend to evaluate. Section 3 gives a summary of the techniques used to undertake stochastic simulations on NiGEM. Section 4 gives a brief overview of NiGEM. Section 5 reports the results of our analysis and looks at the performance of the various policy rules. Section 6 concentrates on the implications of the results for future international policy coordination.

2. *The policy environment*

In order to investigate the performance of monetary policy rules we need to give them an explicit form. The benchmark rule, the uncoordinated policy scheme, and an alternative coordinated policy scheme is presented below.

Benchmark rule:

A standard Taylor rule has a nominal interest rate, r_t, that changes according to a reaction function which gives weight to deviations of output from trend and of inflation from target. The original Taylor rule is given by:

$$r_t = \alpha + \pi_t + \lambda(\pi_t - \pi^*_t) + \gamma(Y_t - Y^*_t) \qquad (1)$$

where π = the annualised domestic inflation rate, Y is log of real domestic output and α denotes equilibrium real interest rate. An asterix denotes target variables. Taylor's original specification (1993) used current levels of inflation and the output gap and we follow that practice, but outcomes for the current inflation rate and output gap are known only with a lag and hence we have to include some minimal element of forecast in our policy analysis. In this rule policy only reacts to these expected deviations of domestic output and inflation from target. Taylor suggested coefficients on inflation and output deviations were given the value 0.5 for a real interest rate rule, and hence 1.5 and 0.5 for a nominal equivalent rule.

Since Taylor's paper (1993), there has been much interest in the evaluation of different monetary policy rules. A substantial part of this literature concentrates on the use of simple policy rules on small stylised models many of which are backward looking closed economy models (see Rudebusch and Svensson (1998), Svensson (1997) and Ball (1997)). They argue, for example, that the optimal policy is some form of inflation targeting through a Taylor type rule, in which interest rates are adjusted in response to the deviation of output and inflation from their desired path. Indeed many have advocated that interest feedback rules that respond to increases in inflation with more than one for one increase in the nominal interest rate, are stabilising[3]. Taylor (1999) suggests that the ECB should follow such a rule where the response coefficient on the inflation target is greater than one. We have argued elsewhere (Barrell, Dury and Hurst (1999), that such a strong response may not be the best approach.

Christiano and Gust (1999) also propose that if a Taylor rule is to be adopted then inflation should be targeted aggressively but not output. The general consensus in the literature is that a Taylor rule characterised by an aggressive response of the interest rate to deviations of inflation from target, that is interest rate policy rules should have an inflation feedback parameter greater than one, is likely to yield good results. In a recent paper by Taylor himself (1999), he suggests that the coefficient on inflation should be 1.5.

Indeed rearranging (1) gives:

$$r_t = \theta + (1+\lambda)(\pi_t - \pi^*_t) + \gamma(Y_t - Y^*_t)$$

where $\theta = \alpha + \pi^*$. With $\lambda = 0.5$ then the coefficient on the deviation of inflation from target is 1.5. However a recent paper by Benhabib, Schmitt-Grohé and Uribe (1998) has argued that such an 'active' policy rule can lead to instability. They show in an optimisation framework that even if there exists a unique steady state equilibrium for this rule, there will exist an infinite number of equilibrium trajectories lying near the active steady state, and they show that the economy can exhibit limit cycles. They advocate that using local techniques to analyse the stability of the system may lead to inappropriate policy regimes.

Coordinated Policy:

We can of course modify the Taylor rule to allow monetary policy to respond not only to domestic conditions but also to deviations of world demand from some target. The rule becomes:

$$r_t = \alpha + \pi_t + \lambda(\pi_t - \pi^*_t) + \gamma(Y_t - Y^*_t) + \beta(Y^{wd}_t - Y^{wd*}_t) \qquad (2)$$

where Y^{wd} is a measure of world output.

For simplicity we have assumed that there are only two cooperating countries, the US and Europe. We assume that Japan is currently not in a position to react to international conditions and we have assumed they follow a pure inflation target. The UK is also assumed to follow a pure inflation targeting rule in this analysis.

[3] See Clarida, Godi and Gertler (1997), Christiano and Gust (1998) and Leeper (1991).

The measure of world output is taken to be the level of OECD output less the country's output that is also being targeted. Therefore US interest rates respond to domestic inflation, domestic output and OECD output less US output. The ECB monetary policy rule will therefore be a function of Euro area conditions and OECD output less Euro area output. In this way both economies are responding to world conditions and specifically they will be responding to conditions in Japan.

The coefficients on the rules are the same across both economies. There may be a case for spreading the burden of stabilising world demand differently across economies but as we are focusing on two economies of roughly the same size it seems sensible to keep the coefficient on world output the same. The coefficients we use in this analysis are $(1+\lambda) = 1.5, \gamma = 0.5, \beta = 0.25$

3. *The model*

NiGEM is an estimated model which uses a 'New-Keynesian' framework in that agents are presumed to be forward-looking but nominal rigidities slow the process of adjustment to external events. The theoretical structure and the relevant simulation properties of NiGEM are described in Barell and Sefton (1997) and NIESR (1998), and further details are given in an annex to this paper. The model contains estimated structures for the whole world, with the major economies having 60-90 equation models with around 20 key behavioural equations. It has complete demand and supply sides, and there is an extensive monetary and financial sector. All countries in the OECD, including South Korea, are modelled separately, as is China. There are regional blocks for East Asia, Latin America, Africa, Miscellaneous Developing countries, and Developing Europe.

Short term interest rate changes should have an impact on long term interest rates, equity prices and exchange rates. NiGEM is most commonly used for scenario analysis under the assumption that expectations in financial markets are rational, in that they are fully consistent with the outcomes of an event given the reactions of policy makers. Hence financial variables can 'jump' in the first period of a scenario. These assumptions are adopted here. The size of the jump depends upon the interest differential that opens up in response to a shock. The anticipation of lower short-term rates will cause long-term rates to fall by the forward convolution of short term interest rate changes. Equity prices will rise when interest rates are anticipated to fall. Hence any shock that is expected to slow down activity will have its effects partly offset by the automatic shock absorbers in the monetary system. The size of the effect will depend upon the monetary rules used by the authorities.

Forward looking long rates have to look T periods forward

$$(1+LR_t) = \Pi_{j=1,T}(1+SR_{t+j})^T$$

We assume that exchange rate markets are forward looking, and exchange rates 'jump' when there is news. An anticipated and sustained fall in interest rates in Japan, say, will cause the Yen/dollar rate to jump in the first period[4]. The size of jumps depends on the effects on interest rates that are anticipated for the future, and hence policy rules affect financial markets.

Forward looking exchange rates have to look one period forward

$$RX_t = RX_{t+1}(1+SRH_t)/(1+SRF_t)$$

In our analyses labour markets are assumed to embody rational expectations, at least where we have evidence that bargainers use forward expectations, much as in Anderton and Barrell (1995). Contracts are overlapping, and there are forward and backward elements in the wage equations, and they display dynamic homogeneity in (almost) all cases. The speed of adjustment of wages and prices is estimated to vary between countries, and depends upon institutions in the labour and product markets. In general the US and the UK react more quickly to excess capacity than do the more regulated continental European markets, and our results reflect these differences, as well as differences in the underlying structure of wealth and consumption. Further details of the model are available on request.

Wage equations can be written as

$$\Delta W/P = \lambda[(W/P)_{t-1} - PROD] + \beta U_t + \delta \Delta P^e + (1-\delta)\Delta P_{t-1} \quad \text{etc}$$

Where W is the nominal wage, P is the price level, PROD is a long term measure of productivity and U is unemployment.

However consumers are not assumed to look forward when making their decisions today, but rather they react to current and past incomes and net financial wealth. This does not mean that future events do not affect their behaviour, as forward looking long rates and equity prices affect debt interest payments and asset values now. Hence financial markets bring forward the consequences of future events, acting as

[4] The forward solution utilises a version of Fair/Taylor and the terminal conditions on forward looking variables involve a rate of growth condition.

'agents' for more passive households. Changing to forward looking household behaviour does not affect our results in any significant way. The model is large, but with a common (estimated and calibrated) underlying structure across all economies. Further details are given in the annex. The whole model is solved simultaneously in forward mode.

The forward-looking nature of these markets is central to model properties, and especially in shocks such as that in East Asia and Latin America. The model is solved in a sequence of loops, utilising the sparse structure of forward links in time. A shock is applied, and the model is run over the full time period, and interest rates are allowed to be endogenous. A fall in demand will, for instance, cut interest rates. Forward looking agents know this, and we emulate this knowledge by running the model a second time, but calculating the long rate as the forward convolution of short rates in the previous run. The model is continually run forward and starts again, and this is repeated until a solution is found where rates of growth of expected variables are constant at the terminal date, and all equations are converged. In particular, long-term interest rates are forward convolutions, and this period's exchange rate depends on that next period adjusted through the arbitrage condition but short term interest rate differentials.

Policy rules are important in 'closing the model' and we have them for fiscal and monetary policy. We assume budget deficits are kept within bounds in the longer term, and taxes rise to do this. Governments are assumed to slowly adjust tax rates to offset any changes in their deficit from its target trajectory, and hence they remain solvent in the simulation (See Barrell and Sefton (1997)). This simple feedback rule is important in ensuring the long run stability of the model. Indeed, as Blanchard, 1986, shows, without a solvency rule (or a no Ponzi games assumption) there is no solution to a forward-looking model. We can describe the simple fiscal rule as

$$Tax_t = Tax_{t-1} + \phi\,[GBRT - GBR]$$

Where Tax is the direct tax rate, GBR and GBRT are the government surplus target and actual surplus, and ϕ is the feedback parameter designed to remove an excess deficit in less that five years. We have discussed our monetary feedback rules above.

4. Stochastic simulations

Within the framework of stochastic simulations, a variety of shocks are imposed on the model. These shocks are taken at random from a particular distribution of past shocks, and are repeatedly applied to the model. Hence the moments of the solution of the endogenous variables can be calculated and uncertainty investigated. Stochastic simulations can be either in respect to the error terms, coefficient estimates or both. In this paper we assume that the coefficient estimates are known with certainty and the stochastic shocks to the model are only applied to the error terms, much as in the rest of the economic literature. We draw our shocks from the period 1993 to 1997, a relatively stable period, at least in terms of outcomes.

We use the boot strap method where the shocks are generated by repeatedly drawing random errors for individual time periods for all equations from the matrix of single equation residuals (SER). The shocks drawn will have the same contemporaneous distribution as the empirical distribution of the SER, which is assumed to be normally distributed, $N(0,\sigma^2)$. In this way the historical correlations of the error terms are maintained across variables, but not through time. If, for example, investment shocks across Europe are highly positively correlated, the error terms will tend to be high together for these countries. There are a number of other methods for drawing the shocks which rely on specifying the variance-covariance matrix or generating pseudo-random shocks which are consistent with the historical residuals. In order to present the results in a condensed form we concentrate on the Root Mean Squared Deviation (RMSD) of variables from their baseline path. Further details are given in an annex

5. *Results*

We need to specify some welfare criterion in order to determine whether a coordinated or independent monetary policy is superior. Each country or bloc is assumed to have similar welfare-loss functions which penalises a combination of output, inflation, interest rate and exchange rate instability. The RMS%D or RMSD can be used to calculate the loss functions, a simple loss function may include either the RMSD for the inflation rate alone or the RMS%D for real GDP alone and this would give exclusive weight to either inflation variability or output variability. It is likely that policy makers will not focus solely on the variability of one variable and will be concerned with the variability of both output and inflation rates and so both will appear in their loss functions. They may also believe that other non-price variables are an indication of economic welfare. Large frequent fluctuations in the interest rate may be regarded as imposing costs on the economy and so may be included in the loss function and this may change the conclusions about the relative performance of the policy rules. The outcome of any loss function will depend on the particular variables included in the function and the relative weights on its arguments. We will look at a number of loss functions which are meant as an illustration. Where the loss function has more than one argument, then equal weight is placed on each.

We have undertaken a set of stochastic replications where shocks from the early 1990s are repeatedly and randomly applied to structural equations for the next five years (including 1999). We have undertaken over two hundred stochastic replications for each rule, each of which involves a set of forward solutions of the model for a new set of shocks. The first time period is solved with shocks for a time slice from the past, and the resulting rational expectations forward run is then used as the baseline for the simulation starting in the second period when a new time slice is applied. The process continues over 20 time periods for a single replication. Therefore for each of the rules we have undertaken 4000 simulations with which we can base our results.

For the experiments undertaken in this paper, the shocks drawn from the past include shocks for the exchange rates although previous work on evaluating rules on large international econometric models, such as Fair (1998), has been based on not shocking the exchange rate. We argue that the exchange rate is a source of shocks and instability and should be included in the sets of shocks applied to the model. However, this does present us with conceptual problems. The construction of historical shocks to sterling is clear, as the bilateral rate against the dollar existed in the past, as did the rates for Japan, Canada, Sweden and so on. However, we are simulating the model with an exchange rate equation for the Euro, a currency that did not exist in the past. Moving from the a regime where individual Euro area countries had their own exchange rates to one where there is single exchange rate for EMU members, introduces some uncertainties as to what shocks to apply to the Euro and indeed whether they should be applied at all. Other work in the literature has sought to avoid these problems by excluding them in the anaylsis. Two previous papers, Barrell, Dury and Hurst (1999), Barrell (1999), show that shocking the exchange rate is very important, particularly for smaller open economies such as the UK.

We could construct a set of shocks to the Euro that was the weighted average of shocks to the individual currencies over the past. However, this would not necessarily be the correct strategy, as EMU has been set up, and hence shocks across bilateral rates within the Union are no longer possible. A better strategy would be to apply the shocks that occurred to the core of EMU (Germany, Belgium, Netherlands, France (and Austria)) over the 1993 to 1997 period, and we adopt this for the Euro. However, this means that we are applying a subset of historical shocks, especially to the European Monetary Union and to the US, as in the latter case shocks to the exchange rate are the result of shocks to all US dollar bilateral rates. However, as a result we exclude some of the intra European devaluation cycles that EMU will prevent happening. We therefore think that our assumptions reflect the pattern of shocks we will experience. The time span for the set of shocks we use is 1993q1 to 1997q4, therefore we are including in our analysis large shocks to the model from countries that have experienced a currency crisis over this time. We include shocks to the Chinese Yuan, the Mexican peso, the Korean Won as well as shocks to East Asian currencies and these shocks are repeatedly applied to the model. Table 1 reports the resulting RMSD (RMS%D) of the model variables. The direction of change is very much as we would expect for Europe and for the US.

- There are large benefits for the US in terms of reduced output and inflation variability. Price level variability for the US falls by 10%.
- The Euro area also gains in terms of reduced output variability although inflation variability is a little higher.
- The nominal interest rate variability for the US and the Euro area increases under policy coordination on average by 10%. A higher rate of variability would be expected as the interest rate is now reacting not only to domestic conditions but to international conditions as well.
- Real effective exchange rate volatility rises for all countries except Europe which sees a fall of 4 %.
- The UK and Japan see a rise in inflation and output variability (particularly the UK) as the US and Europe coordinate their policies. In this exercise the UK and Japan have been following a monetary policy rule of pure inflation targeting and are not participating in the coordination scheme.

The volatilities of output and inflation can be compared to those we have seen over the five years from which we draw shocks in the countries or groups we have been analysing. The standard deviation of output as compared to a time trend over this period for the US is 0.45 as compared to 0.7 or so in the uncoordinated stochastic simulations, whilst it is 0.41 for Europe as compared 1.55 in the uncoordinated simulations. For the UK we have 0.5 as compared to 0.8 or so in the uncoordinated simulations, whilst Japan is the highest at 1.33, as compared to 2.5 or so in the uncoordinated simulations, once again the highest output volatility. Our simple policy responses do not include any active fiscal feedbacks, and hence it is not surprising that output is more volatile than over the past when policy has been used in this way. However, the rankings of the individual countries are the same, with hypothetical standard deviations less than twice the postulated simple volatility. Inflation volatilities over the seed period are much closer to 'actuals', which are 0.7 for the US, 1.3 for the UK, 1.6 for Japan and 1.1 for Europe. As our inflation variability in our simulations is below that in the actuals for the Euro area (and the UK, and to a lesser extend the US) it is not surprising that output is more variable in the simulations. This suggests that in the past output took a greater weight in policy reactions as compared to inflation in Europe and the UK than it does in our simple rules (Taylor: 1.5 on inflation, and .5 for output in Europe. For the UK inflation alone has a coefficient of 1.0.)

Why does the US benefit so much?

We have assumed that under the coordinated rule, both the US and Euroland respond to external events modelled as deviations of world output to some target. This has had a significant impact on the stability of US output and inflation, reducing output variability by just over 5% and inflation variability by nearly 4%. Euroland sees a smaller fall in output variability and almost no change in the variability of inflation. It is useful if we can explain why the US has benefited so much from policy coordination?

With two large economies, the US and Euroland, both reacting to deviations of OECD output from base, it seems likely that for any given shock, OECD output, and consequently world output, would experience a fall in its variability. One would expect that if OECD output were higher than its target level, then a rise in US interest rates, by reducing domestic demand and output in the US, would also reduce demand for goods from countries exporting to the US. This would have an effect on output in these domestic economies and help to bring OECD output back towards its target level. Table 2 below shows that OECD output is stabilised under the coordinated rule. This in turn would stabilise internal demand for the US and Euroland. Hence exports should become more stable.

However, other factors affect exports. The real exchange rate has a significant role and making it more volatile can make real output more unstable as the terms of trade become more volatile. However, the variability of the US real effective exchange rate rises by nearly 10%, yet the variability of net trade is unaffected. As can be seen from Table 2, export variability falls by 1% , which will help to stabilise output, but by less than that we observe.

Table 2 shows that under the coordinated rule the US sees a large fall in the variability of its domestic demand as well as GDP, suggesting that the source of the reduced variability in output is coming from the stabilisation of domestic conditions. This could come from a number of sources. The variability of the nominal short term interest rate rises under the coordinated rule by over 11%. This is likely to have a destabilising effect on the domestic economy as the long term interest rate and hence asset prices become more volatile, increasing the variability of nominal wealth and also increasing the variability of investment. However, we see from the table below that the variability of private consumption, which makes up over 60% of domestic demand, falls by 10%.

Domestic consumption is driven by real personal disposable income and real net wealth. The long run consumption equation is:

$$c = \alpha + \beta * rpdi + (1 - \beta) * rnw$$

where c is the log of consumption, rpdi is the log of real personal disposable income and rnw is the log of real net wealth. The table below shows that while the variability in nominal net wealth increases, the stabilising effect that the policy rule has on prices causes the variability of real net wealth to fall. The variability of the price level falls by 10% under the coordinated rule. As US consumption is relatively sensitive to real wealth effects, a fall in its variability will have a stabilising effect on consumption and therefore output. The covariance between real personal disposable income and real net wealth matters when analysing the causes of the change in the variance of consumption, and the covariance falls by 50% leading to a larger fall in consumption variability than the individual drivers would suggest might happen.

The major force stabilising the US appears to be the stabilisation of the inflation in the world economy. Under the coordinated rule, world demand is stabilised as expected and this causes the variability of the bilateral dollar rates to fall. This in turn stabilises world export prices in dollar terms, whose variability falls by 10% under the coordinated rule. Reduced volatility in world export prices stabilises US import prices and this has a beneficial effect on the variability of US domestic prices. A change in the variability of the world oil price has a significant effect on the variability of US domestic prices and hence a fall in the volatility of the world oil price reinforces the downward effect on the variability of domestic prices. The effects are larger for the US than for Europe and we have to explain this. Prices in the US are more responsive in the short run to demand and cost impulses and this could explain the greater effect that the stabilisation of world export prices has on the US economy. Inertia in the European economies on the other hand may cause the stabilisation of world conditions to have less of an effect in the short term as impulses feed through only slowly.

Charts 1 and 2 show the variability of US output and inflation under both policy rules. Chart 1 shows that the gain in terms of reduced output variability to the US is quite immediate. However as Chart 2 shows, the US does not gain in terms of reduced inflation variability for almost one year.

Welfare losses

Table 3 reports some simple illustrative welfare loss functions. The results are presented in terms of the uncoordinated policy rule being given a value of 100. Therefore a value less than 100 indicates the coordinated policy rule is superior in the context that we are examining. For the US, the inclusion of the real effective exchange rate or the interest rate in the welfare loss function results in the US favouring the uncoordinated policy rule. Results for the Euro area suggest that when output alone or output and inflation together are considered in the loss function the coordinated policy is favoured. This result is the same even when the real exchange rate variability is included in the welfare loss function. However, including the nominal interest rate variability results in higher losses under the coordinated policy rule.

The conclusion from Christodoulakis, Currie and Garatt (1996) suggested that if exchange rate volatility matters, then the ETZ scheme is superior but if exchange rate volatility is not included in the welfare criterion then this scheme is no longer the preferred one. We have found that if exchange rate volatility is not included in the welfare criterion then a coordinated policy will result in lower welfare losses for the US than under the uncoordinated scheme. However, the Euro area may be concerned with interest rate volatility and this is likely to cause higher welfare losses under the coordinated scheme.

Table 1: RMSD (RMS% D) of main economic variables

Variables	Uncoordinated policy	Coordinated policy	Uncoordinated policy = 100
Output			
Y_{Uk}	0.80	0.86	107.37
Y_{US}	0.73	0.69	94.86
Y_{jp}	2.56	2.59	101.24
Y_{EL}	1.56	1.52	97.56
Inflation			
INF_{Uk}	0.74	0.77	103.96
INF_{US}	1.02	0.98	96.44
INF_{jp}	1.11	1.15	103.96
INF_{EL}	0.70	0.71	100.71
Nominal Interest rate			
R_{Uk}	0.74	0.77	104.10
R_{US}	1.66	1.85	111.33
R_{jp}	0.91	0.95	104.55
R_{EL}	1.49	1.63	109.23
Real Effective Exchange rate			
$REFEX_{Uk}$	0.66	0.74	111.86
$REFEX_{US}$	1.02	1.11	108.72
$REFEX_{jp}$	1.70	1.74	102.58
$REFEX_{EL}$	0.84	0.81	96.42

Table 2: RMSD (RMS% D) of main US economic variables

Variables	Uncoordinated policy = 100	Variables	Uncoordinated policy = 100
Net trade	100.00	Nominal net wealth	103.34
Volume of exports	99.00	Real net wealth	98.40
Domestic demand	95.99	Real personal disposable income	97.46
Consumption	90.10	US import prices	0.93
OECD output	0.96	World export prices	0.90
World oil price	0.90	US price level	0.90

Table 3: Welfare losses (uncoordinated policy = 100)

WELFARE LOSS						
	Welfare 1	Welfare 2	Welfare 3	Welfare 4	Welfare 5	Welfare 6
UK	107.37	103.96	105.73	105.20	107.58	106.71
US	94.86	96.44	95.78	103.34	100.54	104.58
JP	101.24	103.96	102.06	102.55	102.23	102.56
EL	97.56	100.71	98.54	102.78	97.97	101.62
TOTAL	100.26	101.27	100.53	103.47	102.08	103.87

Where :

Welfare loss 1: *Real GDP alone*
Welfare loss 2: *Inflation alone*
Welfare loss 3: *Real GDP + inflation*
Welfare loss 4: *Real GDP + inflation + interest rate*
Welfare loss 5: *Real GDP + inflation + real exchange rate*
Welfare loss 6: *Real GDP + inflation + interest rate + real exchange rate*

Chart 1: Variability of US output under both policy rules (RMS%D) over time

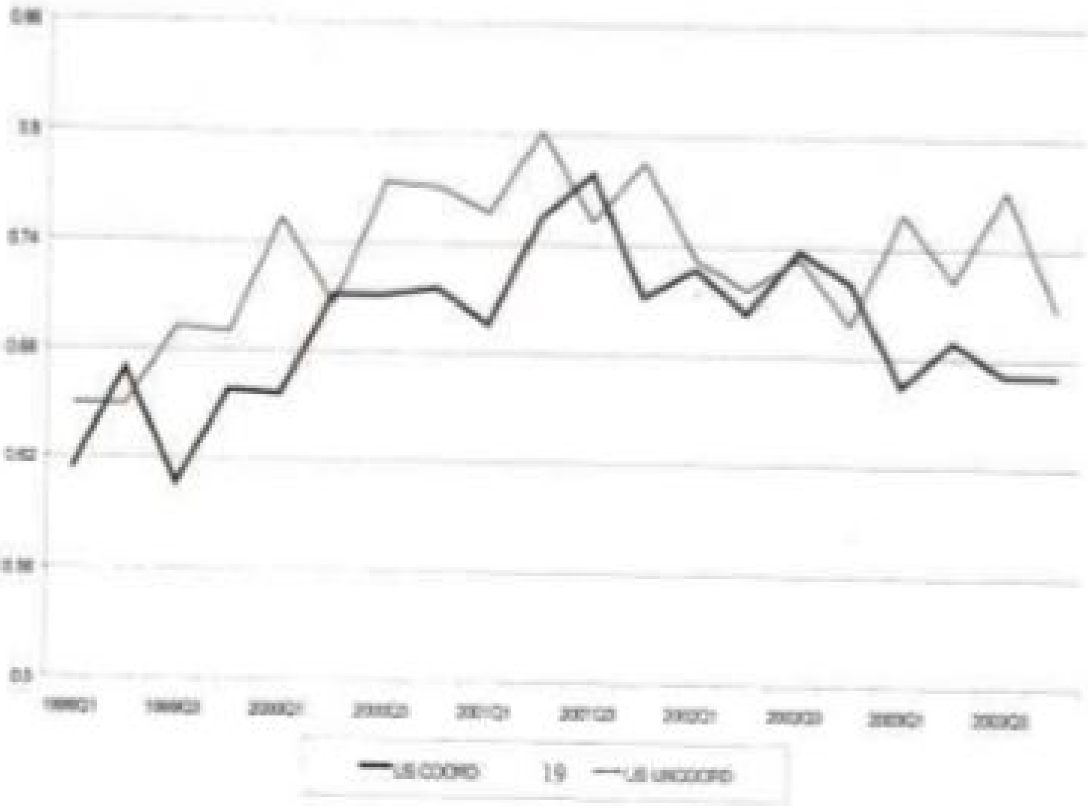
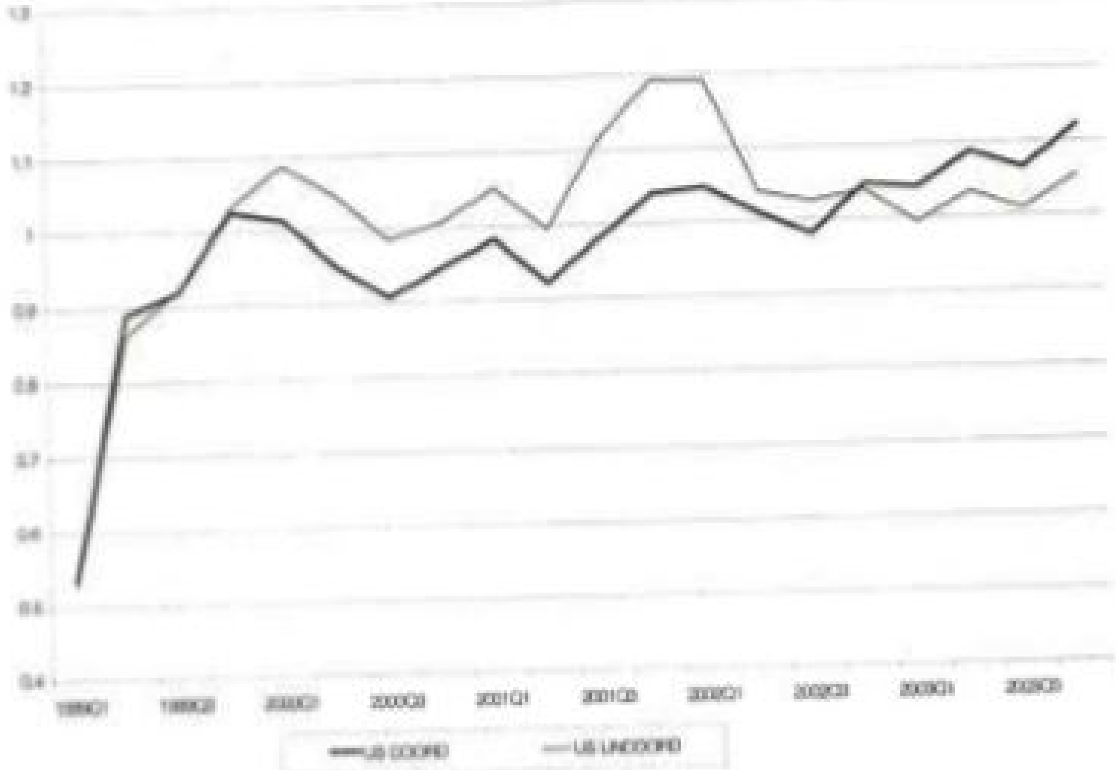


Chart 2: Variability of US inflation under both policy rules (RMSD) over time



The effect of increasing the number of simulations

The results shown above are based on 200 stochastic simulations for each rule. The charts below show how the variability of US and Euroland output and inflation settle down as the number of stochastic simulations are increased. They show that the increased number of simulations improved the estimated variances but that after roughly 100 simulations the results had settled down. This means that a good assessment of the variabilities can be made with around 200 trial runs and that further simulations would not change the results noticeably. US output appears to stabilise with fewer runs than aggregate Euroland output, and inflation variability perhaps takes a little longer to settle than does that of output.

Chart 3: RMS% D for US output under both rules as the number of simulations increases

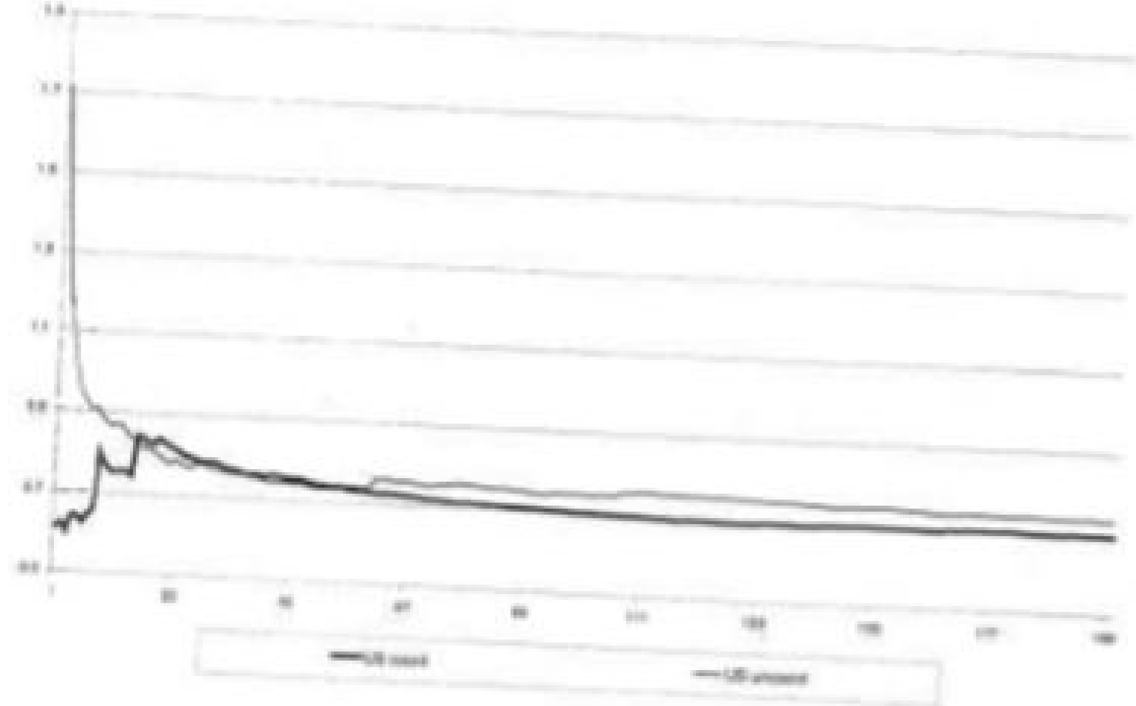


Chart 4: RMS% D for Euroland output under both rules as the number of simulations increases

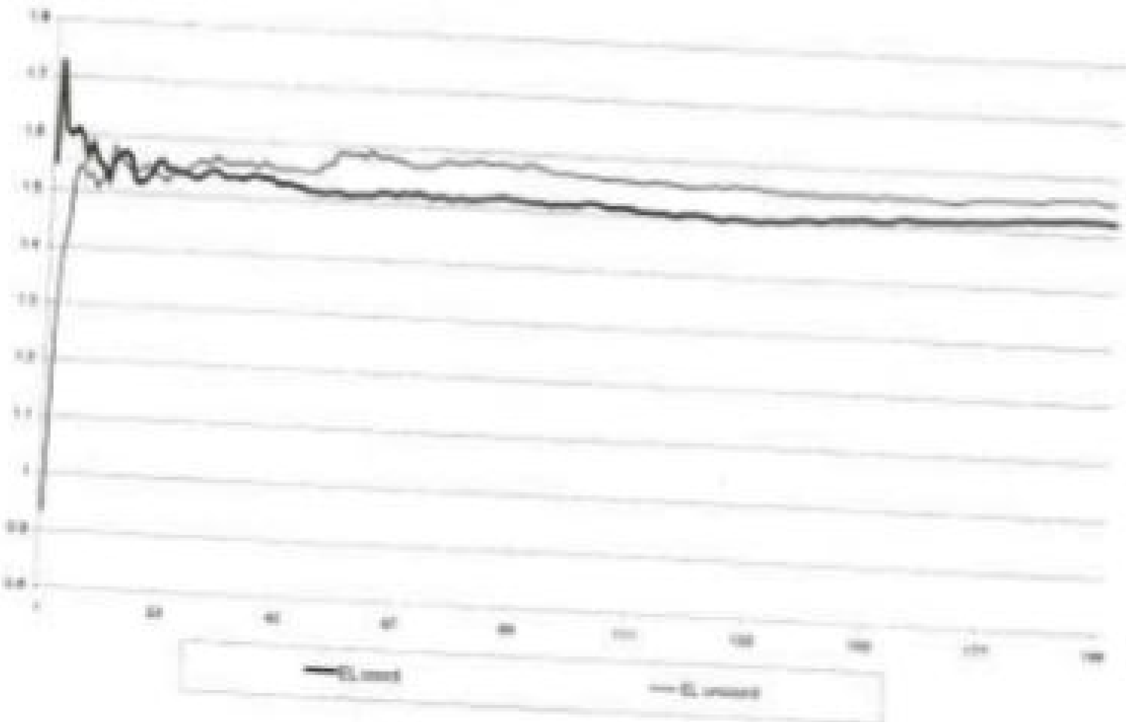


Chart 5: RMS% D for US inflation under both rules as the number of simulations increases

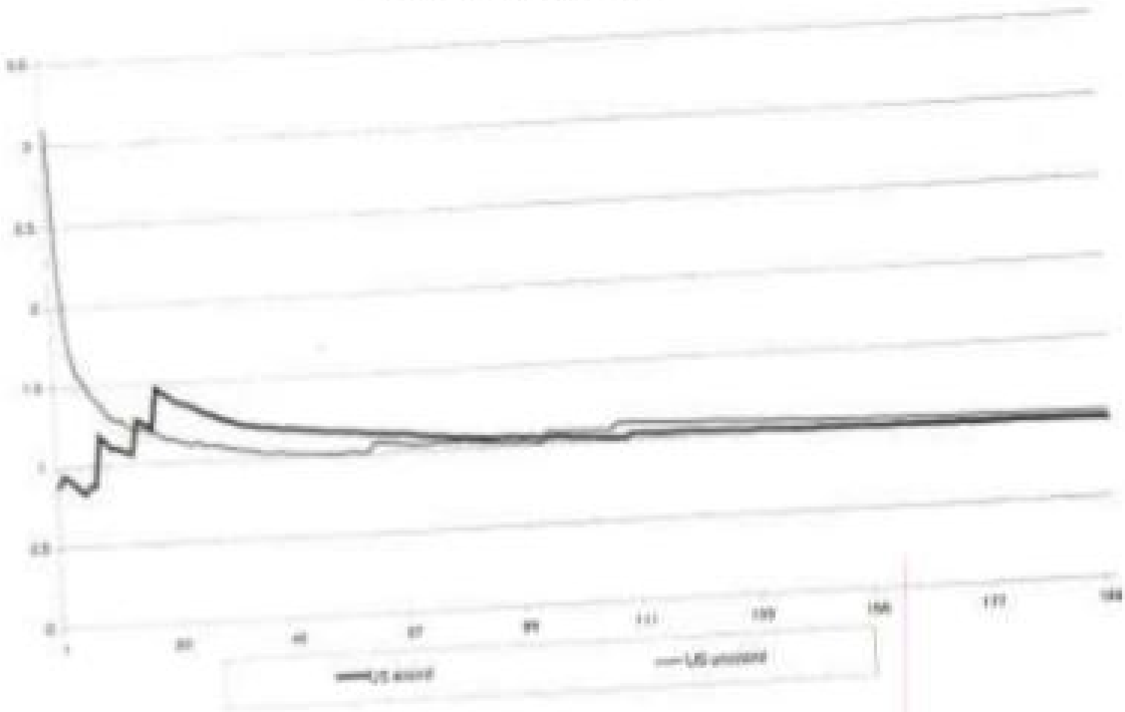
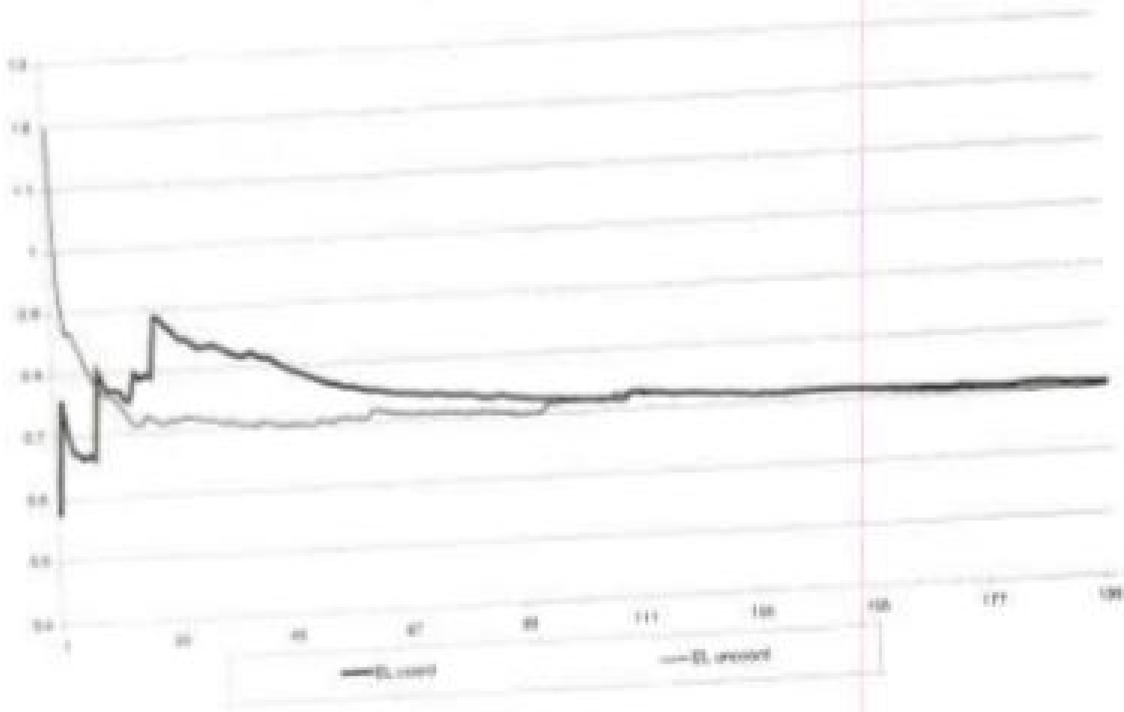


Chart 6: RMS% D for Euroland inflation under both rules as the number of simulations increases



Conclusion

We have undertaking a simple exercise on NiGEM to analyse the potential benefits of the US and the European Central Bank coordinating their monetary policies. We have taken a different route to the standard analysis which tends to examine the effects of exchange rate targeting. We have used stochastic simulations on the model to evaluate 2 simple alternative policy rules, one where monetary policy targets domestic output and inflation and an alternative where world output is included in the reaction function.

Given these results, policy coordination between the US and ECB has beneficial effects in terms of reduced welfare losses. There is a good case for US to push for such a scheme. The Euro area does benefit in terms of reduced output variability, but not as much as the US. Given these results, it may not be the principle of policy coordination that is the issue but the degree of burden sharing and the structure of policy coordination may prove difficult to agree upon. Hughes Hallett (1989) shows that the gains of policy coordination to be asymmetrically distributed and suggests if the gainers are not those who share the burden of coordination are different players then securing any agreement will prove difficult. The more uneven the gains, the less incentive there is for individual countries to participate in a coordinated policy in the absence of side payments. Policy makers may also not prefer to coordinate if they are uncertain that the other players will renege on the bargain. Hughes Hallett (1986) raises the question of the sustainability of policy bargains. He shows that a coordinated policy between the US and Europe is sustainable because the losses that a country suffers if the opponent breaks the bargain outweighs the gains that the opponent might make from cheating.

Annex 1

The nature of the model

For *policy analyses* we need to worry more about the underlying structure of the economy and the longer-term developments in labour markets and technology as well as the reactions of financial markets. The description of the world we use in policy analysis benefits from having a clear and determinate equilibrium. The model must also eventually push the economy toward this equilibrium.

However, it is possible to compromise between these objectives when we estimate the equations of the model, as we look for both the long run structure and the dynamics of adjustment to the long run. Indeed our forecasts are constructed over long bases and we see them as a linking short-term projections with medium term policy discussions. Our equations are made up of two components

$Y(t) = a + b^*X(t) + e(t)$ The long run relationship

This relationship is the long run attractor in the system and describes the equilibrium of the system and would normally be related to the behaviour of actors in the economy. When the economy is out of equilibrium we need to specify the dynamics of adjustment that pull it toward the long run attractor:

$\Delta Y(t) = \lambda[Y(t-1) - a - b^*X(t-1)] + \delta_1{}^*\Delta Y(t-1) + \delta_2{}^*\Delta X(t) + w(t)$

The adjustment around the long run

Where Y and X are variables or vectors of variables, Δ is the change operator, λ a, b, δ_1 and δ_2 are parameters or vectors of parameters and e(t) and w(t) are error terms. The term λ is particularly important in the dynamics because it is the major indicator of the speed with which any dis-equilibrium is removed. The term in square brackets indicates the degree of dis-equilibrium and is often called the 'error' in the error correction mechanism.

All equations we use have a long run structure that has a justification in economic theory. We feel that this is important even in forecasting. A forecast is a particular type of policy analysis with conditional statements that relate to the current conjuncture. We feel that we need to be able to say where the economy would head if the current set of 'shocks' to the system are allowed to work through and no policies are changed.

Modelling the World economy

Any model we build should be a description of the world we live in, rather than a description of the currently fashionable economic theory. However, economic theory tells us a lot about the world, and gives us strong indications about the structure of our model. It is useful, for instance to consider both stocks and flows.

- In a world model we need a description of trade in goods and services, a description of the structure of foreign assets and liabilities, and links between these and the rest of the model. The current account flows onto the asset stock, and cumulated current accounts should affect future income flows.
- Each country that we wish to study needs a description of its domestic economy. This can be broken up into sectors, and the minimum would cover the government, the labour market, consumption behaviour, the supply side of the economy and financial markets.
- These elements need to be integrated into a model of longer-term development. We have tended to use an extended Solow growth model where output grows because the quantity of labour and capital increase and because there is technical change.

In each area we try to look at the role of relative prices and also at the accumulation of assets. It is important to avoid 'black holes' in the model where income is received by one party, but where there is no counterparty paying the income (or the reverse for payments). This is particularly problematic for a world model as world exports do not equal world imports, and we have to ensure that the discrepancy does not grow without bound in the forecast or in a policy analysis.

The model uses a 'New-Keynesian' framework, in that agents are presumed to be forward-looking but nominal rigidities slow the process of adjustment to external events. The theoretical structure and the relevant simulation properties of NiGEM are described in greater detail in Barrell and Sefton (1997) and NIESR (1998).

The model is large, but with a common (estimated and calibrated) underlying structure across all economies. It has complete demand and supply sides, and there is an extensive forward-looking monetary and financial sector. The model contains a wealth equilibrium for the private sector. Governments are constrained to be solvent, and hence also have an asset equilibrium. These two constraints tie down the net asset holdings of the external sector. Thus the long run structure of the model embeds equilibrium capital flows that depend upon these saving and investment balances as well as on the structure of the world economy. All countries in the OECD, including South Korea, are modelled separately, as is China. There are regional blocks for East Asia, Latin America, Africa, OPEC, Miscellaneous Developing countries, and Developing Europe. The major economies are each represented by 60-90 equation models with around 30 key behavioural relationships.

Model Structure

In this section we give a brief description of each sector – trade, government, consumption, investment, the labour market, and technical progress along with some discussion of financial markets and policy reactions. In each case we want to look at the important feedbacks that stabilise the model in the long run

Trade. We look for demand and relative competitiveness effects, and the latter are important feedbacks in the model. There are a variety of competitiveness measures we can construct. For exports we assume that exporters compete against other people who export to the same market (RPX), and demand is given by the imports in the markets to which the country has previously exported (S)

$$\Delta X = \lambda[X(-1) - S(-1) - b^*RPX] + c1^*\Delta X(-1) + c2^*\Delta S + \quad + \text{error}$$

and imports depend upon import prices relative to domestic prices (RPM) and on demand (TFE)

$$\Delta M = \lambda[M(-1) - TFE(-1) - b^*RPM] + c1^*\Delta M(-1) + c2^*\Delta TFE + \quad + \text{error}$$

As exports depend on imports, they will rise together in the model. We have a similar pattern for services trade, but relative price elasticities are higher. In all cases competitiveness depends in part on domestic prices or costs, and a rise in domestic prices not matched either by a change in the exchange rate or foreign prices will mean net exports will fall, and hence output will fall relative to where it would have been. The current account deficit cumulates onto foreign debt, and this forms part of private sector wealth, and hence current deficits are a slowly acting stabilising feedback.

Government. It is important to have sketch models of direct and indirect taxes, and of government spending. We separately identify transfers to individuals and government interest payments. We also have to consider the financing of the government deficit (BUD), and we allow either money (M) or bond finance (DEBT).

$$BUD = \Delta M + \Delta DEBT$$

The debt stock affects interest payments and forms part of private sector wealth. The model explicitly recognises the link between monetary and fiscal policy through their effects on the government budget constraint, and it is wrong to analyse these policies in isolation.

Consumption This reflects the major component of demand, and hence has the most important feedbacks in it. We assume that consumers consider their current income (RPDI income including non-labour income net of taxes) and their real financial wealth (RNW), and that interest rates have a potential effect.

$$\Delta C = \lambda[C(-1) - a^{*}RPDI(-1) - (1-a)^{*}RNW(-1)] + \Delta C(-1) + \quad + \text{error}$$

This equation is one of the most important we can consider in forecasting. We assume that wealth is affected by financial markets through equity and bond prices, and hence if these markets 'expect' something in the future then it will be reflected in prices. News that changes expectations will cause wealth to be revalued, and hence will affect behaviour now. Consumers use the financial markets as agents to assess the future. The rate of spending from wealth (wealth effects) need to be larger than the real interests rate in order for the model to stabilise. Wealth effects are an important but slow acting feedback. They link financial markets, the current account and government to the real economy. A good deal of care needs to be taken on modelling the acquisition of assets and the effects of revaluations.

Investment For forecasting purposes it is adequate to model investment with a simple accelerator model, with some role for the interest rate. However, if we are interested in growth and the long run structure of the model, we have to relate investment to the capital stock, and hence we have to model it as a factor demand, relate it to the demand for labour and link to capacity utilisation. The demand for capital has to depend upon the user cost, which depends on real interest rates with forward looking expectations of inflation. We use a Constant Elasticity of Substitution production function with an estimated elasticity of substitution of around a half.

$$Q = \gamma\left[s(K)^{-\rho} + (1-s)(Le^{\lambda t})^{-\rho}\right]^{-v/\rho}$$

Here *v* denotes returns to scale, j and *s* are production function scale parameters, and the elasticity of substitution, v, is given by 1/(1+u). If v = 1 (u=0), the production is Cobb Douglas. Variables *K* and *L* denote the net capital stock and labour input measured in terms of employee hours. The production function allows for the possibility of labour augmenting technical progress. The parameters of the production function vary across countries, and w, c and p denote respectively labour costs per head, nominal user costs of capital and the price of value added (at factor cost) and e denotes the mark-up. Imposing long-run constant returns to scale (v=1) we obtain log-linear factor demand equations of the form:

$$Ln(L) = [v \ \ln\{e\,(1-s)\} - (1-v\,)\ln(j\,)] + \ln(Q) - (1-v\,)\sigma t - v\ \ln(w/p)$$

$$Ln(K) = [v\ \ln(es) - (1-v\,)\ln(j\,)] + \ln(Q) - v\ \ln(c/p)$$

We estimate these as error corrections around the long run, but there is a lot of calibration. Capacity utilisation affects price setting and depends on actual as compared to desired capital, and once again this is one of the central feedbacks in the model. If output is above capacity prices rise more rapidly than their determinants (foreign prices, costs, expectations) would suggest, and the reverse is the case if the economy is below capacity. If prices fall relative to baseline because the economy is below capacity then real financial wealth rises, and competitiveness improves, and both help raise capacity utilisation through higher domestic demand and exports. These effects stabilise the economy slowly.

The Labour Market contains another important feedback, but again this is difficult to model outside the core OECD countries. We have a labour demand curve, and we assume that employers have a right to manage, and hence the bargain in the labour market is over the real wage. In the long run wages rise in line with productivity all else equal. Other factors matter, for instance if unions become stronger real wages rise and employment falls. Given the determinants of the trajectory for real wages, if unemployment rises then real wages fall relative to trend, and conversely. Hence unemployment acts as an important feedback. However, this only works if labour supply is inelastic or fixed. It is inappropriate as a model where there are large reserves of labour and other measures of labour market excess supply have to be used. In our modelling we allow expectations of the future to affect the dynamic path of the bargain, at least where we can find evidence that this matters.

There is continual structural change in labour markets and sustainable unemployment changes when policies change, and we have to continually update our model so that it reflects the economies we are studying, rather than being just a simple description of past data. Both the determinants of equilibrium and the dynamics of adjustment change, and adjustment, especially in Europe is slow.

We assume that labour markets embody rational expectations, at least where we have evidence that bargainers use forward expectations of future inflation (Anderton and Barrell, 1995). However, not all countries display forward elements in the wage bargain, and we have not found them in Germany, the Netherlands or Austria. In certain circumstances we assume that wage bargainers do not use model consistent expectations, but rather look at a simple time series predictor for next periods inflation.

Financial markets affect asset prices. For most purposes we assume that exchange rate markets are forward looking, and exchange rates 'jump' when there is news. The size of jumps depends on the effects on interest rates that are anticipated for the future, and hence policy rules affect financial markets. We assume that bond and equity markets are also forward looking, and long-term interest rates reflect short rates that are expected in the future. In forecasts we normally 'read' interest rates for the future from long-term rates, and set paths for exchange rates in line with interest differentials. Occasionally we claim to know more than the market.

The forward-looking nature of these markets is central to model properties, and especially in shocks such as that in East Asia and Latin America. The model is solved in a sequence of loops, utilising the sparse structure of forward links in time. A shock is applied, and the model is run over the full time period, and interest rates are allowed to be endogenous. A fall in demand will, for instance, cut interest rates. Forward looking agents know this, and we emulate this knowledge by running the model a second time, but calculating the long rate as the forward convolution of short rates in the previous run. The model is continually run forward and starts again, and this is repeated until a solution is found where rates of growth of expected variables are constant at the terminal date, and all equations are converged. In particular, long-term interest rates are forward convolutions, and this period's exchange rate depends on that next period adjusted through the arbitrage condition but short term interest rate differentials. This algorithm is a version of Fair-Taylor set up in the way Hall (1986) recommends.

Policy rules are important in 'closing the model' and we have them for fiscal and monetary policy. We assume budget deficits are kept within bounds in the longer term, and taxes rise to do this. This simple feedback rule is important in ensuring the long run stability of the model. Indeed, as Blanchard, 1986, shows, without a solvency rule (or a no Ponzi games assumption) there is no solution to a forward-looking model. We can describe the simple fiscal rule as

$Tax_t = Tax_{t-1} + \phi\,[GBRT - GBR]$

Where Tax is the direct tax rate, GBR and GBRT are the government surplus target and actual surplus, and ϕ is the feedback parameter designed to remove an excess deficit in less that five years.

We also assume that the monetary authorities target something (we allow a large variety of rules) that stabilise the price level or the inflation rate in the long term. The speed of response of the authorities affects the properties of the model. In our forward-looking world the expectation that interest rates would be lower would mean that the exchange rate would decline now. This would improve competitiveness in the short run and would raise demand. This would eventually increase prices as compared to where they would have been. If the target for the money stock were raised by 10 percent the exchange rate would have to fall by 10 percent or so in the first period to put the economy on the path to equilibrium. This sort of policy analysis is easy to undertake, and involves one simple change. We can also change either the target rate of growth of the nominal aggregate or the rate of inflation, and analyse the effects of the dynamics of inflation on the model.

Annex 2.

Stochastic simulations

Within the framework of stochastic simulations, different sets of shocks are repeatedly applied to the model. These shocks are taken at random from a particular distribution. By repeatedly simulating the model in this way the moments of the solution of the endogenous variables can be calculated and the uncertainty of the model investigated. Stochastic simulation can be either in respect to the error terms, coefficient estimates or both. In this paper we assume that the coefficient estimates are known with certainty and the stochastic shocks to the model are only applied to the error terms.

The method used is known as the boot strap method where the shocks are generated by repeatedly drawing random errors from the matrix of single equation residuals (SER). The shocks drawn will have the same distribution as the empirical distribution of the SER, which is assumed to be normally distrubuted, $N(0,\sigma^2)$. There are a number of other methods for drawing the shocks which rely on generating pseudo-random shocks which are consistent with the historical residuals or specifying the variance-covariance matrix (see Ireland and Westaway 1990 for a description).

One of the main techniques used for generating shocks is the McCarthy algorithm (1972). This approach uses the formula to generate a vector of shocks:

$$S = T^{0.5}\, rU$$

where S is the vector of random shocks, r is the 1 x T vector of random numbers with distribution $N(0,1)$ and U is the T x M matrix of disturbances from T observations and M structural equations. The properties of S tend to the true structural errors as T tends to infinity, giving an asymptotic estimate of the true covariance matrix.

The method we are using takes the actual historical residuals but are picked at random from the SER matrix. In this way computational requirements before the model is solved are reduced considerably.

There are X stochastic equations in NIGEM, x post recursive and x identity equations. The period taken to calculate the single equation residuals is 1993Q1 to 1997Q4. Each stochastic equation is shocked in the first period with a random drawing of its errors over this historical period and the model is then solved forward to calculate expectations. This can be thought of as being equivalent to a single deterministic simulation.

A second random drawing of error terms is then made and applied to each stochastic equation in the following period, and again the model is solved forward. This is repeated for all time periods being stochastically simulated and is known as a 'trial'. Each trial will consist of T *(time period for which we are stochastically simulating)* draws of X *(number of stochastic equations)* values. This can be done as many times as desired and each trial will yield an estimate of the endogenous variables for each time period. This can be done as many times as desired and each trial will yield an estimate of the endogenous variables for each time period. It is important to solve the model far enough into the future so that the results in a trial solution period are not affected by the terminal date. In this paper we stochastically shock the model over the first 5 years of our forecast baseline but each time a shock is applied, the model is solved forward to 2017q1. For a 5 year solution period, each trial consists of 20 simulations and we undertook 200 stochastic trials for each rule. Therefore the total number of simulations undertaken in this paper was 4000 (20 X 200)

After running the stochastic simulations the moments can be calculated. The expected value of each endogenous variable, at time t, is obtained by dividing the sum of all trial estimates at time t by the number of trials:

$$\tilde{\bar{y}}_{it} = \frac{1}{J}\sum_{j=1}^{J} \hat{y}^j it$$

where $\tilde{\bar{y}}^j{}_{it}$ is the value of the *jth* trial of variable i in period t; J is the number of trials taken.

Given J trials, the stochastic simulation estimate of the variance for level variables such as output and consumption for period t is calculated as:

$$\tilde{\sigma}^2_{it} = \frac{1}{J}\sum_{j=1}^{J}\left[\frac{\left(y^j{}_{it} - y^B{}_{it}\right)}{y^B{}_{it}}\right]^2$$

Where $\tilde{\sigma}^2{}_{it}$ denotes the estimated variance of the variable i in period t, $y^j{}_{it}$ is the value of the *jth* trial of variable i in period t, $y^B{}_{it}$ is the value of variable i on the base in period t, and J is the number of trials taken. This will give a time series of estimated variances for each variable. We then take a simple average of this series over N time periods and take the square root to give a simple summary statistic to help assess the performance of the policy rules over the whole time period. The summary statistic given in the following tables are the *RMS%Ds*, i.e.

$$RMS\%D(y_i) = \sqrt{\left(\frac{1}{N}\right)\sum_{t=1}^{N}\left\{\frac{1}{J}\sum_{j=1}^{J}\left[\frac{\left(y^j{}_{it} - y^B{}_{it}\right)}{y^B{}_{it}}\right]^2\right\}}$$

For variables such as interest rates and the inflation rate, absolute deviations are measured in percentage points, i.e. the RMSD for the interest rate, r, would be:

$$RMSD(r) = \sqrt{\left(\frac{1}{N}\right)\sum_{t=1}^{N}\left\{\frac{1}{J}\sum_{j=1}^{J}\left(r^j{}_t - r^B{}_t\right)^2\right\}} \qquad (5)$$

where $r^j{}_t$ is the value of the interest rate for trial j in period t and rB_t is the value of the interest rate on the base in period t.

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