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Working Paper No. 353
The conduct of global monetary policy and domestic stability

Andrew P Blake and Bojan Markovic

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Andrew P Blake[(1)] and Bojan Markovic[(2)]

Abstract

The purpose of this paper is to examine how important an improvement in global monetary policy might be for the macroeconomic performance of a small open economy such as the United Kingdom. Our paper contributes to the literature by proposing a new methodology to treat indeterminate solutions (*the most-robust* solution), and by analysing a policy improvement within a three-country framework. Both contributions yield a rich set of theoretical and policy implications. We find that the performance of the domestic macroeconomy depends crucially on domestic monetary policy, but there remains significant potential for monetary policy abroad to improve the stability of inflation and output in a small open economy. Importantly, how much of this potential spillover from policy abroad crystallises is still endogenous to the conduct of domestic policy. We also show that an improvement in policy abroad may not reduce domestic volatility when domestic policy is the only *poor* policy globally. In such a case domestic volatility can even become worse. Our paper also yields interesting results related to the impact of a policy improvement abroad on inflation persistence in the domestic economy and her exposure to foreign shocks.

Key words: Indeterminacy, stochastic volatility, Taylor rule, international spillovers, Great Inflation.

JEL classification: C62, D84, E30, E58, E61, F41, F42.

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Summary

Inflation and output in the United Kingdom became much less volatile during the 1990s. There is an ongoing debate trying to establish whether this was caused by the absence of major disturbances in this period or by improved UK monetary policy following the introduction of the inflation-targeting framework. Answering this question is important not just for economic historians, but also for a wide range of practitioners and policymakers, who need to assess the prospects for the future volatility of UK inflation and output. Should the future world be affected by larger and less favourable disturbances, will the volatility of UK inflation and output revert to that seen before the 1990s? Or has more skilled policymaking, both home and globally, permanently reduced the capacity of shocks to increase the volatility of UK inflation and output?

When analysing the contribution of improved policymaking, most of the previous work on this question focused on an improvement in domestic monetary policy. This paper, by contrast, additionally examines the importance of an improvement in global monetary policy for the macroeconomic stability of a small open country like the United Kingdom. Specifically, an improvement in monetary policy means a shift from a policy where real interest rates do not increase in response to a rise in inflation to one where they do. To conduct our analysis we use a three-country model calibrated to mimic the United Kingdom, the United States and the 'Rest of the World'. The model allows for the relative price of exports to vary between countries, due to a 'home bias' for domestically produced goods. To examine the consequences of monetary policy that does not increase the real interest rate when inflation rises, we propose a simple new method for analysing 'indeterminate' solutions, a problem encountered when monetary policy does not produce one unique macroeconomic outcome.

Our key finding is that an improvement in global policy cannot sufficiently explain the extent of the fall in the volatility of output and inflation in the domestic economy. In particular, we find that a well-conducted monetary policy abroad cannot substitute for a well-conducted domestic monetary policy. If domestic monetary policy is well conducted (by which we mean that it increases the real interest rate when inflation rises), then an improvement in global monetary policy is unambiguously good for the domestic economy, because the shocks coming from the world economy are reduced.

By contrast, if domestic monetary policy is badly conducted then an improvement in global policy may not necessarily benefit the domestic economy. It can actually increase the volatility of inflation and output. There are two effects at work. A well-conducted monetary policy abroad stabilises output abroad, which stabilises domestic exports and thus output. But because any policy change, whether well conducted or bad, will affect the relative price of exports, there is a second, offsetting effect. Good global policy naturally takes account of and exploits changes in that price, which lead to more volatility in the domestic economy's exports. Good domestic policy would then offset this external source of volatility, but poor policy will not do so sufficiently. The precise effect depends on the specific parameterisation of the model, but in the hypothetical case that we examine had only domestic monetary policy been badly

conducted, the second (destabilising) effect would have dominated, and the global policy improvement would have harmed the domestic economy.

We also find that an improvement in global monetary policy reduces the exposure of the domestic economy to disturbances originating abroad, indicating that an inadequate monetary policy abroad amplifies the impact of disturbances originating abroad. Furthermore, an improvement in global monetary policy increases the exposure of the domestic economy to foreign supply relative to foreign demand disturbances. This is because the second (destabilising) relative price effect is particularly important for supply disturbances, while demand disturbances mainly spill over across countries through the first (stabilising) global demand effect.

1 Introduction and motivation

The volatility of inflation and output has substantially reduced in the United Kingdom since the early 1990s[1] and in the United States from the 1980s.[2] There is an ongoing debate trying to establish whether this was caused by the absence of major adverse shocks in this period, or by improved monetary policy in these countries.[3] Answering this question is important not just for economic historians, but also for a wide range of practitioners and policymakers, who need to assess the prospects for the future volatility of inflation and output. Should the future world be affected by larger and less favourable shocks than in the recent past, will the volatility of target variables revert to that seen in the 1970s? Or has more skilled policymaking permanently reduced the capacity of shocks to increase the volatility of inflation and output?

Recent empirical evidence, exemplified by Canova (2006) and Gambetti *et al* (2005) for the United States, and Benati (2007) for the United Kingdom, finds that good luck, ie lack of adverse shocks, rather than good policy, played the dominant role in the reduction in the volatility of output and inflation during the 1990s. However, most of these studies focus on closed-economy variables. This necessarily implies that any improvements in monetary policy abroad can only be interpreted as an example of the absence of major adverse shocks.

As a matter of casual empiricism, it seems uncontroversial to assert that monetary policy around the world has much improved since the 1970s. Taylor (1999) and Clarida *et al* (2002) provide evidence of such a shift in US monetary policy. Nelson (2007) provides evidence of an improvement in UK policymakers' understanding of the transmission mechanism since the 1980s. Today's policymakers better understand what causes inflation and the limits to assessing the state of an economy, particularly in real time. They also appreciate more the costs of high and volatile inflation (King (1997), Taylor (1997), and DeLong (1997)). This led some policymakers to adopt a more institutionalised commitment to low and stable inflation, often through an explicit inflation-targeting regime. These changes must have contributed to the reduced volatility of inflation and output in the United Kingdom and the United States. But the question remains: how much were any new monetary policy arrangements instrumental in the improved macro outcomes, or was lower volatility mainly achieved by a lack of large disturbances in the 1990s?

Many empirical studies document a much lower volatility of *shocks* in the 1990s than in the 1970s (McConnell and Perez-Quiros (2000), Stock and Watson (2003), and Ahmed *et al*

[1] Benati (2004, 2006) documents how the inflation-targeting regime has been characterised by the most stable macroeconomic environment in the United Kingdom since the metallic standard era. Some authors (eg Stock and Watson (2003)) claim, however, that the decline in the volatility of UK inflation began even before the introduction of the inflation-targeting regime, ie during the 1980s.
[2] See McConnell and Perez-Quiros (2000), and Stock and Watson (2003), among others.
[3] Some recent studies (eg Stock and Watson (2003), and Blanchard and Gali (2007)) argue that the fall in volatility might be caused by structural changes, such as a fall in the share of traded goods or a fall in real wage rigidity. Examining the role of these structural changes remains out of the scope of our paper.

(2004)). As noted above, empirical work by Canova (2006) and Benati (2007) pointed towards a dominant role for good luck – a lower volatility of non-policy shocks – in fostering the more stable macroeconomic environment. This work has tended to use empirical techniques, such as structural VARs, to identify the causes behind the phenomenon. Their results show that out of three identified structural shocks (monetary policy, demand and supply) the bulk of the reduction in macroeconomic variability can be attributed to a reduction in the volatility of non-policy shocks. But these results may have been distorted by an inability to capture any improvements in the monetary policy abroad using constant coefficient models.

The purpose of this paper is to examine how important an improvement in monetary policy abroad might be for the macroeconomic performance of a small open economy such as the United Kingdom. We do so by analysing how 'UK' inflation and output respond to domestic and foreign demand and supply shocks, and compare two cases: first, when a 'US' central bank conducts 'good' monetary policy, and second, when 'US' monetary policy is instead 'poor'. To conduct our analysis we use a representative three-country model that parallels the Centre-Periphery model of Corsetti, Pesenti, Roubini and Tille (2000), extended by adding dynamics, a non-traded sector in each country, and exogenous supply and demand shocks. The model is calibrated to resemble three economies, which we assume are the United States, United Kingdom and 'Rest of the world' (ROW). To characterise 'poor' policy properly we propose a simple new method for analysing solutions under indeterminacy, a problem encountered when monetary policy is insufficiently aggressive, as demonstrated by Lubik and Schorfheide (2004).

To our knowledge, there are no other papers that analyse the contribution of indeterminate monetary policy abroad to domestic macroeconomic stability in the case of a small open economy such as the United Kingdom. Bullard and Singh (2006) apply a model of multiple large industrial countries and find that when the worldwide equilibrium is indeterminate due to 'poor' monetary policy in some countries, all countries are exposed to increased endogenous volatility. Their analysis is partial as they simulate 'sunspot' rather than fundamental shocks, based on a single, arbitrarily selected solution.[4]

In our analysis we follow Lubik and Schorfheide (2004) and Bullard and Singh (2006), and characterise 'poor' monetary policy as one that fails to satisfy the Taylor principle.[5] Such policies necessarily leave the solution indeterminate and we need to select meaningful solutions from a potential infinity. We do this by seeking the solution that is in a specific sense the most robust. The advantage of this approach is that we are able to compare it to a set of alternative solutions. We show that this approach works well, picking up solutions that are always close to the least volatile available.

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[4] Jääskelä and Kulish (2007) consider the impact of indeterminacy in a two-country model and show that the small country has an effect on the large one if the larger one fails to act properly. This is consistent with our results below.

[5] The Taylor principle assumes that the nominal interest rate should react to deviations of inflation from the target with a coefficient higher than one.

Our main results are as follows. We find that any reduction in the volatility of UK inflation and output depends crucially on UK monetary policy. But there remains significant potential for monetary policy abroad to improve the stability of UK inflation and output. The extent that this potential crystallises is still endogenous to the conduct of UK monetary policy. Additionally, we identify an interesting phenomenon: an improvement in policy abroad would not reduce UK volatility if UK monetary policy were the only 'poor' policy globally, because the global policy operates not only on global income in a stabilising manner, but also induces some offsetting volatility in the relative prices of exports. The latter effect dominates in our parametrisation. The paper also yields interesting results related to the impact of policy improvements abroad on the UK inflation persistence and her exposure to foreign shocks.

The rest of the paper is organised in the following way. Sections 2 and 3 are intended for more technical readers. Section 2 sets out the model, while Section 3 presents our proposed methodology to deal with indeterminate solutions. Readers less interested in technical aspects of the paper may want to skip immediately to Section 4, which discusses the results. Section 5 conducts sensitivity and robustness checks, while Section 6 concludes.

2 The model

We apply our suggested method to a three-country version of a relatively standard new open economy dynamic stochastic general equilibrium model.[6] As we are interested in analysing the impact on a small open economy, the three countries are calibrated to be consistent with the United Kingdom (UK), the United States (US), and the rest of the world (ROW). Households, firms and government are all separately modelled. Each of these behave in a standard way: Households consume goods and provide labour and capital to firms, firms in each country produce a single good, which can be traded or non-traded and governments tax and spend. We assume local currency pricing, but purchasing power parity breaks down due to a home bias in consumption and the existence of a non-traded goods sector.

2.1 Households

Risk-averse households in each country *j* are infinitely lived with preferences given by:

$$U_0^j = E_t \sum_{t=0}^{\infty} \beta^t \left[\omega_t^j \frac{\left(C_t^j\right)^{1-\xi_C}}{1-\xi_C} + \frac{\chi}{1-\xi_M} \left(\frac{M_t^j}{P_t^j} \right)^{1-\xi_M} + \varphi \frac{\left(1-H_t^j\right)^{1-\xi_H}}{1-\xi_H} \right] \quad \textbf{(1)}$$

where E_t denotes the expectations operator conditional on time *t* information, and β is the discount factor. Households are assumed to derive utility from consumption, C_t, real money balances, M_t/P_t, and leisure, $1\text{-}H_t$. The elasticities of substitution (ξ_C, ξ_M, ξ_H, χ and φ) are

[6] The model is a modification of an *N*-country model developed internally in the Bank of England, and used for a variety of purposes. For an alternative description of the model calibrated to analyse how the choice of Asian exchange rate regimes impacts on Europe see Markovic and Povoledo (2007).

calibrated separately for each country. Labour supply, H_t, is homogenous and perfectly mobile between the sectors within the country, and it is assumed that:

$$H_t^j = H_{T,t}^j + H_{N,t}^j \qquad \textbf{(2)}$$

where $H_T^j = \int_{S_T^j} H_T^j\left(z_T^j\right) dz_T^j$ and $H_N^j = \int_{S_N^j} H_N^j\left(z_N^j\right) dz_N^j$ are aggregates across firms in traded (T) and non-traded (N) sectors. The demand shock, ω^j, is modelled as a shock to consumption preferences, following Neiss and Nelson (2003).

Total consumption C^j is a composite index of traded, C_T^j, and non-traded, C_N^j, goods:

$$C_t^j = \left[\left(\alpha^j\right)^{\frac{1}{\mu}} \left(C_{T,t}^j\right)^{\frac{\mu-1}{\mu}} + \left(1-\alpha^j\right)^{\frac{1}{\mu}} \left(C_{N,t}^j\right)^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} \qquad \textbf{(3)}$$

where $0 \le \alpha^j \le 1$ is the share of the traded consumption, and $1- \alpha^j$ is the share of the non-traded consumption in the consumption basket. Consumption index of traded goods is then allocated between consumption of *ROW*'s goods and the consumption bundle of 'periphery' goods (P):

$$C_{T,t}^j = \left\{ \left(\gamma_P\right)^{\frac{1}{\rho}} \left(C_{P,T,t}^j\right)^{\frac{\rho-1}{\rho}} + \left[\left(1-\gamma_P\right)h^{ROW}\right]^{\frac{1}{\rho}} \left(C_{ROW,T,t}^j\right)^{\frac{\rho-1}{\rho}} \right\}^{\frac{\rho}{\rho-1}} \qquad \textbf{(4)}$$

with $0 \le \gamma_P \le 1$ the size of the P bundle, and $1 - \gamma_P$ the size of the *ROW*. The P consumption bundle consists of UK and US traded goods:

$$C_{P,T,t}^j = \left\{ \left[\left(\gamma_{UK}\right)h^{UK}\right]^{\frac{1}{\psi}} \left(C_{UK,T,t}^j\right)^{\frac{\psi-1}{\psi}} + \left[\left(1-\gamma_{UK}\right)h^{US}\right]^{\frac{1}{\psi}} \left(C_{US,T,t}^j\right)^{\frac{\psi-1}{\psi}} \right\}^{\frac{\psi}{\psi-1}} \qquad \textbf{(5)}$$

with μ being the elasticity of substitution between T and N goods, ρ the elasticity of substitution between *ROW* and P traded goods, and ψ between UK and US traded goods. The parameters h^{UK}, h^{US} and h^{ROW} represent home bias in consumption. Each individual good is further differentiated in a bundle of individual monopolistically competitive varieties, with the elasticity of substitution θ.

The budget constraint of the household in country j in period t is expressed in real terms as:

$$\frac{B_{US,t}^j}{P_t^j}\frac{\varepsilon_t^j}{\varepsilon_t^{US}} + \frac{\eta}{2}\left(\frac{B_{US,t}^j}{P_t^j}\frac{\varepsilon_t^j}{\varepsilon_t^{US}}\right)^2 + \frac{M_t^j}{P_t^j} + C_t^j - \frac{T_t^j}{P_t^j} =$$

$$\left(1+i_{t-1}^{US}\right)\frac{B_{US,t-1}^j}{P_t^j}\frac{\varepsilon_t^j}{\varepsilon_t^{US}} + \frac{M_{t-1}^j}{P_t^j} + H_t^j W_t^j + \Pi_{T,t}^j + \Pi_{N,t}^j + R_t^j \qquad \textbf{(6)}$$

Households allocate resources between consumption, real money balances, the dollar-denominated[7] non state contingent nominal bonds,[8] B_{US}^{j}, and taxes paid to the government, T_t. Households' resources consist of their wage income W^j, the profits from the ownership of domestic firms in traded and non-traded sectors, Π_T^j and Π_N^j, the lump-sum rebates from the government, R^j, and the gross return on their initial bond holding. The risk-free interest paid on dollar-denominated bonds is i^{US}, and its value in home currency is computed using the exchange rate ε^j.[9] The small cost of holding bonds $\eta > 0$ ensures the stationarity of the model, as observed in Schmitt-Grohe and Uribe (2003), and Ghironi and Melitz (2005).

2.2 Firms

Production of domestic differentiated goods is by a continuum of symmetric, monopolistically competitive firms, producing z_T and z_N, in the traded and non-traded sectors. In every period t individual firms maximise the present value of their expected profits:

$$E_t \sum_{i=0}^{\infty} \beta^i \frac{\omega_{t+i}^j \left(C_{t+i}^j\right)^{-\xi_C} / P_{t+i}^j}{\omega_t^j \left(C_t^j\right)^{-\xi_C} / P_t^j} \left[SR_{T,t+i}^j\left(z_T^j\right) - H_{T,t+i}^j\left(z_T^j\right) W_{t+i}^j P_{t+i}^j\right] \quad \textbf{(7)}$$

$$SR_{T,t}^j\left(z_T^j\right) = \left[1 - \Gamma_{T,t}^j\left(z_T^j\right)\right] P_{j,T,t}^j\left(z_T^j\right) \tilde{Y}_{T,t}^j\left(z_T^j\right) \quad \textbf{(8)}$$

subject to their respective demand curves:

$$\tilde{Y}_{T,t}^j\left(z_T^j\right) = \frac{1}{\alpha^j \gamma_j} \left(\frac{P_{j,T,t}^j\left(z_T^j\right)}{P_{j,T,t}^j}\right)^{-\theta} \left[\gamma_j C_{j,T,t}^j + \left(1-\gamma_j\right) C_{j,T,t}^f\right] \quad \textbf{(9)}$$

The expected profit consists of a difference between sales revenues, $SR_t^j\left(z^j\right)$, and the cost of production. The downward-sloping demand for individual goods consists of the demand from consumers in country j, and the demand from other two countries $f \neq j$. Firms are subject to Rotemberg-type price-setting: in each period firms have to pay a non-linear adjustment cost $\Gamma_{T,N,t}^j$ in order to change their prices. We follow Ireland (2001), who models the price-adjustment cost as a deviation of inflation from its steady-state level:

$$\Gamma_{T,t}^{UK}\left(z_T^{UK}\right) = \frac{\phi}{2}\left(\frac{P_{UK,T,t}^{UK}\left(z_T^{UK}\right)}{\overline{\pi}^{UK} P_{UK,T,t-1}^{UK}\left(z_T^{UK}\right)} - 1\right)^2 \quad \textbf{(10)}$$

Each firm in both sectors has access to a production technology that uses labour, $H_t^j\left(z^j\right)$, as its only input:

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[7] Having both domestic and foreign non state contingent nominal bonds would not change any of the model dynamics, assuming that the holding cost does not significantly vary among different bonds.
[8] The market clearing implies that bonds are in zero net supply worldwide.
[9] ε^J represents the price of country j's currency in terms of *ROW*'s currency.

$$\widetilde{Y}_{T,t}^{j}\left(z_T^j\right)=A_{T,t}^{j}\left[H_{T,t}^{j}\left(z_T^j\right)\right]^{\zeta} \quad \textbf{(11)}$$

$$\widetilde{Y}_{N,t}^{j}\left(z_N^j\right)=A_{N,t}^{j}\left[H_{N,t}^{j}\left(z_N^j\right)\right]^{\zeta} \quad \textbf{(12)}$$

where ζ is the elasticity of output with respect to labour. $A_{T,t}^j$ and $A_{N,t}^j$ are sector-specific supply (productivity) shocks.

2.3 Government

Government, our final agent in the model, represents both the fiscal and monetary authority. Fiscal policy is completely passive. Each period, the government runs a balanced budget in the following way:

$$M_t^j - M_{t-1}^j = T_t^j \quad \textbf{(13)}$$

Monetary policy is specified as a standard Taylor-type interest rate feedback rule with smooth interest rate adjustment:

$$\left(1+i_t^j\right)=\left(1+i_{t-1}^j\right)^{\rho_i}\left[\left(1+\bar{i}^j\right)\left(\frac{\pi_t^j}{\bar{\pi}^j}\right)^{\rho_\pi}\left(\frac{y_t^j}{\bar{y}^j}\right)^{\rho_y}\right]^{1-\rho_i} \quad \textbf{(14)}$$

where ρ_i , ρ_π and ρ_y are non-negative parameters, $\bar{i}^j$ is the steady-state nominal interest rate, π_t^j is gross inflation rate, $\bar{\pi}^j$ the inflation target set equal to its steady-state gross rate, and y_t^j is output deviation from its steady-state level, $\bar{y}^j$. In our simulations, we set ρ_y at zero to simplify the analysis of determinacy region and feedback on the inflation rate alone. In this case monetary policy ensures determinacy as long as $\rho_\pi > 1$.

Our analysis of the effect of the monetary policy is based on two cases:

1. when $\rho_\pi^j > 1$, country *j*'s monetary policy is assumed to be 'good';
2. when $\rho_\pi^j < 1$, country *j*'s monetary policy is assumed to be 'poor'.

2.4 Calibration

The model is calibrated to match some key structural features of the United Kingdom, the United States and ROW economies. We solve the model numerically using Dynare (see Juillard (2001)). All the calibrated parameter values and their sources are reported in Table A.

Table A: Parameters in the model

PARAMETER		VALUE UK	US	ROW	Source
β	Discount factor	0.99	0.99	0.99	
ξ^c	Intertemporal elasticity of consumption	5	5	5	Chari *et al* (2002)
ξ^h	Intertemporal elasticity of leisure	10	10	10	
F	Frisch elasticity of labour supply	0.23	0.23	0.23	Gali *et al* (2007)
ς	Elasticity of labour supply in the production function	0.8	0.8	0.8	
θ	Elasticity of substitution	6.67*	7.88**	7.88**	*Benigno and Thoenissen (2003); **Rotemberg and Woodford (1998)
ϕ^I	Nominal rigidity	77	77	77	
ψ	Elasticity of substitution between UK & US goods	3	3	3	Obstfeld and Rogoff (2005)
ρ	Elasticity of substitution between periphery & ROW	2	2	2	Obstfeld and Rogoff (2005)
μ	Elasticity of substitution between traded & non-traded	1	1	1	Obstfeld and Rogoff (2005)
φ	Weight on leisure in the utility function	2.51	3.03	0.32	
α	Share of traded in total goods	0.45*	0.32**	0.45	*Spange and Zabczyk (2006); **IMF (2005)
γ_j	Country size	0.05	0.29	0.66	
h	Home bias parameters	18.33	2.68	4.64	
η^a	Cost of holding bonds parameter	0.0025	0.0025	0.0025	Ghironi and Melitz (2005)
$\rho^{T,N}$	AR coefficient in supply shocks	0.81	0.81	0.81	Benigno and Thoenissen (2003)
ρ^ω	AR coefficient in demand shock	0.33	0.33	0.33	Neiss and Nelson (2003)
ρ^i	AR coefficient in policy rule	0.5	0.5	0.5	
ρ^π	Coefficient on inflation in policy rule	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5	

Most of the parameters are taken from other models, similar in spirit to ours. Others are specific to our model. The quarterly discount factor β pins down the equilibrium real interest rate in the model at 4%. The weight on leisure in the utility function, φ, is calibrated to impose that the steady-state fraction of time households spend working is 1/3. The elasticity of labour supply in the production function, ζ, is calibrated to match the steady-state ratio of wages to output of 0.7, following Harrison *et al* (2005) for the United Kingdom, and Rotemberg and Woodford (1999) for the United States and ROW.

The values for the preference bias parameters – country size, γ_j, and home bias, h^j – jointly determine the implied ratios of imports to GDP. We first set the country size and then set the value of home bias parameter so as to match empirically observed ratios of imports to GDP for the United Kingdom, United States and ROW – 28%, 12.5% and 4.5%, respectively. The calibration also ensures that the shares of UK, US and ROW imports coming from their respective trading partners matches those observed in the data. The share of tradable goods, α^j, is based upon the estimate of Spange and Zabczyk (2006) for the United Kingdom, and the International Monetary Fund (2005)[10] for the United States, and the ROW. The elasticity of substitution between individual goods, θ, is taken from Benigno and Thoenissen (2003) for the United Kingdom, and Rotemberg and Woodford (1998) for the United States and the ROW.

Table B: Volatility of UK, US and model-generated time series: percent standard deviations

	Data		Model	
	UK[a]	US[b]	UK	US
Inflation	0.29	0.25	0.30	0.32
Output	0.73	0.52	0.68	0.66
Consumption	0.72	0.45	0.50	0.52
US-UK real exchange rate	5.70[c]		1.07	

[a] Standard deviations of business-cycle components found in Benati (2006, Table F). We report here Benati's values for the inflation-targeting period in the United Kingdom. Benati reports the volatility of quarterly GDP deflator given on a *per annum* basis. To make it comparable with our *per quarter* inflation we divide Benati's number by four.
[b] The rolling regression of real GDP growth and GDP deflator found in Blanchard and Simon (2001). They use 20-quarter rolling horizons, which helps ensure stationary series. We approximate the numbers based on Figures 6 and 9 for the period 1990-2000.
[c] Our calculation for the sample period 1990:1 – 2005:4, based on the OECD data.

The autoregressive parameter in the supply shock is taken from Benigno and Thoenissen (2003), while that in the demand shock is taken from Neiss and Nelson (2003).[11] The standard deviations of the shocks are chosen to approximate the standard deviation of output and inflation in United Kingdom and the United States as reported in Table B. The standard deviations of impulse responses produced by the model roughly match those observed in data for inflation, output, and consumption. The standard deviation of the real exchange rate is much lower in the model than in data. This feature is a well-documented problem in the open economy literature.

[10] See 'Globalization and external imbalances', Chapter 3, *World Economic Outlook*, April 2005.
[11] Our autoregressive parameters for both supply and demand shocks are somewhat on the upper bound of the previous estimates.

2.5 Definition of 'good' and 'poor' policies

Empirical studies find that US monetary policy during the 1960s and 1970s did not conform to the Taylor principle. Both Taylor (1999) and Clarida *et al* (2002) estimate the coefficient on inflation in the policy rule to less than one. This estimate would imply the indeterminacy of the equilibrium price level (Woodford (2003, chapter 2)). Clarida *et al* further propose that this indeterminacy of the equilibrium explains the instability of US inflation and real activity during the 1970s. The similar result – the estimated coefficient on inflation of less than one in the policy rule – has been found by Nelson (2003) for the pre inflation-targeting period in the United Kingdom.

Table C: Estimated coefficients for interest rate feedback rules

Country	Study	Sample period	Long-run response	
			Inflation	Output gap
US	Clarida, Gali and Gertler (2002)[a]	Pre-Volcker	0.68	0.28
		Volcker-Greenspan	2.14	1.49
UK	Nelson (2003)[b]	1976-1979	0.62	0.11
		1979-1987	0.38	0.16
		1987-1990	0.00	0.45
		1992-1997	1.27	0.47

[a] We report only estimates obtained using the rate of change of the consumer prices index (CPI), the same variable used in the policy rule in our model.
[b] Nelson (2003) measures inflation only as the percentage change in the retail prices index (RPI), rather than the CPI.

Following these empirical studies and the results in Woodford (2003), we call the monetary policy rule of a given country 'good' when the coefficient on inflation in interest rate feedback rule, ρ_π^j, is higher than one. When this coefficient is lower than one, we term the monetary policy rule 'poor'. The aim of our paper is not to search for the optimal policy rule, but rather to provide an indication of the potential of the improvement in the monetary policy abroad to improve the macroeconomic stability in the United Kingdom. We thus assume the coefficient on inflation in the policy rule, ρ_π^j, takes the value of 1.5 if the policy is 'good', and 0.5 if the policy is 'poor'. Table C shows that these numbers are roughly in line with those obtained in Clarida *et al* (2002), and Nelson (2003).[12] The autoregressive coefficient in the interest rate feedback rule, ρ_i^j, is always assumed to be 0.5.

[12] Clarida *et al* (2002) and Nelson (2003) include output gap in their policy rule. This lowers the coefficient on inflation in the policy rule, necessary to ensure determinacy, to somewhat less than one. But it still remains very close to one. The exact formulae for the

3 Solution methodology

We face a fundamental problem when we wish to analyse the impact of monetary policy in our model. The solution for the case of a 'poor' policy (approximated with the coefficient on inflation of 0.5) is not unique, as the conditions for uniqueness determined by Blanchard and Kahn (1980) are not satisfied. This has been noted by various authors following on from Clarida *et al* (2002). In this section we describe the procedure that we use to choose between indeterminate solutions, and explain its advantages compared to other analogous methods.

3.1 The treatment of indeterminate solutions

There are a number of ways we can deal with indeterminate solutions, and we discuss several here, concentrating on perfect foresight solutions. Let us briefly describe the computation of solutions that satisfy the Blanchard-Kahn criteria defined below and describe how we can deal with deficiencies in them.

The model described in Section 1 is a linear rational expectations one with 23 expectational variables. A simple representation of such a model is:

$$\begin{bmatrix} z_t \\ x_{t+1}^e \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} z_{t-1} \\ x_t \end{bmatrix} \qquad \textbf{(15)}$$

where the vector x_t is all the expectational variables that we expect to 'jump' to clear the saddlepath if all countries follow a 'good' policy. In particular, this includes consumption, output and inflation in each country together with financial variable such as exchange rates. z_{t-1} is the vector of variable predetermined at time *t*, and includes lagged interest rates, lagged government spending, shock variables and so on.

The usual numerical solution of **(15)** is obtained by the Blanchard and Kahn (1980) formula, where the matrix *A* is diagonalised such that it can be written in the form $A = M^{-1}\Lambda M$, where Λ is a diagonal matrix of eigenvalues arranged in ascending order and *M* the corresponding matrix of eigenvectors. Performing a change of variables, such that:

$$\begin{bmatrix} \eta_t \\ \mu_t \end{bmatrix} = M \begin{bmatrix} z_{t-1} \\ x_t \end{bmatrix} \qquad \textbf{(16)}$$

it must be that the dynamics of the new variables are governed by:

$$\begin{bmatrix} \eta_{t+1} \\ \mu_{t+1} \end{bmatrix} = \begin{bmatrix} \Lambda_s & 0 \\ 0 & \Lambda_u \end{bmatrix} \begin{bmatrix} \eta_t \\ \mu_t \end{bmatrix}. \qquad \textbf{(17)}$$

Since the eigenvalues are ordered in by absolute ascending value, the μ's are explosive unless they are set to zero. If the number of unstable roots is equal to the number of expectational variables then setting

coefficient on inflation that ensures determinacy in such a case is $1-\frac{1-\beta}{k}\rho^y$, where β is a discount factor, *k* the slope of the Phillips curve, and ρ_y the coefficient on output gap.

$$x_t = -M_{22}^{-1} M_{21} z_{t-1} \quad \textbf{(18)}$$

yields the unique non-explosive solution such that $\mu_t = 0, \forall t$.

This is the rational expectations solution where we have partitioned the matrix *M* consistently with the number of jump variables. This solution suppresses the unstable behaviour and ensures that the evolution of all variables is consistent with each other and satisfies the rationality requirement. Sims (2001) extends this to consider certain unstable processes and additionally gives a solution for indeterminate cases when there are too few unstable roots and a consequent infinity of solutions.

What does 'too few' unstable roots mean? We have indicated that it implies an infinity of solutions, but why? Think of the following: what if we ordered the variables so that we have the last *k* variables as the expectational ones? Then if we had *k*-1 unstable roots we could jump the last *k*-1 of them onto the saddle path, but be left with a single variable for which we had no initial condition. An example might make this clearer. Imagine a notional system with three variables; capital, inflation and output, in that order. Two of these we wish to jump onto the saddle path – inflation and output – but perhaps we have only one unstable root. If we calculate a reaction function (call it *N*) for output, it would be a function of capital and inflation. But inflation is an expectational variable, and as such a forward difference equation. With a stable root we can pick any initial value of inflation and get a stable solution.[13] This also extends to output, if we order inflation last. Picking any value for output affects the jump in inflation, but produces a stable and rational solution.

What we need is a reaction function, *N*, of the same row dimension as the number of 'jumps', *k*. Although not all variables jump with indeterminacy, we need to eliminate the unstable roots and have some rule to set the initial values for all the variables jointly. In the example above, our underdimensioned *N* sorts this out for any arbitrary value of the 'left-over' expectational variables. However, it can be done by a rule that essentially replicates the reaction function by some external choice to make up the missing rows of *N*.

Sims (2001) actually shows the algebraic implications of this, and indicates how any of the candidate infinite number of solutions could be calculated. Lubik and Schorfheide (2003, 2004) use an ingenious approach to calculate their reaction function by essentially making agents do the work that policymakers have failed to do. Their trick is to choose the reaction function that ensures rationality but is closest to an arbitrary one, which would be determinate. Nevertheless, it is not at all clear why an agent (and certainly not in co-ordination with all other agents) would want to do this. In such a case, policymakers are essentially inessential for the stability of an

[13] A different initial value of inflation affects the jump in output through the reaction function, but everything will evolve rationally and in a stable fashion.

economy. A policymaker could exploit this to reduce interest rate volatility while maintaining inflation on target, say.

One way of avoiding this type of 'moral hazard' problem is to make agents choose their reaction function on some basis that is entirely free from assumptions about the policy rule.[14] Lubik and Schorfheide (2004, page 199) suggested that it might be possible to track the root you might expect to be stable and treat it as if it were still an unstable root in calculating the reaction function. The argument, however, extends to any stable root. Essentially, one could include multiple eigenvectors from M associated with enough additional stable roots to substitute for the unstable ones and calculate N using the formula in equation **(18)**. As long as M_{22} is invertible, one can use this to calculate the initial conditions for all k variables.[15] Bullard and Singh (2006), perhaps in the spirit of tracking the correct root, choose the largest stable root[16] after ordering the roots in absolute value. However, there is no reason to assume that this root is any more associated with deficient monetary policy than any other.

The non-singularity of M_{22} is an important issue. If it is singular, then the linear space that requires spanning to properly solve the model rationally is not contained in the selected eigenvectors. In such a case, it is prudent to check the viability of any candidate solution. The condition number of M_{22} indicates how sensitive its inverse is to small changes in its parameters. This indicates 'how invertible' the matrix is. The condition number (computed here as the ratio of the largest to the smallest singular value of M_{22}) is a numerical indication of rank, with a large number indicating rank deficiency.[17] Using the singular values (essentially the square root of the eigenvalues of the square of a given matrix) is a numerically robust indicator of conditioning with respect to invertibility. Very large numbers indicate that there would be large swings in the values of x_t for tiny changes in the values of M_{22}.

We propose using the lowest condition number solution to calculate the reaction function in case of indeterminacy. The attractiveness of this procedure is that agents could use it to determine a solution associated with the 'most' non-singular matrix. This gives us a selection criterion which is independent from any policy considerations, and is an 'internally generated' solution. In what follows, we use the condition number to exclude any solution that would result in M_{22} being badly conditioned with respect to inversion and therefore prone to generating results highly sensitive to small numerical errors. We also exclude solutions with zero roots, since they imply higher volatility for the endogenous variables.[18] We then use the condition number to

[14] For example it might be the case that agents think that a policy will be adopted in the future that rules out indeterminacy currently. We assume that agents expect policy to be continued indefinitely.
[15] There are a number of additional considerations, such as how to deal with complex roots. We modified DYNARE to automatically reorder the generalised Schur decompositions to put any desired eigenvector(s) in the reaction function N.
[16] 'Largest' is consistent with our description of the Blanchard-Kahn conditions. Their solution equivalently chooses the smallest unstable root consistent with their writing of the model.
[17] See Judd (1998, pages 67-70) for a discussion of condition numbers and related matters.
[18] We calculate every candidate solution for the model which depends on the number of stable roots and the deficiency of N. For our model with three too few roots this is about 25,000 possible solutions. Throwing out the rank-deficient ones gets this down to under 5,000, and then throwing out ones with zero roots gets us to a number close to 20 possible solutions.

rank potential solutions, and pick the one with the lowest condition number. The chosen solution is deemed the 'most stable' indeterminate solution with respect to inversion. We call this solution *the most-robust solution*.[19] The properties of this procedure are further analysed by considering possible alternatives. We find that this procedure reliably delivers a solution among the most stable ones. We can thus confidently claim that this is a satisfactory procedure for finding a reasonable solution.

4 Results

In our model, US monetary policy affects the UK economy through trade and the asset market. As long as US prices are sticky, a change in US monetary policy shifts demand for all products in the consumption basket of US households, and thus affects demand for UK exports to the United States. The asset market effect operates as long as there is some capital flow between the United States and the United Kingdom. Whenever US agents borrow or lend to UK agents, a change in US monetary policy shifts UK interest rates and thus consumption of UK households.

In this section we compare the way monetary authorities conduct their policy affects:

(1) the transmission of US and UK supply and demand shocks to UK inflation and output;

(2) the volatility of UK inflation and output;

(3) the exposure of UK inflation and output to foreign shocks; and

(4) the persistence of UK inflation.

Our first finding, confirming that of Bullard and Singh (2006), is that one country cannot by itself guarantee a determinate world equilibrium. When all three countries follow 'good' monetary policy, the solution is well defined and unique. But when at least one of the countries follows 'poor' monetary policy, the worldwide equilibrium is indeterminate. The dimension of indeterminacy is larger if more countries conduct 'poor' monetary policy.

Since the solution for our 'poor' policy is not unique, we follow the procedure explained in Section 3 and choose one of the solutions, the one with the lowest condition number indicating the most stable indeterminate solution. In Section 5 we then check whether our main results are robust to changes in the criteria for the chosen non-unique solution.

[19] Clearly this definition of robustness is arbitrary and we could look for other candidates. A considerable advantage is that this measure can be readily calculated as part of the solution procedure.

4.1 Impulse response analysis

In this section we briefly explain how the quality of the US monetary policy affects the transmission of US and UK supply and demand shocks to UK output and inflation.[20] A brief explanation of the transmission process itself is provided in Appendix I. We focus our analysis on the effect of an improvement in US monetary policy on impulse responses of UK output and inflation. As discussed in previous sections, we compare the 'good' policy (determinate) case with the 'poor' policy (indeterminate) case, where the latter is the solution selected by our procedure. Charts with impulse responses are given in Appendix II.

4.1.1 Supply and demand shocks in the United States

Chart A.1 in Appendix II shows that the model predicts that when UK policy is always 'good', an improvement in US policy reduces the volatility of UK output and inflation, especially on impact. UK output is less volatile because, when US policy is 'good', the demand for UK exports is more stable. In turn, UK CPI inflation is less volatile because both US prices and the UK/US nominal exchange rate are more stable.

Chart A.2 shows that, when UK policy is always 'poor', an improvement in US policy does *not* reduce the volatility of UK output and inflation. Although an improvement in US policy stabilises US demand and prices, 'poor' UK policy is not able to exploit this to improve UK domestic stability. This is because of the trade-off between the two effects that an improvement in US policy has for UK stability. The first (stabilising) effect includes the aggregate demand effect (which reflects in the above-mentioned greater stability of US demand for UK exports), and the direct cost effect (which reflects the greater price stability of UK imports from the United States). The second (destabilising) effect implies that a well-conducted US policy increases the volatility of relative prices between the UK and US goods, leading to a higher volatility of UK exports, and thus potentially destabilises UK output. When UK policy is 'poor' and the shock in the United States is a supply shock, it is this second (destabilising) effect that dominates. Crucially, the UK macroeconomic performance is worst when the United Kingdom is the only country with a 'poor' policy, as the destabilising effect becomes the most powerful in such a case.

If instead there is a demand shock in the United States, an improvement in US policy also improves UK stability, irrespectively of whether UK policy is 'good' or 'poor' (see Charts A.3 and A.4). This is because the demand shock (naturally) mainly operates through the aggregate demand effect – it increases demand for all goods (UK, US and ROW), and the destabilising effect is not as powerful as in the case of the supply shock.

[20] The 'supply' shock is modelled as a productivity shock in the traded sector, while the 'demand' shock is modelled as a preference shock in households' utility function.

4.1.2 Supply and demand shocks in the United Kingdom

An improvement in US policy has much less impact on UK stability when the shocks originate in the United Kingdom, especially when UK policy is 'good' (Charts A.5 and A.7). When UK policy is 'poor' and shocks are domestically generated, an improvement in US policy has a bigger impact on UK domestic stability (Charts A.6 and A.8). It mainly reduces the volatility of UK output and inflation. Nevertheless, in the case of a positive UK supply shock, the strong destabilising effect implies that the increased competitiveness of US goods following an improvement in her policy reduces UK output gains. Interestingly, the worst macroeconomic stability again appears to be when the United Kingdom is the only country with a 'poor' policy in the world.

4.1.3 Conclusions based on impulse responses

The above analysis brings us to a number of important conclusions. First, it indicates the crucial importance of domestic monetary policy. Only when the United Kingdom conducts 'good' policy, is she *always* able to exploit an improvement in US policy in order to improve domestic stability. Second, an improvement in US policy has a bigger impact on UK stability for shocks that originate in the United States. This is because 'poor' US policy amplifies the effects of US shocks. Third, when UK policy is 'good', an improvement in US policy unambiguously improves UK domestic stability. Finally, when UK policy is 'poor', an improvement in US policy can render the UK domestic stability worse.

This last observation generates an interesting phenomenon: it implies that an improvement in monetary policy abroad does not reduce domestic volatility when domestic policy is the only poor policy globally.

4.2 Volatilities

In this section we analyse the standard deviations of UK inflation and output following supply and demand shocks under several scenarios.

Table D: Volatility of UK inflation and output: percent standard deviations

UK always 'good'	Only UK 'good'	Only US 'poor'	All 'good'
UK CPI inflation	0.65	0.44	0.30
UK output	0.80	0.79	0.68
UK always 'poor'	All 'poor'	Only US 'good'	Only UK 'poor'
UK CPI inflation	1.40	0.96	2.05
UK output	0.73	0.74	1.49

Table D reports standard deviations in cases when the United Kingdom always conducts either ‘good’ or ‘poor’ monetary policy. It yields two main conclusions when the United Kingdom always conducts ‘good’ policy. First, an improvement in US monetary policy reduces the volatility of UK inflation and output. When US monetary policy improves, the standard deviation of UK inflation reduces from 0.44% to 0.30%, and the standard deviation of UK output reduces from 0.79% to 0.68%. Second, the more the policies in other countries improve (both United States and ROW), the bigger the stabilising effect on the United Kingdom. The table shows that the standard deviation of UK inflation is the highest (0.65%) when both the United States and ROW conduct ‘poor’ monetary policy.

The conclusions in the case when the United Kingdom always conducts ‘poor’ policy are considerably different compared to ‘good’ UK policy. First, an improvement in US monetary policy reduces the volatility of UK inflation, but not the volatility of UK output. When US monetary policy improves, the standard deviation of UK inflation falls from 1.40% to 0.96%, but the standard deviation of UK output increases marginally from 0.73% to 0.74%. This indicates the dominance of the destabilising effect (the extra volatility in relative prices and thus UK exports) when the UK conducts ‘poor’ policy. Second, when the UK policy is ‘poor’, an improvement in monetary policy in both other countries (US and ROW) leads to the *worst* outcome. The standard deviation of UK inflation increases to 2.05%, and the standard deviation of UK output rises to 1.49%. This result confirms the interesting phenomenon mentioned above.

From Table D we deduce the crucial importance of the UK domestic monetary policy for the stability of her inflation. When other countries conduct ‘good’ policy, an improvement in UK policy reduces the standard deviation of UK inflation from 2.05% to 0.30%.[21] When other countries conduct ‘poor’ policy, an improvement in UK policy reduces the standard deviation of UK inflation from 1.40% to 0.65%.[22]

Finally, we assess the potential of an improvement in global monetary policy (all three countries) to reduce the volatility of UK output and inflation by comparing the ‘all poor’ and ‘all good’ cases. The results show that an improvement in global monetary policy reduces the standard deviation of UK inflation from 1.40% to 0.30%, and the standard deviation of UK output from 0.73% to 0.68%.

4.3 Exposure to foreign shocks

In this section we briefly assess the extent to which an improvement in policy abroad reduces the exposure of UK inflation and output to shocks that originate abroad. We do so by looking at variance decomposition of UK inflation and output, which is reported in charts in Appendix III.

[21] We here compare the ‘only UK poor’ with ‘all good’ case.
[22] We here compare the ‘all poor’ and the ‘only UK good’ case.

Table E shows that when the UK policy is 'good' an improvement in policy abroad reduces the exposure of UK inflation to shocks originating abroad from 96% to 83%, and that of output from 32% to 7%. The results further show that an improvement in policy abroad increases the exposure of UK economy to foreign supply shocks compared with foreign demand shocks. For example, an improvement in the US policy reduces exposure of UK inflation to US demand shocks from 11.2% to 1.6%, while the exposure to US supply shocks increases from 7.4% to 10.5%.[23]

Table E: Variance decomposition when the UK policy is always 'good': percentage of the total variance of UK variables explained by various shocks

Variables	UK			US			ROW			ΣUS	ΣUS/ ROW
	ST	SN	D	ST	SN	D	ST	SN	D		
only UK 'good'											
UK inflation	1.39	1.68	1.41	0.42	2.58	8.57	5.63	11.00	67.32	11.57	95.52
UK output	19.93	40.56	7.77	0.45	2.72	7.21	0.04	1.03	20.3	10.38	31.75
only US 'poor'											
UK inflation	3.08	3.62	2.38	1.21	6.16	11.17	11.96	24.49	35.94	18.54	90.93
UK output	20.64	41.99	8.01	0.52	3.09	7.11	0.06	1.78	16.81	10.72	29.37
all 'good'											
UK inflation	6.03	7.65	3.05	1.59	8.95	1.64	21.27	38.53	11.3	12.18	83.28
UK output	27.92	56.87	8.68	0.42	2.36	0.69	0.17	1.04	1.86	3.47	6.54

ST: supply shock in the traded sector; SN: supply shock in the non-traded sector; D: demand shock; ΣUS: sum of shocks originating in the United States; ΣUS/ROW: sum of shocks originating abroad (in the US and ROW).

Table F: Variance decomposition when the UK policy is always 'poor': percentage of the total variance of UK variables explained by various shocks

Variables	UK			US			ROW			ΣUS	ΣUS/ ROW
	ST	SN	D	ST	SN	D	ST	SN	D		
all 'poor'											
UK inflation	0.16	2.20	0.77	0.26	0.34	3.27	1.82	7.41	83.76	3.87	96.86
UK output	26.34	33.88	3.51	1.32	3.49	1.18	2.00	3.37	24.91	5.99	36.27
only US 'good'											
UK inflation	1.38	10.91	0.58	4.19	28.37	0.65	33.63	18.41	1.88	33.21	87.13
UK output	20.89	26.34	9.60	2.65	19.82	1.39	9.00	7.27	3.04	23.86	43.17
only UK 'poor'											
UK inflation	14.40	58.96	0.65	3.39	0.56	0.20	19.28	1.09	1.47	4.15	25.99
UK output	4.58	73.91	3.56	1.68	1.30	0.44	11.78	0.79	1.96	3.42	17.95

ST: supply shock in the traded sector; SN: supply shock in the non-traded sector; D: demand shock; ΣUS: sum of shocks originating in the United States; ΣUS/ROW: sum of shocks originating abroad (in the US and ROW).

Table F shows that when the UK policy is 'poor' an improvement in policy abroad reduces the exposure of UK inflation and output to foreign shocks. This reduction is much stronger than in the case of a 'good' UK policy.[24] In addition, an improvement in policy abroad increases the exposure of the UK economy to foreign supply shocks compared with foreign demand shocks, even more strikingly than when the UK policy is 'good'.

[23] This indicates the importance of the destabilising effect in the case of supply shocks. An improved US monetary policy is better able to manage US competitiveness through its impact on relative prices following the supply shock in the United States, and this brings about a certain expenditure-switching loss and extra volatility to UK exports.
[24] The exposure of UK inflation to foreign shocks falls from 97% to 26%.

4.4 *Inflation persistence*

Table G shows that when UK policy is 'good' an improvement in policy abroad increases the persistence of UK inflation; while when UK policy is 'poor' an improvement in policy abroad reduces the persistence of UK inflation.

Table G: Persistence of UK inflation: order one autoregressive coefficient

UK always 'good'	Only UK 'good'	Only US 'poor'	All 'good'
	0.14	0.28	0.47
UK always 'poor'	All 'poor'	Only US 'good'	Only UK 'poor'
	0.61	0.51	0.32

This might seem somewhat at odds with other findings about persistence. Lubik and Schorfheide (2004) demonstrate that, within a single-economy framework, inflation persistence increases in an indeterminate solution compared with a determinate one. This is not the case here, as the fully determinate solution is more persistent (on our measure) than the indeterminate ones with 'good' UK policy. However, inflation becomes more persistent if UK policy is 'poor' and the model becomes 'even more' indeterminate. With a more complicated dynamic structure more outcomes are possible, but notice there is consistency in our results across regimes. It seems often the case that we trade off volatility for persistence. If inflation 'jumps' more for a given shock, but the dynamics are characterised by similar long-run properties then the decay back has to be faster, so volatility is higher but persistence is less.

5 Sensitivity analysis

Our analysis is not constrained solely to the most-robust (best-conditioned) indeterminate solution. We also check other relevant solutions. Among an infinite number of potential solutions, we accept those that:

- can be calculated from the eigenvectors alone with a 'small enough' condition number;
- exclude eigenvectors associated with zero roots as candidate solutions.

The first restriction enables us to replicate the type of analysis performed by agents when determining their expectations. If the system is indeterminate, agents can pick up an infinite number of rational solutions. Nevertheless, even in such a case, rational agents would avoid solutions with obvious instabilities. Technically, such solutions are characterised by a very high condition number for the matrix M_{22}.[25] The second restriction means that we suppress eigenvectors which are certainly not associated with the dynamics of the process brought about by the 'poor' policy rule. A 'poor' policy rule should induce a stable but non-zero root.

[25] See Section 2.1.

These restrictions reduce the number of candidate solutions radically in most cases. For example, for each of our policy regimes we can reduce the number of solutions to around 20 using the two simple rules above. As this is a reduction from more than *20,000* candidates before the rules were applied these seem reasonable rules plausibly used by agents to rank candidate solutions. We then look to see the implications of using the most-robust solution relative to the remaining candidate solutions.

5.1 Results using multiple indeterminate solutions

Chart 1 compares volatilities of UK output and inflation associated with various candidate indeterminate solutions with those from the determinate solution by graphing them.

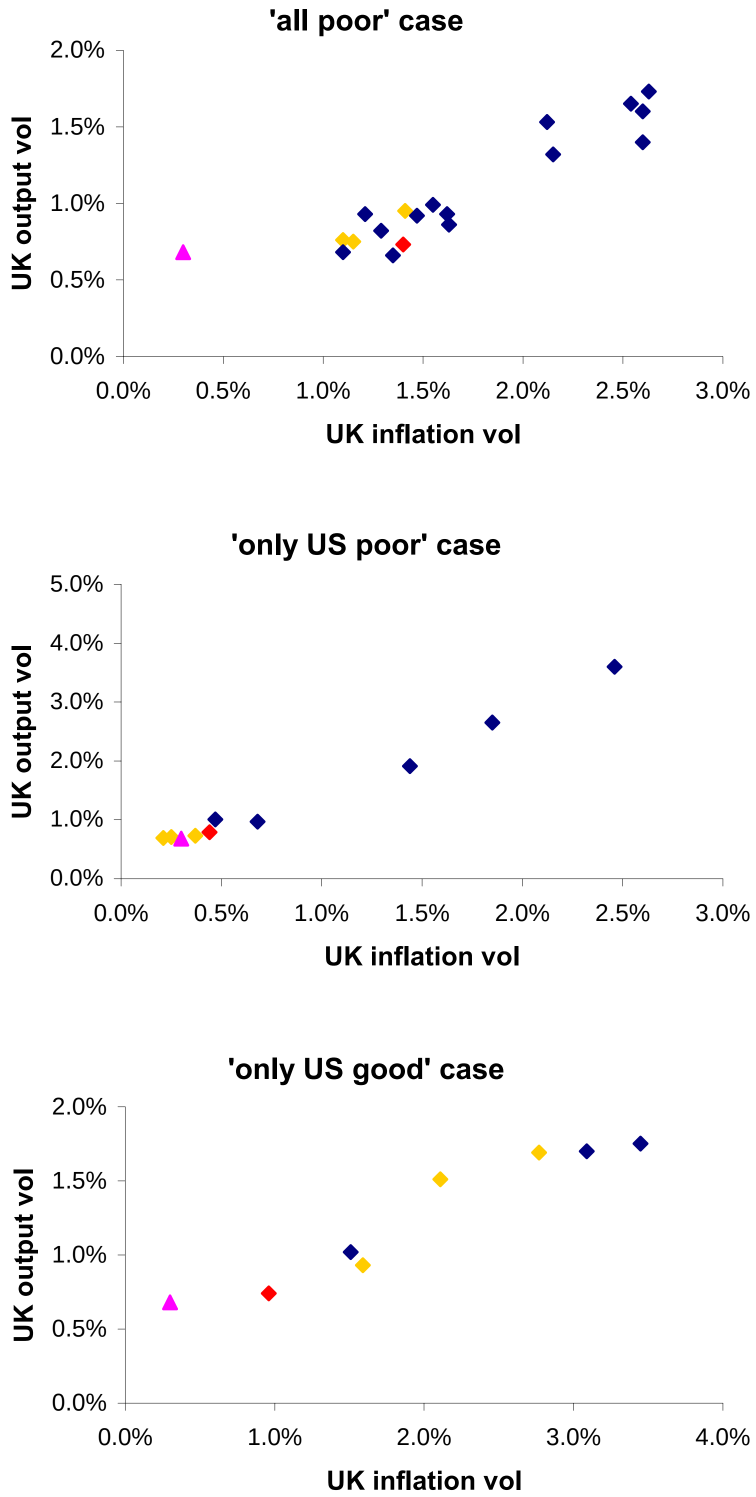
It shows the determinate solution (the pink triangle), the most-robust indeterminate solution (the red diamond), three alternative low-condition number solutions[26] (yellow diamonds), and other candidate solutions (blue diamonds).[27]

The results indicate that our most-robust (lowest-condition number) solution procedure generates a relatively good outcome for inflation and output volatility compared to other indeterminate solutions. Indeed, our selection criterion generates a solution which is usually part of the cluster of admissible solutions based on the eigenvectors that are close to the determinate solution.

Our results also indicate that a determinate ‘all good’ solution is almost always superior to any indeterminate solution. Of course, it should be possible to improve on the ‘all good’ Taylor rule-based solution as none of these are truly optimal policies. Given that the indeterminate solutions imply dynamics that are similar to the determinate Taylor rule once the jump is determined it is perhaps unsurprising that there are a number of fairly good candidate solutions that we could adopt. We take the graphs as a solid indication that our procedure produces credible solutions consistent with rational agent behaviour.

[26] These three solutions are those with lowest-condition number after excluding the most-robust solution.
[27] Other solutions (with higher-condition numbers) are, of course, not captured in the charts as they produce much higher volatilities of both inflation and output.

Chart 1: The most-robust solution relative to other candidate solutions



▲ - the determinate solution
♦ - the most-robust solution (lowest-condition number)
♦ - low-condition number solutions
♦ - other candidate solutions

6 Conclusions

On the methodological side, our paper contributes to the existing literature by: (a) proposing a simple new method to treat indeterminate solutions, and (b) analysing policy co-ordination issues within a three-country framework.

Theoretical implications

We propose adopting the 'most robust' indeterminate solution. Sensitivity analysis shows that this is always among the least volatile solutions. We also analyse a number of candidate indeterminate solutions. By using 'reasonable' criteria we can reduce the number of these solutions from potentially tens of thousands to a few dozens for our model, which makes the analysis of all candidate eigenvector-based indeterminate solutions feasible.

Policy implications

We confirm the results found in some previous studies that one country cannot by itself guarantee the existence of determinate world equilibrium, and that the dimension of indeterminacy is larger when more countries conduct 'poor' monetary policy.

Our main finding is that the stability of the UK economy depends crucially on UK monetary policy, although there remains significant potential for monetary policy abroad (which in the existing literature was captured as *good luck*) to improve the stability of UK inflation and output. This is because good monetary policy abroad stabilises both the demand for UK exports and prices of UK imports. The stabilising impact of policy abroad is especially strong when shocks originate abroad, indicating that 'poor' monetary policy abroad amplifies the impact of foreign shocks.

The other important finding is that the impact of policy improvements abroad on UK inflation and output depends on the quality of the UK domestic policy itself. In other words, 'good luck' or the absence of adverse shocks depends on how well domestic monetary policy is conducted. If domestic monetary policy is 'good', then an improvement in global monetary policy is stabilising for UK inflation and output. But if domestic monetary policy is 'poor', then an improvement in global policy can make matters worse, especially when the United Kingdom is the only 'poor' player globally. This interesting phenomenon arises from the destabilising expenditure-switching effect, whereby an improvement in policy abroad raises the volatility of the relative price of exports, thus causing extra volatility in the demand for domestic exports and in domestic output. This turns out to dominate the more straightforward stabilisation effect coming from reduced global income volatility. Naturally, this result depends on the particular parametrisation we adopt and will not hold in all possible cases.

We also find that an improvement in policy abroad reduces the exposure of the UK economy to shocks *originating* abroad, and increases her exposure to foreign supply *relative* to foreign demand shocks. This is because the destabilising effect becomes stronger when policy abroad improves and because this effect is particularly important for supply shocks. Furthermore, we find that inflation persistence may rise or fall when policy 'improves' both at home and abroad. Hence, the universal increase in inflation persistence due to 'poor' policy, noted by Lubik and Schorfheide (2004), does not hold in the three-country model.

Appendix I: Description of impulse responses to US supply and demand shocks[28]

A supply shock in the United States[29]

The supply shock in the United States that we consider is a positive productivity shock in the traded goods sector. There are obvious US domestic effects from this shock. Internationally, the reduced marginal costs for US firms benefit them by causing a fall in US traded prices. As they become more competitive internationally, US firms respond to increased demand for traded goods by an increase in output. This contributes to increases in GDP. This feeds back into the domestic economy, as both the reduced prices of tradables and higher domestic income from increased trade boost consumption spending. With effective monetary policy in place consumption spending is further increased as nominal interest rates fall in line with the fall in domestic inflation.

The external effects of the shocks will come through both trade and asset markets. Higher US consumption increases demand for goods in all countries, including the United Kingdom. In general this will raise the amount of trade, with world demand switching towards the now cheaper US goods. US households will save part of any increased income in order to help smooth the consumption profile, and consequently invest abroad. The US current account improves and the real interest rate in both the United Kingdom and the rest of the world falls. Lower real interest rates increase consumption by United Kingdom residents. How this affects output outside the US will crucially depend on how much supply responds to increased demand relative to the switch to cheaper US-made goods. We find that the impact on the UK is such that the switch to the US-made goods dominates and UK output falls.

Overall, CPI inflation in the UK then falls: imported goods prices fall, and the prices of UK-produced traded goods fall as marginal costs fall due to cheaper imports. Monetary policy responds by cutting nominal interest rates. As the shock is a US one, the impact on UK prices is much less than it would have been had the shock been domestically generated, and the ensuing price changes can be damped by appropriate monetary policy.

A demand shock in the United States[30]

We have micro-founded demand shocks in the model, which are preference shocks. We consider an increased preference for consumption expenditure by the US. This inevitably increases demand, which is satisfied by increased current and future US output. In turn this leads to higher future marginal costs, which causes US inflation to increase. Monetary policy responds predictably by raising the nominal interest rate to reduce domestic demand and

[28] The description of the shock transmission summarises that in Markovic and Povoledo (2007) who analyse in detail a variety of shocks (including these ones) for a model with a different calibration but nonetheless similar features.
[29] See the light blue line in Chart A.1.
[30] See light blue line in Chart A.3.

appreciate the dollar. While this latter consequence has relatively little effect at home it has wider international repercussions.

In order to increase their consumption, US households borrow funds from abroad, including the United Kingdom. This higher external demand for funds raises UK real interest rates, and UK consumption falls. Since the shock hits United States directly, the price of US traded goods relative to UK traded goods increases (US terms of trade improve), and world demand switches away from the US traded goods.

As with the supply shock any impact on UK output depends on the relative strength of the direct consumption and relative price effects. UK consumption falls and so the demand for domestically produced goods falls too, but the higher price of US-produced goods leads to an increase in the demand for UK goods. The impact effect for our model is a net rise in UK output on impact. CPI inflation rises on the back of rising output and higher wages through higher current and expected future marginal costs.

Appendix II: Charts with impulse responses to supply and demand shocks

Chart A.1: Supply shock in the United States – UK policy always 'good'

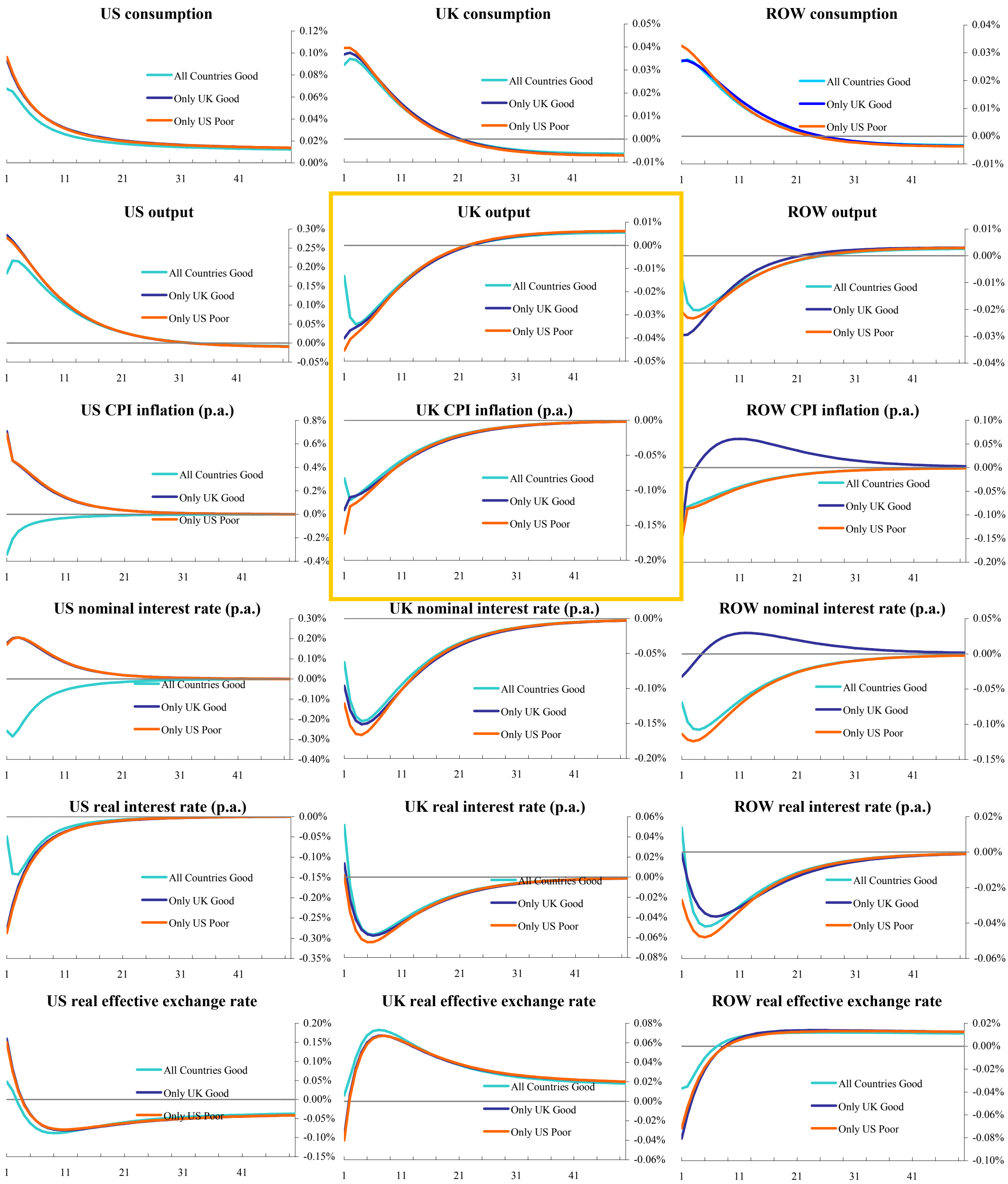


Chart A.2: Supply shock in the United States – UK policy always 'poor'

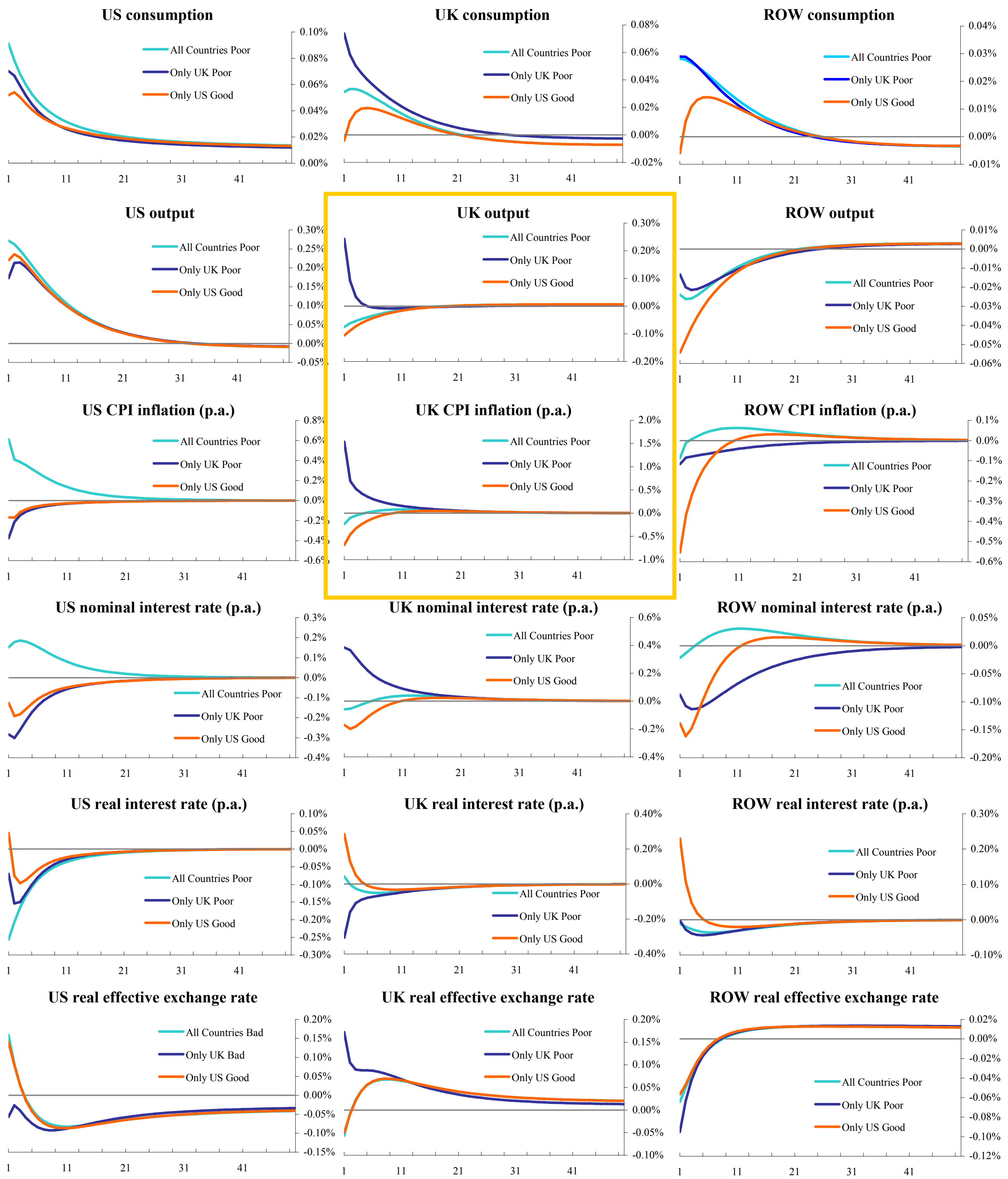


Chart A.3: Demand shock in the United States – UK policy always ‘good’

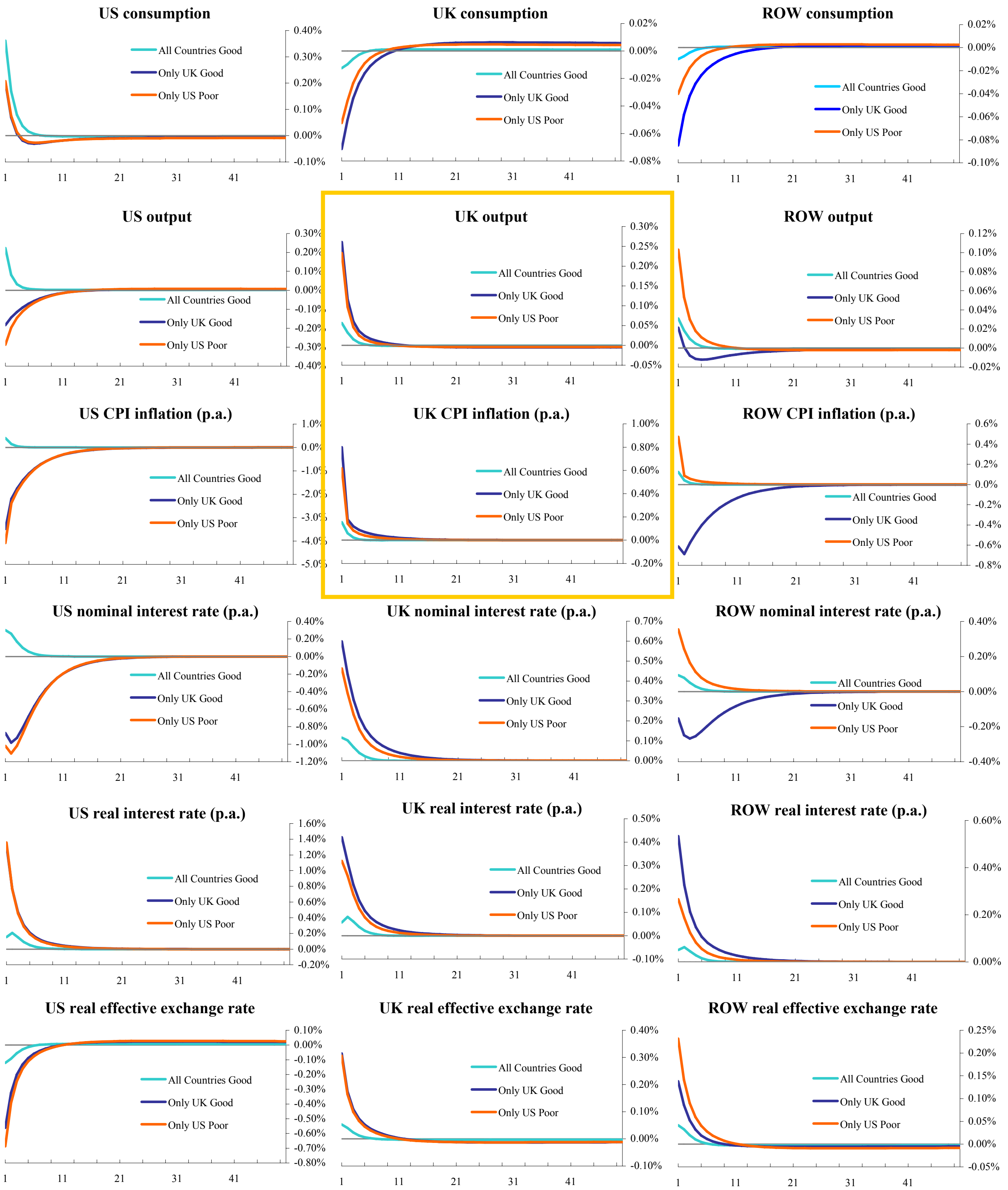


Chart A.4: Demand shock in the United States – UK policy always 'poor'

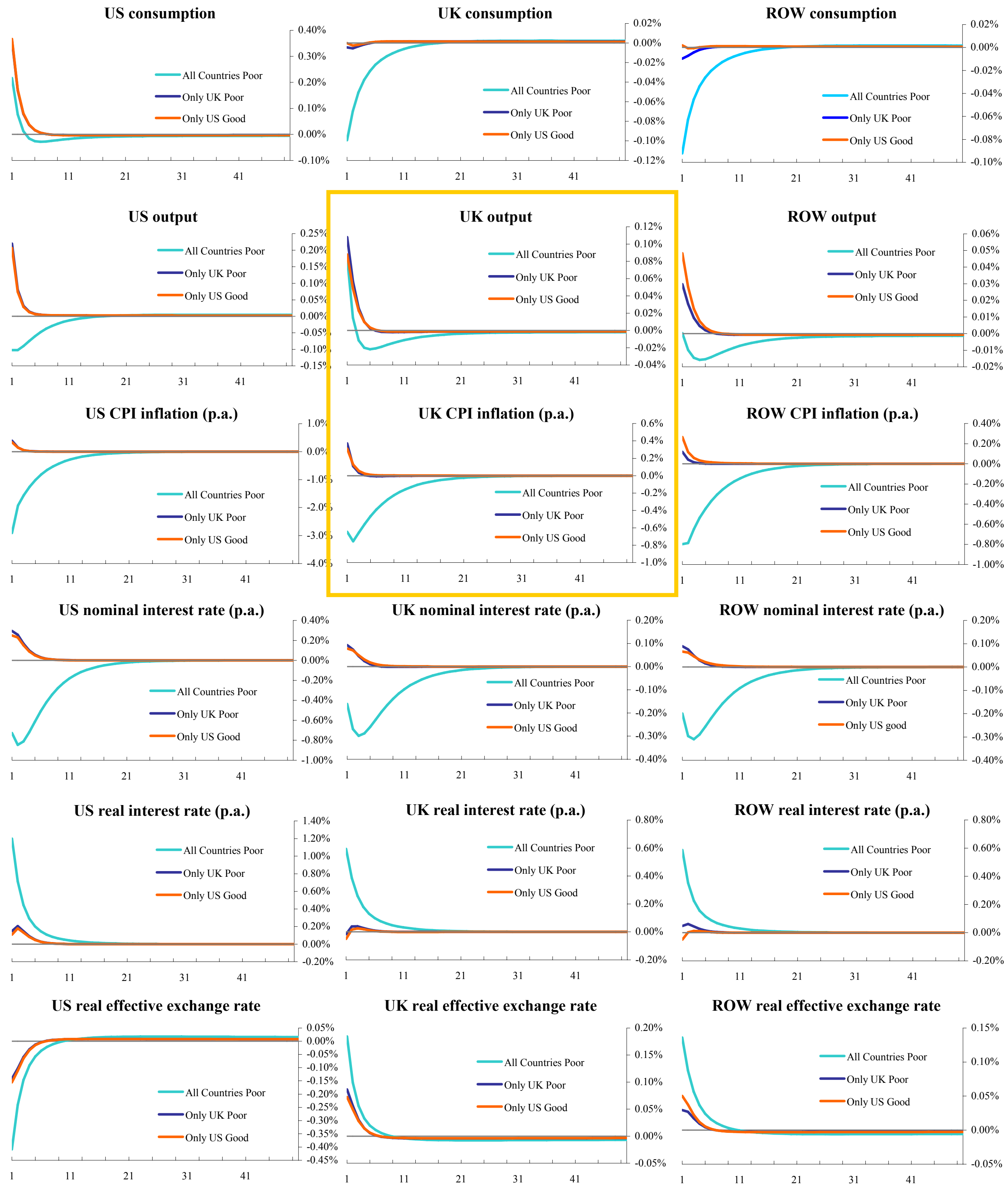


Chart A.5: Supply shock in the United Kingdom – UK policy always 'good'

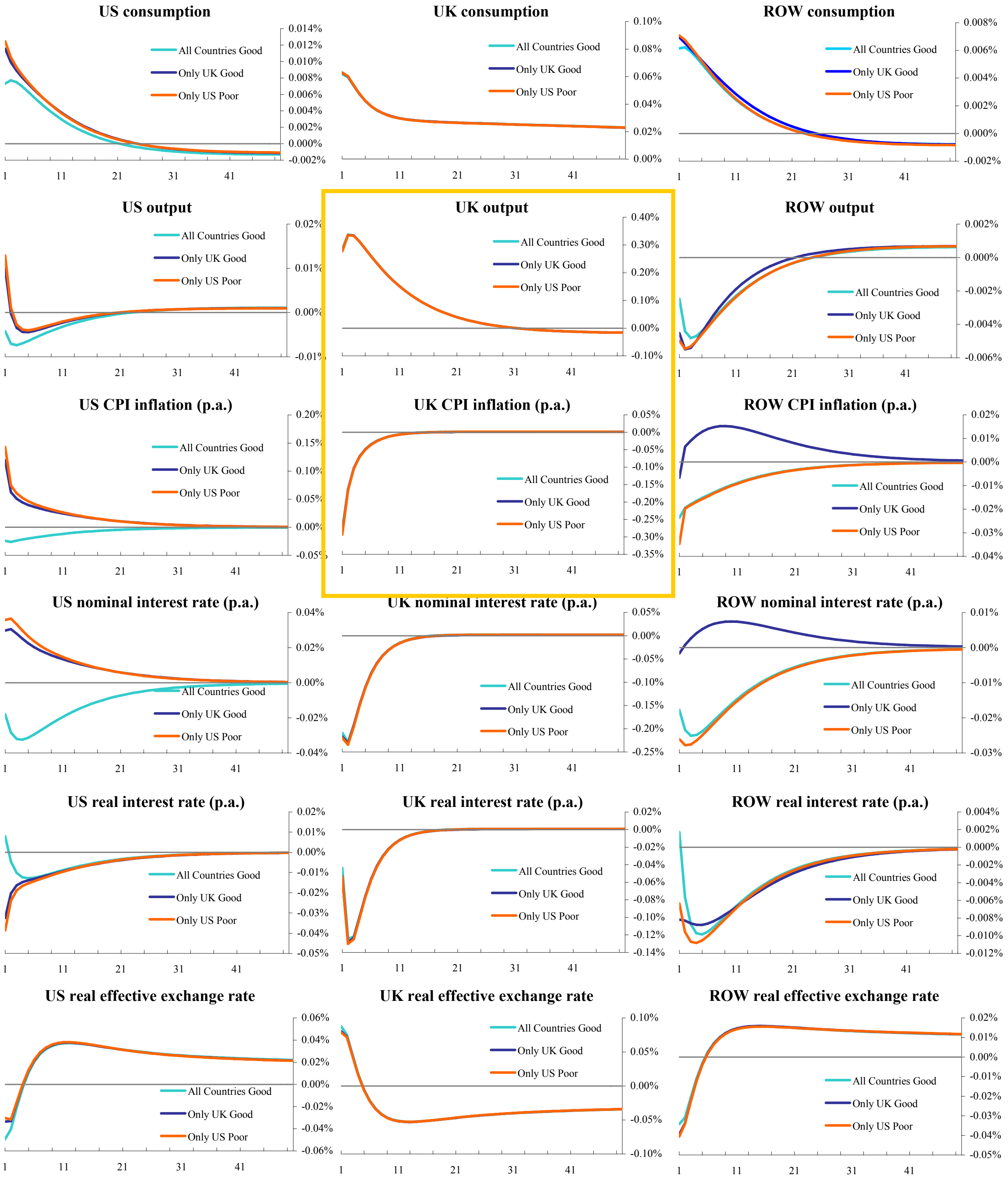


Chart A.6: Supply shock in the United Kingdom – UK policy always 'poor'

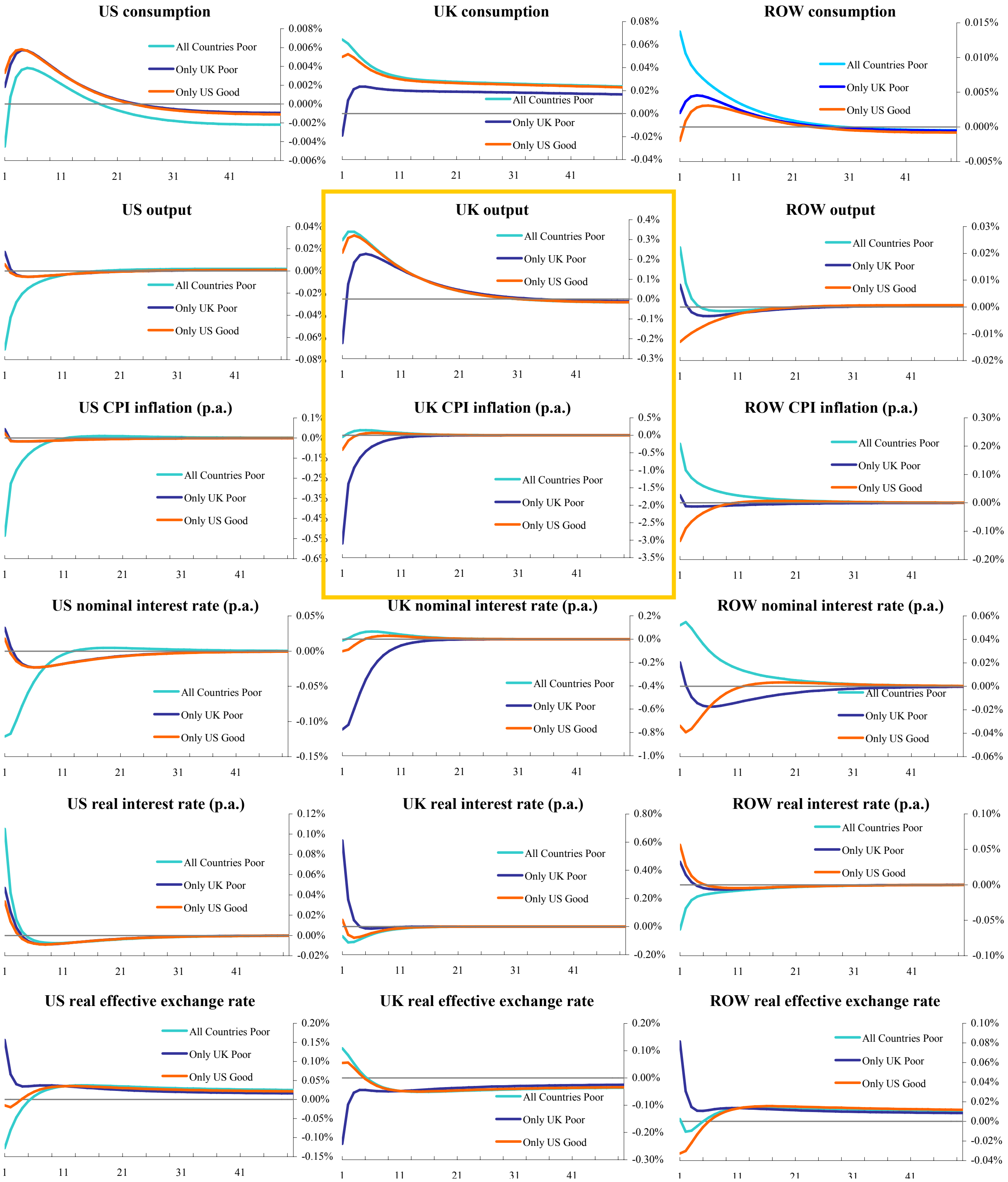


Chart A.7: Demand shock in the United Kingdom – UK policy always 'good'

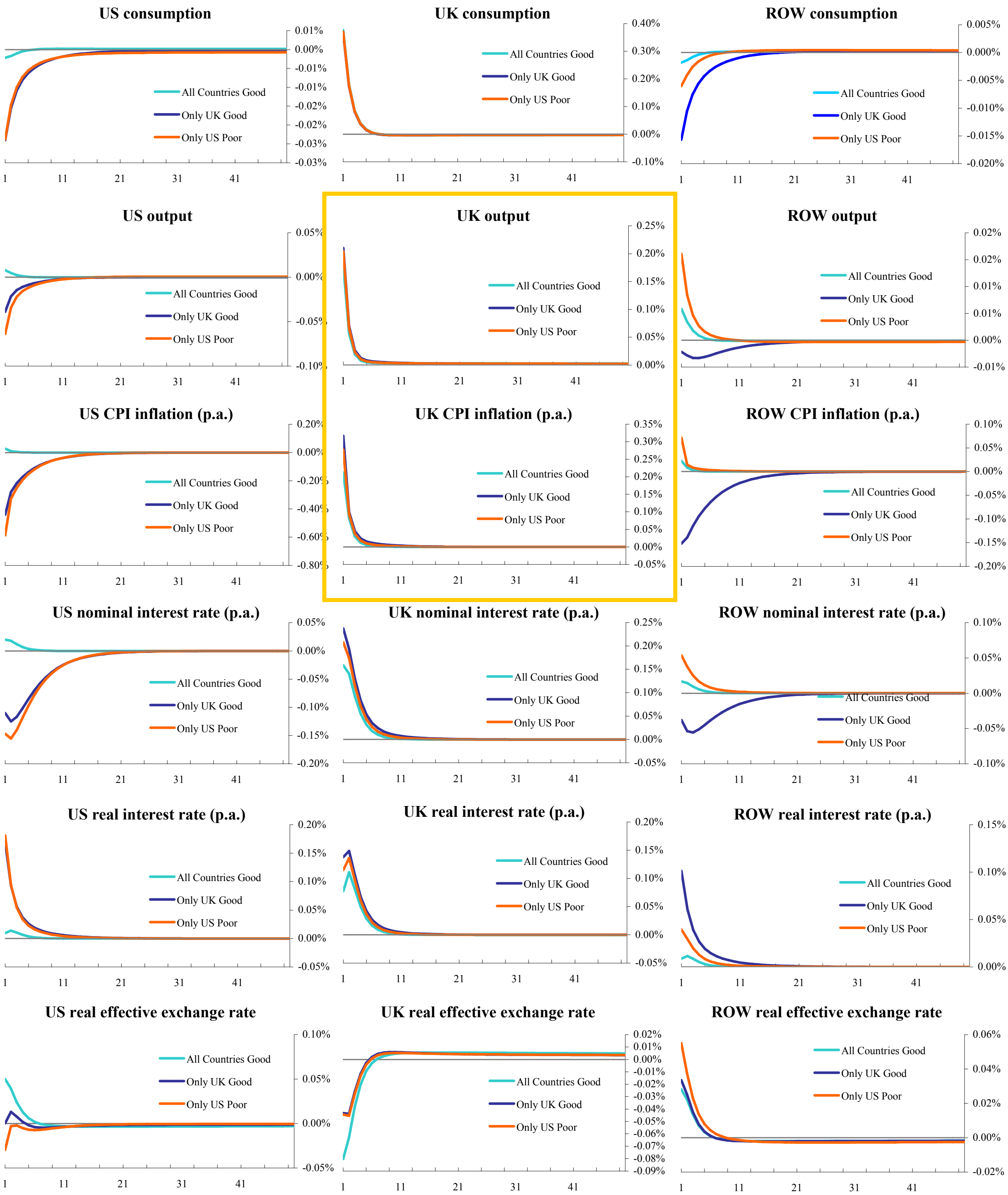
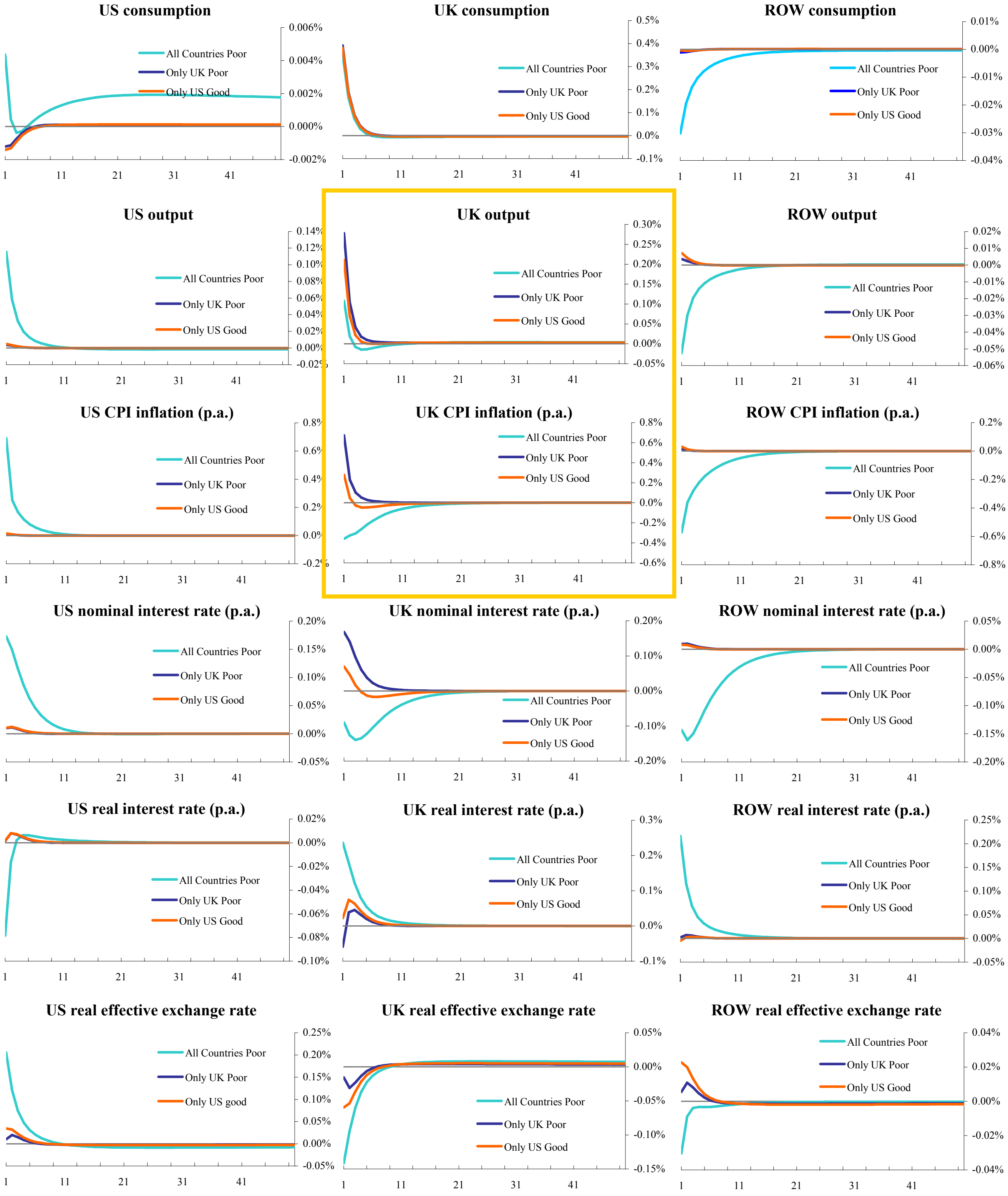


Chart A.8: Demand shock in the United Kingdom – UK policy always 'poor'



Appendix III: Stochastic simulations and variance decomposition results

Chart A.9: Volatilities when UK policy is always 'good'

Case: Only UK Good

	σ	Coefficient of Correlation 1	2	3	4	5	Variance Decomposition e_stuk	e_snuk	e_duk	e_stus	e_snus	e_dus	e_strw	e_snrw	e_drw	ΣUS	ΣUS-ROW
UK CPI inf	0.0065	0.1386	0.0496	-0.005	-0.041	-0.064	1.39	1.68	1.41	0.42	2.58	8.57	5.63	11	67.32	11.57	95.52
UK output	0.008	0.6044	0.3447	0.1607	0.0269	-0.07	19.93	40.56	7.77	0.45	2.72	7.21	0.04	1.03	20.3	10.38	31.75
UK cons	0.0055	0.5254	0.2456	0.0746	-0.033	-0.1	2.03	10.02	46.55	1	1.94	2.21	10.54	8.44	17.28	5.15	41.41
US CPI inf	0.0127	0.5809	0.3303	0.1417	0.0035	-0.094	0.05	0.07	0.89	2.41	3.65	55.99	1.44	1.32	34.18	62.05	98.99
US output	0.0071	0.6931	0.4404	0.2362	0.0755	-0.047	0.02	0	0.23	16.31	76.79	3.38	0.67	1.11	1.5	96.48	99.76
US cons	0.0054	0.6006	0.3346	0.15	0.0195	-0.073	0.07	0.08	0.23	4.28	33.25	16.05	8.43	7.81	29.79	53.58	99.61
UK/US rer	0.0127	0.7005	0.4656	0.2728	0.1147	-0.012	0.99	22.01	0.14	1.97	50.45	19.16	0.83	0.24	4.21	71.58	76.86

Case: Only US Poor

	σ	Coefficient of Correlation 1	2	3	4	5	Variance Decomposition e_stuk	e_snuk	e_duk	e_stus	e_snus	e_dus	e_strw	e_snrw	e_drw	ΣUS	ΣUS-ROW
UK CPI inf	0.0044	0.2769	0.1131	0.0217	-0.036	-0.073	3.08	3.62	2.38	1.21	6.16	11.17	11.96	24.49	35.94	18.54	90.93
UK output	0.0079	0.608	0.3503	0.166	0.0307	-0.067	20.64	41.99	8.01	0.52	3.09	7.11	0.06	1.78	16.81	10.72	29.37
UK cons	0.0051	0.5212	0.2402	0.07	-0.036	-0.101	2.38	11.63	55.3	1.3	2.27	1.39	11.64	9.8	4.3	4.96	30.7
US CPI inf	0.0203	0.4602	0.238	0.0816	-0.027	-0.1	0.03	0.05	0.57	0.92	1.81	28.54	1.15	2.97	63.97	31.27	99.36
US output	0.0091	0.5787	0.3226	0.1466	0.0195	-0.072	0.02	0.01	0.31	9.69	48.31	4.38	0.97	1.04	35.27	62.38	99.66
US cons	0.0055	0.5827	0.3156	0.1351	0.0098	-0.077	0.08	0.09	0.21	4.34	32.57	15.82	10.78	11.39	24.72	52.73	99.62
UK/US rer	0.0148	0.6155	0.3739	0.1989	0.0646	-0.038	0.7	16.01	0.05	1.4	38.07	17.89	0.29	0.63	24.96	57.36	83.24

Case: All Good

	σ	Coefficient of Correlation 1	2	3	4	5	Variance Decomposition e_stuk	e_snuk	e_duk	e_stus	e_snus	e_dus	e_strw	e_snrw	e_drw	ΣUS	ΣUS-ROW
UK CPI inf	0.003	0.4681	0.2394	0.0945	-0.004	-0.073	6.03	7.65	3.05	1.59	8.95	1.64	21.27	38.53	11.3	12.18	83.28
UK output	0.0068	0.7104	0.4513	0.239	0.0728	-0.052	27.92	56.87	8.68	0.42	2.36	0.69	0.17	1.04	1.86	3.47	6.54
UK cons	0.005	0.5158	0.236	0.0678	-0.036	-0.1	2.47	12.25	61.05	1.07	2.03	0.1	11.6	8.77	0.65	3.2	24.22
US CPI inf	0.0032	0.5193	0.2719	0.1155	0.0076	-0.069	0.07	0.17	0.04	7.76	28.86	9.36	16.25	28.9	8.59	45.98	99.72
US output	0.0066	0.6885	0.43	0.2241	0.0648	-0.055	0.02	0.03	0.01	11.25	72.5	13.65	0.11	0.98	1.45	97.4	99.94
US cons	0.0052	0.5543	0.2825	0.1077	-0.008	-0.086	0.05	0.04	0	2.82	30.68	50.15	8.89	6.86	0.52	83.65	99.92
UK/US rer	0.0107	0.815	0.5902	0.3732	0.1816	0.0218	1.64	31.81	0.81	1.29	62.4	1.36	0.41	0.27	0.02	65.05	65.75

σ: per cent standard deviations; e_st: supply shock in the traded sector; e_sn: supply shock in the non-traded sector; e_d: demand shock; ΣUS: sum of shocks originating in the United States; ΣUS/ROW: sum of shocks originating abroad (in the US and ROW); uk: United Kingdom; us: United States; rw: Rest of the world; rer: real exchange rate.

Chart A.10: Volatilities when UK policy is always ‘poor’

Case: All Poor

	σ	Coefficient of Correlation					Variance Decomposition										
		1	2	3	4	5	e_stuk	e_snuk	e_duk	e_stus	e_snus	e_dus	e_strw	e_snrw	e_drw	ΣUS	ΣUS-ROW
UK CPI inf	0.014	0.61	0.3402	0.1431	0.0008	-0.099	0.16	2.2	0.77	0.26	0.34	3.27	1.82	7.41	83.76	3.87	96.86
UK output	0.0073	0.6597	0.4059	0.2102	0.0597	-0.054	26.34	33.88	3.51	1.32	3.49	1.18	2	3.37	24.91	5.99	36.27
UK cons	0.0064	0.5229	0.2444	0.0741	-0.033	-0.101	1.59	6.04	32.41	0.6	1.43	3.06	9.55	10.08	35.25	5.09	59.97
US CPI inf	0.0134	0.604	0.3428	0.1476	0.0051	-0.095	0.86	1.42	1.59	1.69	1.85	36.49	0.47	2.52	53.12	40.03	96.14
US output	0.007	0.6931	0.4408	0.237	0.0765	-0.046	0.64	1.11	1.51	16.07	73.75	1.62	0.12	0.17	5.01	91.44	96.74
US cons	0.0057	0.5872	0.3197	0.1379	0.0113	-0.077	0.02	0.02	0.01	3.65	28.7	16.11	8.96	9.13	33.39	48.46	99.94
UK/US rer	0.0121	0.7207	0.4861	0.2887	0.1254	-0.006	2.47	23.15	3.57	2.53	53.25	9.85	0.97	1.25	2.95	65.63	70.8

Case: Only US Good

	σ	Coefficient of Correlation					Variance Decomposition										
		1	2	3	4	5	e_stuk	e_snuk	e_duk	e_stus	e_snus	e_dus	e_strw	e_snrw	e_drw	ΣUS	ΣUS-ROW
UK CPI inf	0.0096	0.5136	0.2431	0.0656	-0.051	-0.125	1.38	10.91	0.58	4.19	28.37	0.65	33.63	18.41	1.88	33.21	87.13
UK output	0.0074	0.6552	0.3918	0.1927	0.0439	-0.065	20.89	26.34	9.6	2.65	19.82	1.39	9	7.27	3.04	23.86	43.17
UK cons	0.0044	0.4576	0.1738	0.0213	-0.062	-0.108	2.29	10.73	79.33	0.45	1.33	0.01	4.11	1.6	0.16	1.79	7.66
US CPI inf	0.0023	0.4878	0.274	0.1322	0.0294	-0.047	0.17	0.05	0.03	5.67	44.83	13.35	22.16	8.04	5.69	63.85	99.74
US output	0.0071	0.6625	0.4037	0.2043	0.0526	-0.06	0.01	0.01	0.01	11.26	74.81	11.08	1.55	0.69	0.59	97.15	99.98
US cons	0.0048	0.5326	0.2626	0.0961	-0.012	-0.082	0.03	0.01	0	2.24	28.05	62.19	4.93	2.25	0.3	92.48	99.96
UK/US rer	0.0122	0.7421	0.506	0.3012	0.1301	-0.008	0.62	17.5	0.38	2.29	71.63	1.67	3.74	2.03	0.13	75.59	81.49

Case: Only UK Poor

	σ	Coefficient of Correlation					Variance Decomposition										
		1	2	3	4	5	e_stuk	e_snuk	e_duk	e_stus	e_snus	e_dus	e_strw	e_snrw	e_drw	ΣUS	ΣUS-ROW
UK CPI inf	0.0205	0.3231	0.1339	0.0183	-0.054	-0.097	14.4	58.96	0.65	3.39	0.56	0.2	19.28	1.09	1.47	4.15	25.99
UK output	0.0149	0.464	0.1934	0.0421	-0.049	-0.104	4.58	73.91	3.56	1.68	1.3	0.44	11.78	0.79	1.96	3.42	17.95
UK cons	0.006	0.5085	0.2352	0.0724	-0.029	-0.094	0.4	28.4	44.53	2.09	0.99	0.02	18.38	5.09	0.1	3.1	26.67
US CPI inf	0.0033	0.5029	0.2635	0.1118	0.0069	-0.068	0.18	1.82	0.01	8.63	27.31	8.71	19.03	26.82	7.5	44.65	98
US output	0.0066	0.6883	0.4298	0.2239	0.0646	-0.055	0.07	0.52	0	10.74	72.95	13.41	0.14	0.91	1.26	97.1	99.41
US cons	0.0052	0.5544	0.2825	0.1078	-0.008	-0.086	0.02	0.18	0	2.96	30.29	49.87	9.49	6.72	0.47	83.12	99.8
UK/US rer	0.0155	0.6166	0.3739	0.1992	0.066	-0.036	2.07	55.03	0.06	0.95	32.21	1.04	8.28	0.08	0.28	34.2	42.84

σ: per cent standard deviations; e_st: supply shock in the traded sector; e_sn: supply shock in the non-traded sector; e_d: demand shock; ΣUS: sum of shocks originating in the United States; ΣUS/ROW: sum of shocks originating abroad (in the US and ROW); uk: United Kingdom; us: United States; rw: Rest of the world; rer: real exchange rate.

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