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CHANGES IN EQUITY RISK PERCEPTIONS: GLOBAL CONSEQUENCES  
AND POLICY RESPONSES

Warwick J. McKibbin  
and David Vines

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Warwick J. McKibbin is a professor in the economics department of the Research School of Pacific and Asian Studies at the Australian National University (ANU), a non-resident Senior Fellow in the Economic Studies Program at the Brookings Institution, and a Professorial Fellow at the Lowy Institute for International Policy in Sydney. David Vines is a professor at the Bailliol College and Department of Economics at Oxford University, the Research School of Pacific and Asian Studies at the Australian National University (ANU) and a researcher at the Centre for Economic Policy Research. The views expressed are those of the authors and should not be interpreted as reflecting the views of other individuals or institutions named above.

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# Changes in Equity Risk Perceptions: Global Consequences and Policy Responses

## ABSTRACT

The current weakness in the global economy has generated a debate on the likely outlook for the world economy and the appropriate response for monetary policies. The world economy is currently being buffeted by a number of major shocks. A particular feature has been the large fall in equity markets in many countries. In this paper we use the MSG3 global economic model to assess the impact on the global economy of a sharp rise in the equity risk premium in a number of countries. In particular we examine whether a rise in equity risk premia (or fall in productivity which has many similar implications) is a shock to aggregate supply or aggregate demand. We explore the difference in the transmission mechanism if the shocks occur just in one country (i.e. the United States) versus across the OECD generally. We then assess the appropriate responses of monetary policy to shocks of this type and explore whether there are gains to coordinating the monetary policy responses of the G7.

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Warwick J. McKibbin  
Research School of Pacific & Asian Studies  
Australian National University  
ACT 0200, Australia

and Economics Studies Program  
The Brookings Institution  
1775 Massachusetts Ave NW  
Washington D.C. 20036 USA

David Vines  
Balliol College and  
Department of Economics  
Oxford University  
Manor Rd Oxford, OX1 3UQ, UK

and Research School of Pacific and  
Asian Studies  
Australian National University  
ACT 0200, Australia

and Centre for Economic Policy  
Research

## 1. Introduction

The continuing weakness in the global economy has led to a serious debate about causes and remedies. On the one hand have been those who seek to treat it as a downturn similar to other recent recessions, in 1975, 1980 - 82, and 1991- 92. These episodes can be thought of as temporary demand shocks. Satisfactory management of these would require a speedy cut in real interest rates to stimulate demand and lead the economy back close to the NAIRU. On the other hand there have been those who treat the current slowdown as a longer term disruption of supply, caused by an over-accumulation of particular kinds of capital, a reduction in the rate of productivity growth, an increase in the risk premium applied to equity market investment or a bursting of an equity market bubble. These kinds of shocks are much harder to manage. The experience of the earlier downturns may provide less guidance to policy makers than many commentators currently argue.

In 2002, the consensus view appeared to be one where the slowdown would be a relatively short-lived “V” shaped one, with a quite rapid recovery towards full employment, a return of inflation to its general target range, and a rise of global interest rates towards long term levels. But this position depends at least in part on a view that the slowdown has been caused mainly by a short-term demand reduction, which can be partly smoothed by monetary policy, and possibly also by fiscal policy. The alternative view is that the downturn is instead a consequence of a reduction in the growth of supply potential, either through a revision of productivity growth, or through the adjustment to excess investment in information technology or through great uncertainty in the world in the wake of the September 11 terrorist attacks, as well as a decline in demand through low investment and declines in equity wealth. Such reductions in demand, which have an underlying supply-side cause, might be more difficult to smooth. In other words, the current downturn might be a shorter-term demand-side feature, which can be managed by policy adjustment, or a more structural downturn emerging from longer-term business cycle features, which is more difficult to deal with through monetary policy response.

This paper will address this difference of view. We believe that the latter view is the correct interpretation of the *causes* of the downturn, so that the downturn has underlying “supply-side” causes due to the ending of the long boom of the 1990s. In this paper we summarize the supply side shock through focussing on an increase in the risk premium on equities (but the results are very similar to a decline in economy wide TFP growth in that the attractiveness of capital accumulation is diminished). But we want to connect the supply shock to the arguments that the world is currently experiencing negative demand shocks. The link between the two approaches can be demonstrated

through a model which clearly identifies the demand effects of such a supply side shock, through its effects in causing a reduction the demand for capital, and thus in investment. We want to see the extent to which such an outcome, coming from the supply side, might nevertheless be possible to smooth with appropriate monetary policy on the demand side.

We will focus not only on policy-making in the US but also on the extent to which policy-making in Europe, and in the rest of the world, can complement that in the US, and thus on the implications of the downturn for policy-making in Europe, Canada and Japan. We will also describe the implications of this shock for the developing world, and in particular for regions where the shock does not occur but which are affected by the transmission of its consequences.

The paper uses the MSG3<sup>1</sup> multi-country model. The key feature of this model is that it combines the modern intertemporal optimization approach to modelling economic behaviour (as found in Blanchard and Fischer, 1989, and Obstfeld and Rogoff, 1996) with short-run rule-of-thumb behaviour. In doing this it brings together real business cycle models on the one hand<sup>2</sup>, which have a fully articulated analysis of forward-looking producers and consumers, and modern macroeconomic models on the other hand, which describe the effects of demand downturns in the face of wage (and price) stickiness. The key feature of the model is the way it models asset markets and the integration of these markets with real economic activity, in particular the meshing together of equity markets and bond markets, joined by highly mobile international flows of financial capital, and short-run fixity of physical capital. Other key features of the models are set out in section 3.

Our general findings are striking and have significant implications for present day debates on macroeconomic policy.

We find that in response to an increase in global risk (or decline in TFP growth), real wages must fall a great deal over time, compared with what they would have been, because of the reduction in the capital stock per worker, which occurs because of the increased riskiness of capital. The real interest rate must fall to cause demand to rise to make up for the very large reduction in investment which this increased riskiness provokes. In the short run, given that aggregate supply falls slowly

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<sup>1</sup> The MSG3 model is a 2 sector version of the G-Cubed model developed in McKibbin and Wilcoxon (1998). It is a descendant of the approaches of the MSG2 model in McKibbin and Sachs (1991) and the Jorgensen Wilcoxon (1991) Model.

<sup>2</sup> See Backus et al (1992).

but investment falls sharply, consumption must rise to make up for the reduction in investment; the consequence is surprisingly strong consumption, of the kind that has worried many commentators as revealing an “imbalance” – we see it as a natural consequence of the kind of shock that we are studying. Unemployment emerges, even when monetary policy is expansive enough to induce a rise in consumption enough to use up some of the spare resources. Furthermore a significant rise in the price of housing – as a consequence of the fall in interest rates and a substitution out of equities into other asset classes – is a key part of the way in which consumers’ wealth is raised so as to induce the necessary increase in consumption. A corollary of this is that there is also a boom in the production of housing. Again these effects on the housing market have been seen by many commentators as an “imbalance” – we see them as a consequence, too, of the shock which we are studying. We find that expansionary monetary policy by the monetary policy-maker in each country can partly reduce the output loss and resulting unemployment, but only by relatively little. The change in these variables affected by policy action, is small relative to the underlying adjustment in response to the shock, but they are nonetheless significant in the very short term. Similarly we find that international cooperation over monetary policy between policy-makers can further assist with reducing the output loss and the resulting unemployment.

## 2 Model Structure

The MSG3 model is a dynamic intertemporal general equilibrium models that attempt to integrate the best features of traditional CGE models, real business cycle models and Keynesian macro-econometric models. A 2 sector stylized version summarizing the key features are outlined in Appendix A.

A summary of the key features of the model is contained in Table 1 and the country and sector coverage (as well as assumption about exchange rate regimes) is given in Table 2.

The five main features of the model are as follows:

(a) The model is based on explicit optimization by the agents (consumers and firms) in each economy. Where these models differ from static CGE models<sup>3</sup> is in the assumption of *intertemporal* optimization by economic agents, subject to explicit intertemporal budget constraints. Thus, in

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<sup>3</sup> See Hertel (1997)

contrast to static CGE models, time and dynamics are of fundamental importance in the MSG3 models. This makes their core theoretical structures like that of real business cycle models<sup>4</sup>.

(b) In order to track the macro time series, the behaviour of agents is modified to allow for short-run deviations from optimal behaviour, either due to myopia or to restrictions on the ability of households and firms to borrow at the risk-free bond rate on government debt. For both households and firms, deviations from intertemporal optimizing behaviour take the form of rules of thumb, which are consistent with an optimizing agent that does not update predictions based on new information about future events. These rules of thumb are chosen to generate the same steady state behaviour as optimizing agents so that in the long run there is only a single intertemporal optimizing equilibrium of the model. In the short run, actual behaviour is assumed to be a weighted average of the optimizing and the rule of thumb assumptions. Thus, aggregate consumption is a weighted average of consumption based on wealth (current asset valuation and expected future after tax labour income) and consumption based on current disposable income. This is consistent with the econometric results in Campbell and Mankiw (1987) and Hayashi (1982). Similarly, aggregate investment is a weighted average of investment based on Tobin's  $q$  (a market valuation of the expected future change in the marginal product of capital relative to the cost) and investment based on current firm profit-income.

(c) As in all policy-relevant macroeconomic models (but unlike in many CGE models), there is an explicit treatment of the holding of financial assets including money. Money is explicitly introduced into the model through a restriction that households require money to purchase goods. This assumption gives money an explicit role.

(d) The model allows for short-run nominal wage rigidity (by different degrees in different countries) and therefore allow for significant periods of unemployment depending on the labour market institutions in each country. This assumption, when taken together with the explicit role for money, is what gives the model its "macroeconomic" characteristics. (Here again the model's assumptions differ from the standard market clearing assumption in most CGE models.)

(e) The model distinguishes between the stickiness of physical capital within sectors and within countries and the flexibility of financial capital, which immediately flows to where expected returns

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<sup>4</sup> See for example Backus et al (1992)

are highest. This important distinction leads to a critical difference between the *quantity of physical capital* that is available at any time to produce goods and services, and the *valuation of that capital* as a result of decisions about the allocation of financial capital.

As a result of this structure, the models contain rich dynamic behaviour, driven on the one hand by asset accumulation and, on the other hand, by wage adjustment to a neoclassical steady state.

A key point to note is the way household durables, especially housing are incorporated into the model. This is set out in detail in Appendix A. Households are assumed to consume services from a stock of durables, which largely consists of housing (from this point we will refer to the entire stock of household durable as “housing” as a short-cut). Investment in housing is determined as part of the consumer’s optimization problem under the assumption that housing capital accumulation is subject to rising marginal costs of adjustment (similar to that for private capital in production). In other words it takes time for the housing stock to change in response to a change in the demand for capital services. Thus surprise increase in demand will lead to capital gains to existing owners of housing but gradual adjustment on the supply side. Households buy capital goods from the capital goods production sector and add them to the existing stock of capital over time. Households then consume a flow of services from the stock of housing over time.

In summary, the model embodies a wide range of assumptions about individual behaviour and empirical regularities in a general equilibrium framework. The complex interdependencies are then solved out numerically. It is important to stress that the term ‘general equilibrium’ is used here to signify that as many interactions are possible are captured, not that the economy is in a full market clearing equilibrium at each point in time. Although it is assumed that market forces eventually drive the world economy to a neoclassical steady state growth- equilibrium, unemployment does emerge for long periods due to wage stickiness, to an extent which differs between countries due to differences in labour market institutions.

The equations for a stylized two-country/two-sector version of the model are presented in Appendix A. The theoretical basis of the model can be found in McKibbin and Wilcoxon (1998) and online at [www.gcubed.com](http://www.gcubed.com).

### 3 The Shock(s) to be studied

It is important to describe exactly what shock we are implementing in the model. We define the equity risk premium as the term  $\mu$  in equation 1 (this is equation 11 in Appendix A). In this equation “i” is the sector number and ‘t’ is period t. Equation (1) shows that the change in  $\lambda$  (which is Tobin’s Q adjusted by the relative price of investment goods – see Appendix A) is related to the real interest rates adjusted by depreciation and the risk premium, the marginal product of capital and a term (quadratic in the rate of investment J/K) capturing the contribution to the marginal cost of capital of the adjustment cost of capital.

$$(1) \quad \frac{d\lambda_{it}}{dt} = (r_t + \delta_i + \mu_t) \lambda_{it} - (1 - \tau_2) \frac{dQ_{it}}{dK_{it}} - \frac{\phi_i}{2} P_{it}' (1 - \tau_4) \left( \frac{J_{it}}{K_{it}} \right)^2$$

Equation (1) can be interpreted as an arbitrage condition relating returns on equity to returns on other real and financial assets and the equity risk premium. Thus we assume that the equity risk premium is the excess return on capital relative to the real interest rate adjusted for depreciation and allowing for adjustment costs, required to induce people to hold equities relative to government bonds with a real interest rate “r”. A rise in the equity risk premium would mean that either the marginal product of capital must rise in the long run or real interest rates must fall or a combination of both

Equation (1) can also be integrated and written as the equal to the present value of the after-tax marginal product of capital in production (the first term in the integral) plus the savings in subsequent adjustment costs it generates.

$$(2) \quad \lambda_{it} = \int_t^{\infty} \left( (1 - \tau_2) p_i^* \frac{dQ_i}{dk_i} \Big|_{\hat{j}, \hat{k}} + (1 - \tau_4) p_i' \frac{\phi_i}{2} \left( \frac{\hat{J}_i}{\hat{k}_i} \right)^2 \right) e^{-(R(s) + \delta + \mu)(s-t)} ds$$

As mentioned above, this demonstrates that  $\lambda$  is similar to Tobin’s marginal Q concept (see Appendix A for the transformation by the relative price of investment goods, required to  $\lambda$  required to generate Tobin’s Q).



There are a number of ways to interpret a rise in the equity risk premium. The first is a rise in the current and expected risk premium back to longer-term values away from the low values reached in the 1990s at the peak of enthusiasm of the “new Economy”. This can be interpreted as the bursting of an equity price bubble. This is potentially a permanent shock if it was expected that the risk premium in the 1990s would continue because of fundamental changes in the world economy but now these expectations have been fundamentally revised. Another interpretation is that there has been a general rise in uncertainty because of September 11 and other global events, which will not necessarily be permanent. To cover these various interpretations we consider a persistent (but ultimately temporary) risk shock as well as a permanent shock. The persistent temporary shock reflects our most likely guess and is the focus of most of the simulation analysis.

We calibrate the size and duration of the shock in our exercise as follows. Evidence suggests that the level of the risk premium had been as high as 8 percent up until the 1980s, and that it steadily fell until the late 1990s converging towards zero. In the simulations considered in this paper, we take the increase in the risk premium as 5 percent (ie 500 basis points), which reverses 5/8 of the fall, which happened in the 1990s. In most of the simulations we take this as dying out over ten years. The risk premium is thus 500 basis points in the first year, 450 basis points higher in the second year, 400 basis points higher in the third year, and so on down to 0 basis points in the 11<sup>th</sup> year. For purposes of comparison we also compare the outcomes with what would happen if this rise in the risk premium were sustained forever. The shocks commence in the year 2001.

The reason for the choice of a shock lasting ten years is that it lasts long enough to have a significant effect on investment and the capital stock, with consequential effects on the supply capacity of the economy. If the shock lasted for only a year or two then this would not be the case. And yet the shock gradually dies out and so is not a permanent change: we are not analysing results which are the consequences of *permanent* changes in the stock of capital. But for comparison we study what would happen if there were a shock of this size which was permanent.

We apply this shock to all developed OECD countries to study the effects of a rise in the risk premium in all developed countries. We also study below what happens if this shock happens only in the US. The OECD wide shock is symmetric within the OECD but asymmetric relative to the developing countries, which are also in the model. Focussing on results for China give some insights on the adjustment of countries outside the OECD. The results for a US only shock are

asymmetric within the OECD, which gives additional information on the nature of the transmission of the shock globally.

#### **4 An Outline of Transmission of the Permanent and the Temporary, Symmetric and Asymmetric Shock**

The relevant features of the model have been explained above. We begin by discussing the effects of a permanent rise in the equity risk premium. This provides the background for a discussion at the end of this section of the temporary shock. In Section 5 we discuss the appropriate macroeconomic policy responses to a temporary rise in the equity risk premium in detail. For both the permanent and temporary cases discussed in this Section, monetary policy follows the simple rule of a fixed money supply in the US and all other countries, except in the EMU where there is a fixed money supply for EMU countries and a monetary union (ie a fixed exchange rate) between the member countries, and in China, OPEC and non-oil developing countries which are assumed to be pegging to the \$US.

##### **4.1 Permanent Shock**

We will see that the implications of the permanent shock of 500 basis points are very significant. These results demonstrate how important changes in discount rates and risk premia can be for economic activity. It is important to stress that the scale of the permanent shock is not meant to capture what has happened in the world economy but instead is designed to reveal the underlying forces at work in our study below of the temporary shock (which is scaled to represent what we believe is a reasonable stylization of what has been happening recently).

##### *Effects on the US*

We begin by discussing the effects of a permanent symmetric shock applied to all OECD countries. Results for a permanent rise in the equity risk premium and a temporary rise in the equity risk premium in all OECD countries are contained in Figure 1. This figure shows the impacts on the United States (a country experiencing the shock directly) and China (a country not directly experiencing the shock) as examples. China as with all developing countries, is assumed not to directly experience the shock.

In the face of a permanent risk shock in the industrial countries, firms gradually adjust the stock of physical capital to its lower desired level, which depends on (a) the expected productivity of capital and thus on the extent to which it is expected to yield returns to capital, and (b) on the risk premium which investors apply to these returns. The demand for capital depends on Tobin's  $q$ , which in turn depends on the ratio of the future changes in the marginal product of capital and real interest rates. In the steady state, Tobin's  $Q$  relates marginal product of capital to the sum of the real interest rate, the rate of depreciation of capital, and the risk premium. Our shock is to increase the risk premium in the way described above, and so leads to a lower  $q$  in the short run directly through a higher rate for discounting future profitability of firms. As a result investment falls.

The change in the equity risk premium will also have direct effects on consumption. There is a decline in the value of capital reflected in a decline in equity values. The expected change in the future capital stock will cause a reduction in the value of human capital (the stock of future earnings expected to be derived from the application of capital to labour, using a reduced amount of capital). To the extent that consumers are forward looking with respect to future labour income and together with the fall in the stock market value of wealth this will tend to depress consumption. However, there is a rise in the value of other assets such as housing (discussed in detail below). To the extent that households are liquidity constrained they will also tend to reduce consumption because income has fallen as a result of lower investment.

The immediate impacts of this shock will thus have two components.

- (a) There will be a reduction in aggregate demand during the period during which capital is adjusting to the new lower level.
- (b) There is a gradual reduction in supply, caused by the reduction in the stock of capital as a result of the lower level of investment.

The reduction in the capital stock is very gradual (although the valuation through equity price falls is sharp), and the resulting reduction in supply will therefore be very gradual, too.

How do these impacts impinge on the economy? First, we find that the reduction in demand runs ahead of the reduction in supply. This means that there is a long-lasting need, by real interest-rate falls, to promote demand – to limiting the reduction in investment, and to cause consumption to rise

(even although there are the above-described impact effects causing it to fall).<sup>5</sup> Second, prices and wages are sticky, because wages are set one period in advance. As a result, changes in demand described above, relative to changes in supply, move the economy away from the full utilisation of resources. In particular the demand for labour will fall, and there will be unemployment.

Figure 1 presents some of the outcomes for the US. (We do not show the outcomes for any other developed country because the results are very similar – we discuss this below). In the following discussion the six charts within each figure are referred to as 6a through 6f with 6a in the top left hand corner, 6b in the top right hand corner and 6f the bottom right hand corner of the figure.

Figure 1e shows the large and long lasting falls in the real interest rate that result from this permanent risk shock.<sup>6</sup> The speed at which capital is adjusted down to the new lower level depends crucially on costs of adjustment. Figure 1b shows that, even with such a large reduction in the real interest rate, a permanent increase in the risk premium of 5 percent would cause a very very large reduction in the capital stock in the US – namely 90 percent of GDP (which is equivalent to approximately 40 percent since the capital to output ratio is approximately 1.8) and that the reduction of the capital stock to its new lower level takes 20 years. This large fall in the capital stock is what we expect. Although we start out of steady state, with the capital stock gradually adjusting towards steady state, it was doing so along a path consistent with the expected marginal product of capital, the long run real interest rate (5%) and depreciation (10%); now it must adjust to a new steady state in which the risk premium has risen by 5% (500 basis points). That is an increase in the marginal product of capital of one third, and it causes a reduction in the stock of capital of

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5 We will discuss the determinants of, and the behaviour of, consumption below.

6 It is important to explain the effects on the interest rate. The risk shock will lower the demand for investment and lead to a reduced level of capital, and a lower long run level of investment for replacing the depreciation which occurs. In a simple Ramsey model something which lowered the stock of capital would lead to a lower human capital and lower consumption, just such that lower savings matched the lower investment, and just such that the fall in investment and consumption together just matched the fall in output, without any change in the interest rate. However things are different here. First, the reduction in the stock of capital is only gradual, so that in the short-to-medium run those consumers who are forward-looking see through to time when the capital stock, and output and wages, are already lower than they are now. This will tend to reduced consumption and increase savings relative to current level of output, lowering the short run. Second, even in the long run the interest rate is affected by the risk premium. At the initial interest rate, the risk premium will mean that the stock of capital is lower than it was before, with a lower capital to output ratio, and so a lower proportion of output being required to cover depreciation. If the interest rate stayed as before, the proportion of income saved would remain as before [footnote - for forward-looking consumers – that seems a correct claim about intertemporal choice], [in long run backward looking consumers do not save, but the proportion of such consumers is unchanged]. So savings would be higher than investment. Hence proportion of the wedge imposed by the risk premium must fall on the interest rate.

more than twice that amount because the production function is not Cobb Douglas and has an elasticity of substitution of less than unity. Over time the changes in capital change the supply potential of the economy.

Figure 1a shows what happens, as a result of the shock to employment. If wages and prices were perfectly flexible there would not be unemployment like this. Figure 1a shows that, in response to this shock, there would be a reduction of employment, which reaches a maximum of close to 10 percent, before real wage flexibility eliminates it. Eventually unemployment is removed by a fall in the real wage of close to 9% (relative to baseline). As we will see later, there is a role for monetary policy in intervening to smooth the unemployment consequences of these shocks.

Figure 1c shows the negative effect on GDP in the US. Although in the short run this is influenced by unemployment, eventually it is determined by the reduction in supply caused by the reduction in the capital stock. We see that, within 20 years, the reduction in output is very large at –23 percent (relative to base). It is useful to compare this with the fall in the capital stock, which as noted above falls close to 90 percent of GDP, which is equivalent to a percentage fall of approximately 50 percent. The ratio of the proportionate fall in output to the proportionate fall in capital is about 45 percent because capital is only one of the factors of production, which will in equilibrium become more labour intensive. The ratio is more than the capital share of about one third, which is what is what would be expected if the production function was Cobb Douglas

Overall we can see that such a shock, if it were permanent, would have a very large effect on the US economy as well as on other OECD economies (not shown here). There would be a long-lasting fall in output. This would be as a result of a very long lasting reduction in the investment demand for capital, and a permanent reduction in its supply.

#### *Effects in other OECD countries*

If such a permanent shock were confined to a single economy then this reduction in the real interest rate will have significant consequences for the exchange rate, and consequently implications for the trade balance. If the OECD economies are sufficiently symmetrical then there are no large movements of this kind (see Figures 1d and 1f). There are some inter-country differences within Europe which are discussed below.

### *Effects in Developing Countries*

Figure 1 also plots the outcomes for China, which is not directly experiencing the OECD-wide shock. In the face of the sustained fall in world interest rates, China experiences a significant increase in investment and rise in the capital stock and a significant increase in GDP (5% initially). This also causes a long-lasting boom to employment in China. The Chinese real exchange rate appreciates as capital flows into China and real interest rates fall significantly (note that the nominal exchange rate is pegged to the \$US). The Chinese economy runs a large current account deficit with advanced countries reflecting the large capital inflow. However there are quickly diminishing returns to the additional capital because the adjustment costs are proportional to the rate of investment. The transmission to China (and other developing countries) shows that increased growth in unaffected economies is one way in which the shocks to the world caused by risk shocks are moderated. The real exchange rate of China eventually depreciates significantly, to prevent the current account deficit, caused by higher growth, from causing external asset liabilities to explode without limit. The real depreciation and higher income enable the external liabilities to be serviced through rising exports relative to imports over time.

#### **4.2 Temporary Shock**

Figure 1 also shows results for a temporary risk shock, of the same size (500 basis points), but which gradually fades out over 10 years. The real interest rate falls in the first three years by nearly three quarters of its fall in the permanent case. Although the capital stock eventually returns to base, after more than 20 years, it falls in the first ten years by more than 15 percent of GDP. GDP is down by about 5 percent after ten years, before recovering.

Overall we can see that such a shock, if it were temporary rather than permanent, would still have considerable effects on the global economy. The outcomes shown would not actually cause a recession (change in growth rates can be calculated from the slopes of the GDP graph which is deviations from baseline). But they would cause a very long-lasting reduction in the growth rate of output of approaching half a percent per year, for up to 10 years. This is as a drawn out (over ten years) reduction in the investment demand for capital, and a permanent reduction in the supply capacity of the economy for nearly 10 years. Employment is close to 2.5 percent lower during the

transition.

### 4.3 US versus OECD-Wide Shock

Figure 2 contains the results for the United States and China comparing the results for the temporary shock in the OECD with the US only shock. The results for the temporary OECD-wide shock are the same as that for the temporary shock in figure 1, however removing the permanent shock from the graphs changes the scale significantly. The ‘S’ next to each country indicates a symmetric shock (OECD wide) whereas the A signifies an asymmetric shock (US only).

The underlying economic story of the results has already been outlined above. The main point of these results in Figure 2 is to show that the effect on the US is overwhelmingly the change in the US risk premium. The results differ more for the US current account, which under a US only shock improves by three times the amount compared to the OECD wide shock. Similarly the real exchange rate changes are three times the magnitude when the shock only occurs in the United States compared to the OECD-wide shock. It is not surprising that the asymmetric shocks show up in the bilateral variables between countries.

For China it is clear that the impact on GDP and the capital stock is more than double under the OECD wide shock than under the US only shock. The reallocation of global capital is that much larger when all industrial economies experience the risk shock compared to when the US only experiences the shock. Also the movement in the Chinese real exchange rate is more than double for the OECD wide shock.

### 4.4 Detailed macroeconomic adjustment within the United

In figure 3 we present more detailed results on the adjustments that occur within the US economy for the OECD wide temporary risk premium shock. We assume in this and earlier figures that the simple monetary regime in place is a fixed money supply rule. The remainder of the results in this paper will examine optimal money rules but for diagnostic purposes it is useful to begin with the fixed money stock assumption of the basic IS/LM framework.

Figure 3a shows the behaviour of the major macroeconomic aggregates, all for the US. Figure 3b

shows the behaviour of major assets – value of capital (i.e.  $qK$ ), government bonds, foreign assets, human capital, and wealth. Figure 3c shows what happens to employment and inflation of both consumer and producer prices and Figure 3d shows outcomes for the levels of wages and consumer and producer prices; it thus depicts a large fall in real wages of around 9 percent; during the period that capital is down it is this which prices workers back in to jobs and reduces the resulting unemployment. Figure 3e shows asset prices including the interest rate and Tobin's  $Q$  for capital used in production and Tobin's  $Q$  in housing capital. Figure 3f shows the real exchange rate, all for the US.

We have already explained the overall macroeconomic adjustment story to the change in the equity risk premium. The required return to capital rises due to the higher risk premium on equities. This causes a large fall in the US share market, summarized in the Asset Price Chart under Tobin's  $Q$ . Note in this chart that although the stock market falls sharply there is an equally sharp rise in the Tobin's  $Q$  for housing. People substitute out of equities into other assets such as government debt driving up the price of debt and therefore driving down the real interest rate. They also substitute into consumer durables (primarily housing) in this model. The combination of this substitution plus the fall in real interest rates increases the  $Q$  for housing further. Because the stock of housing, like the stock of physical capital is costly to adjust, the result is a rise in the price of housing and a rise in the return to investing in housing. This lasts for 5 years even though the shock is temporary.

### *The role of consumption and of housing*

Figure 3a also shows that consumption actually rises slightly as a result of the shock. But we have already noted that forward looking consumers will see the future productive power of labour as being lower as a result of the falling capital stock, which will lead to a fall in the value of real wages. Those consumers who are forward-looking will see the fall in future income and the value of equities and will cut consumption accordingly. How then is the rise in consumption brought about in the face of this by the falling rate of interest?

The fall in the real interest rate has two consequences for wealth.

- (i) Human capital rises (See Figure 3b). This happens, even despite the reduction in the real wage (See Figure 3d), because a fall in the interest rate increases the discounted value of any real income.



- (ii) The value of existing houses rises. This is reflected by the rise in the value of Tobin's  $q$  for housing (see Figure 3e). It happens for two reasons. First the rise in the risk premium through the fall in the real interest rate, increases the present discounted value of housing services, causing the value of existing houses to rise. Second the relative price of producing new housing falls. This is because the price of investment goods falls (relative to the price of other produced goods), because of the reduction in the demand for investment. That makes new housing cheaper, because it is produced in a way which is intensive in the use of investment goods, and that increases the value of existing housing.

The rise in human capital and in the value of housing, together mean that the value of overall wealth initially goes up (See Figure 3b). This happens even though the productive potential of the economy has fallen, and even although the value of financial wealth will have fallen significantly with the fall in the value of the stock market (see the fall in Tobin's  $q$  (non-energy) in Figure 3e).

The resulting rise in the value of wealth can then explain the rise in consumption on goods. Furthermore, because of the increase in Tobin's  $q$  for housing there is an increase in expenditure on housing itself, which is part of consumption.

Thus the fall in the interest rate actually more than overturns the negative effects, mentioned above, of falling capital stock leading to fall in consumption (because forward looking consumers foresee falling output). That is why consumption goes up even although the productivity of the economy – at least for a period of time – will actually have fallen. The role of a rise in house prices, and a rise in expenditure on housing, is essential in limiting the negative consequences of this shock.

In summary, Figure 3a shows a sharp fall in real investment but a rise in private consumption. This helps dampen the GDP decline, which is largely driven by falling investment. The GDP decline is also partly offset because of a real depreciation of the \$US in effective terms. Europe and the rest of the OECD are also experiencing the shock thus most of the change in real exchange rates is relative to developing countries. If the shock only occurred in the US the exchange rate change would be larger and the trade balance improvement is larger helping to dampen the negative effects of the shock.

An important insight from these results is that the more the equity risk shock is a global event the greater the negative impacts on the affected countries because there is less ability to buffer the shock through balance of payments adjustment. Also the role of other assets in the economy, especially housing is important in understanding the transmission of the shock within an economy.

## 5 Macroeconomic Policy and Outcomes

In this section investigate the effects of a policymaker pursuing not a fixed money supply, but instead adjusting interest rates so that the outcome optimises an intertemporal loss function<sup>7</sup> shown in equation (3).

$$(3) W_{it} = \sum_{t=0}^{\infty} \delta^t \tau_{it}' \Omega_i \tau_{it}$$

Assume that a policymaker chooses a vector of control variables ( $U_{it}$ ) to minimize (3) subject to the structure of the world economy as given by the MSG3 model. Where  $\tau$  is a vector of targets (in the current case either inflation alone or inflation and employment) relative to desired levels,  $\Omega$  is a matrix of weights on each target included in the  $\tau$  vector, and the 'i' subscript refers to country i.

It is important to note that we assume the policy maker cares not about the gap between actual output and capacity output, but about the gap between actual and desired employment. We use employment rather than capacity output because our shock is making capacity output change endogenously, and to fall. A policy maker who pursued the previously projected capacity level of output would create an inflation bias. Whereas employment will return to its natural rate within the model over time and this eliminates the inflation bias.

A second, important aspect of the objective function is that we make the inflation part of the objective function, producer price inflation rather than consumer price inflation. We do this because

of the strong effects the change in the price of housing services have on the measure of consumer price level in this model. The producer price index is closer to the concept of inflation used in the conventional macroeconomics literature as it turns out the particular shock we are examining in this paper leads to a substantial change in the price of housing services which monetary authorities may not want to respond to. Housing services and their pricing is something less than fully captured in most actual measures of the CPI and we do not want to entangle our results with this effect.

#### (i) United States

Figure 4 shows results for the United States under the case where monetary authorities put all weight on inflation (INFP) relative to the case where a weight of 2 is put on inflation a 1 on employment deviation from desired (INFEMP). If the policymaker puts double the weight on inflation as on employment and optimises monetary policy on this basis, the real outcomes for the US economy are very similar over time – almost identical - to those with a fixed money supply. Although in the initial years there are significant differences. The scale of the graphs and the long time period tend to disguise the monetary impacts in the very short term. Note in Figure 4b that producer price inflation is targeted exactly in the INF regime but is allowed to fluctuate relative to desired when allowance is also made for deviations in employment from desired (figure 1a).

If the policy maker puts an infinite relative weight on inflation (i.e. two relative to zero on employment) we see that output and employment outcomes of the shock can be made “worse” – i.e. more severe. Employment falls more (i.e. unemployment rises more), because monetary policy is tighter. However notice that nominal interest rates are lower under the inflation target. This is because when employment is given some weight in the targeting, inflation is higher and thus the inflation premium in the nominal interest rate is higher. The key point is that the real interest rate is higher under inflation targeting and therefore monetary policy is tighter in this case.

We see two things from this section.

The first of these is as expected, and obvious. A looser monetary can reduce the unemployment costs of the shock. In more detail, we see that this is a shock which, during the period in which its

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7 Recent studies following this approach using the MSG2 model to focus on policy issues within Europe include Haber at al (2001) , Haber et al (2002) and Neck et al (2002)

negative effects on the capital stock remain present, requires a significant fall in the real wage. To bring these about by wage cuts, without any rise in the price level, requires a significant amount of unemployment. The unemployment required to produce the wage cuts can be reduced by having some inflation.

The second result is less obvious, and important. This is that a more expansionary monetary policy, even a very expansionary monetary policy does not seem to be able to make very much difference to the level of unemployment along the long period of transition but does make a difference in the very short run. The downturn caused by the risk shock seems to be in large part a downturn – lower output and lower employment - that is hard to change greatly by monetary policy. To a considerable extent it is a supply side phenomenon which cannot be changed much by monetary policy and comes from the reduction in supply potential caused by the reduction in the stock of capital. Instead it is due to the fact that wages are sufficiently flexible in this model that a change in monetary policy, although it can have an effect for a few years before it is reflected in wages, cannot do so for more than a few years, no matter how large it is because any future changes will quickly feed into wages.

#### (ii) France

To illustrate the transmission of the shock to other countries we next present results for an illustrative European country, France. Figure 5 contains results when the shock is an OECD wide shock including in France but with the optimal policy response (with the European wide inflation and employment in the European Central Bank's objective function). This can be compared with Figure 6, which also contains results for France but in the case where the shock only occurs in the United States.

The macroeconomic adjustment in France when there is an OECD-wide risk shock is very similar to that for the United States that has already been analyzed in figure 3. The major difference is the smaller change in the Euro relative to the dollar and therefore the less offset there is for French GDP from an improvement in net exports. Indeed exports fall much more in France than in the US. The nominal effective exchange rate changes little in France compared to the US. Also there is a much larger rise in prices in France since the ECB is targeting European wide variables it does not place a great deal of weight on French inflation. This implies a rise in nominal wages in France

compared to a fall in nominal wages in the US. There is also a much more persistent rise in prices in France because of the ECB' reaction.

When the shock occurs in the United States only, France faces a very different type of shock. Recall that the US shock reduced US real interest rates and causes a global reallocation of capital. Financial capital flows into Europe as a whole, which appreciates the Euro. Asset prices are also driven up in Europe and real interest rates fall due to the inflow of capital from the United States. Asset values also rise and there is a physical accumulation of capital. Employment rises above base as the European economy experiences a positive supply shock due to the capital reallocation, but a negative foreign demand shock due to the slowdown in the US economy. The net effect is positive for Europe both in terms of higher employment as well as lower inflation. This contrasts with the stagflationary effect of the own country shock. It is worth pointing out that there is no direct control over French inflation because the ECB is targeting European wide inflation and employment. Therefore prices and wages in France rise over time.

## **7 International Cooperation between Policy Makers**

We finally study international cooperation between policymakers. We solve for the non-cooperative (time consistent) Nash equilibrium in which policy makers solve the objective function summarized in the previous section taking as given the behaviour of other policymakers. We also solve the cooperative equilibrium where a global policymaker weights each country's objective function by that country's GDP relative to the group and sets policy appropriately. This follows the techniques outlined in McKibbin and Sachs (1991)

An important innovation here is, as in the previous section, making the policy makers care not about the gap between actual output and capacity output, but instead about employment. We did this in the previous section to avoid the policy makers introducing an inflation bias. To do so is doubly important in this section because we know from Rogoff (1985) that if policymakers have an inflation bias then cooperation between them can be welfare reducing since it enables them to avoid depreciating the real exchange rate when they expand individually and thus strengthens the temptation to each to exploit inflation bias by attempting to over-expand.

In such a setup we expect there to be a cooperation issue. In particular the attempts by the individual policymakers to get demand back to supply by expansionary monetary policy makers partly limited by the fact that this would cause the exchange rate to depreciate and cause inflation. Cooperation will enable them to avoid this and so to be more expansionary, (even although they do not have an inflation bias and would not seek to expand as and when the economy had returned to full employment).

Figure 7 shows results, which conform to this expected outcome. Cooperation gives a more expansionary response to the shock. It enables the policy makers to trade off lost output for higher inflation. These results mirror the results from the literature of the 1980s when policy cooperation was shown to avoid excessively contractionary responses to inflationary shocks<sup>8</sup>. Here we show that cooperation enables more expansionary (and more inflationary) responses to negative demand shocks.

But the results, although of the expected sign, are highly important in that they are small. They suggest, just like the studies from the 1980s, that the effects of cooperation would be very limited. This is because a more expansionary monetary policy induced by cooperation, does not seem to be able to make very much difference to the level of unemployment resulting from the shock that we are studying. As already noted, the downturn caused by the risk shock seems to be in large part a downturn – lower output and lower employment - which is hard to change greatly by monetary policy. To a considerable extent it is a supply side phenomenon which cannot be changed much by monetary policy and comes from the reduction in supply potential caused by the reduction in the stock of capital. Monetary cooperation in these circumstances (compared to the country following their own optimal policies) seems unlikely to be able to yield much benefit. In reality however it is not clear that countries are currently following optimal policies individually. To the extent that cooperation might move them away from the currently inappropriate policies such as in Japan and Europe, cooperation might have much larger payoffs than simulated in the artificial world of this

modelling exercise.

## **8 Conclusions.**

We find that the global adjustment to shifts in equity risk premia is significant. They comprise both demand and supply side shocks and therefore are difficult to manage with monetary policies. We find that what some commentators regards as imbalances such as shifts in current accounts and changes in housing prices can be explained as optimal responses to the types of shocks being experienced (although the actual changes observed might be larger than optimal, the direction of change is consistent with the adjustment in this paper). Adjusting monetary policies to deal with these ‘imbalances’ would be counterproductive. There is a role for monetary policy in smoothing the adjustment on the demand side relative to the adjustment on the supply side, however monetary policy cannot offset the underlying supply side consequences of the shock.

The transmission of equity shocks has important implication for countries not experiencing the shock both within the OECD and within the developing world. The supply side of countries not experiencing the equity risk shocks will tend to be positively affected but external demand declines. The negative external demand shock but positive domestic supply shock induced by foreign capital inflow is very different to the experience of the affected countries which experience domestic supply and demand contractions. The optimal adjustment of policy in different countries is therefore likely to differ across countries.

We have taken the changes to equity risk to be completely external to the model. This is might be unsatisfactory since risk perceptions may in fact be endogenous to the policy responses. The determinations of risk assessment, is an important area of research that needs a great deal of research. We have also ignored the role of fiscal policy, which may have importantly different effects than monetary policy. Haber et al (2001,2002) have already demonstrated the importance of this issue within Europe. Future work will extend the current analysis to the topic of this paper.

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8 see McKibbin (1997) for a survey of these results.

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**Table 1: Key Features of the Model**

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- ① Specification of the demand and supply sides of economies;
  - ① Integration of real and financial markets of these economies with explicit arbitrage linkage real and financial rates of return;
  - ① Intertemporal accounting of stocks and flows of real resources and financial assets;
  - ① Imposition of intertemporal budget constraints so that agents and countries cannot forever borrow or lend without undertaking the required resource transfers necessary to service outstanding liabilities;
  - ① Short-run behavior is a weighted average of neoclassical optimizing behavior based on expected future income streams and Keynesian current income;
  - ① The real side of the model is dis-aggregated to allow for production of multiple goods and services within economies;
  - ① International trade in goods, services and financial assets;
  - ① Full short-run and long-run macroeconomic closure with macro dynamics at an annual frequency around a long-run Solow/Swan/Ramsey neoclassical growth model.
  - ① The model is solved for a full rational expectations equilibrium at an annual frequency from 2001 to 2070.
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Table 2: The MSG3 Model version 50o

| <b>Countries:</b>              | <b>Exchange rate Regime:</b> |
|--------------------------------|------------------------------|
| United States                  | float                        |
| Japan                          | float                        |
| Australia                      | float                        |
| Canada                         | float                        |
| United Kingdom                 | float                        |
| Germany                        | Euro (floating)              |
| Austria                        | Euro (floating)              |
| France                         | Euro (floating)              |
| Italy                          | Euro (floating)              |
| Rest of Euro Zone              | Euro (floating)              |
| Rest of OECD                   | float                        |
| China                          | peg to \$US                  |
| non Oil Developing countries   | peg to \$US                  |
| Eastern Europe and Russia      | float                        |
| OPEC                           | peg to \$US                  |
| <b>Sectors:</b>                |                              |
| Energy                         |                              |
| Non – Energy                   |                              |
| Capital goods producing sector |                              |

### ***Appendix I: A stylized 2 country G-Cubed model***

In this section a stylized 2-country model is presented which distils the essence of the MSG3 model (a 2 sector version of the G-Cubed model) and in particular how the intertemporal aspects of the model are handled. The reader is referred to McKibbin and Wilcoxon (1998) for greater detail.

In this stylized model there are 2 symmetric countries. Each country consists of several economic agents: households, the government, the financial sector and 2 firms, one each in the 2 production sectors. The two sectors of production are energy and non-energy (this is much like the aggregate structure of the MSG2 model). The following gives an overview of the theoretical structure of the model by describing the decisions facing these agents in one of these countries. Throughout the discussion all quantity variables will be normalized by the economy's endowment of effective labor units. Thus, the model's long run steady state will represent an economy in a balanced growth equilibrium.

#### ***Firms***

We assume that each of the two sectors can be represented by a price-taking firm which chooses variable inputs and its level of investment in order to maximize its stock market value. Each firm's production technology is represented by a constant elasticity of substitution (CES) function. Output is a function of capital, labor, energy and materials:

$$(1) \quad Q_i = A_i^o \left( \sum_{j=k,l,e,m} (\delta_{ij}^o)^{1/\sigma_i^o} x_{ij}^{(\sigma_i^o-1)/\sigma_i^o} \right)^{\sigma_i^o/(\sigma_i^o-1)}$$

where  $Q_i$  is the output of industry  $i$ ,  $x_{ij}$  is industry  $i$ 's use of input  $j$ , and  $A_i^o$ ,  $\delta_{ij}^o$ , and  $\sigma_i^o$  are parameters.  $A_i^o$  reflects the level of technology,  $\sigma_i^o$  is the elasticity of substitution, and the  $\delta_{ij}^o$  parameters reflect the weights of different inputs in production; the superscript  $o$  indicates that the parameters apply to the top, or "output", tier. Without loss of generality, we constrain the  $\delta_{ij}^o$ 's to

sum to one.

The goods and services purchased by firms are, in turn, aggregates of imported and domestic commodities which are taken to be imperfect substitutes. We assume that all agents in the economy have identical preferences over foreign and domestic varieties of each commodity. We represent these preferences by defining composite commodities that are produced from imported and domestic goods. Each of these commodities,  $Y_i$ , is a CES function of inputs domestic output,  $Q_i$ , and an aggregate of goods imported from all of the country's trading partners,  $M_i$ :

$$(2) \quad y_i = A_i^{fd} \left( \left( \delta_{id}^{fd} \right)^{1/\sigma_i^{fd}} Q_i^{(\sigma_i^{fd}-1)/\sigma_i^{fd}} + \left( \delta_{if}^{fd} \right)^{1/\sigma_i^{fd}} M_i^{(\sigma_i^{fd}-1)/\sigma_i^{fd}} \right)^{\sigma_i^{fd}/(\sigma_i^{fd}-1)}$$

where  $\sigma_i^{fd}$  is the elasticity of substitution between domestic and foreign goods.<sup>9</sup> For example, the energy product purchased by agents in the model are a composite of imported and domestic energy. The aggregate imported good,  $M_i$ , is itself a CES composite of imports from individual countries,  $M_{ic}$ , where  $c$  is an index indicating the country of origin:

$$(3) \quad M_i = A_i^{ff} \left( \sum_{c=1}^7 \left( \delta_{ic}^{ff} \right)^{1/\sigma_i^{ff}} M_{ic}^{(\sigma_i^{ff}-1)/\sigma_i^{ff}} \right)^{\sigma_i^{ff}/(\sigma_i^{ff}-1)}$$

The elasticity of substitution between imports from different countries is  $\sigma_i^{ff}$ .

By constraining all agents in the model to have the same preferences over the origin of goods we require that, for example, the agricultural and service sectors have the identical preferences over domestic oil and imported oil.<sup>10</sup> This accords with the input-output data we use and allows a very convenient nesting of production, investment and consumption decisions.

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<sup>9</sup> This approach follows Armington (1969).

<sup>10</sup> This does not require that both sectors purchase the same amount of oil, or even that they purchase oil at all; only that they both feel the same way about the origins of oil they buy.

In each sector the capital stock changes according to the rate of fixed capital formation ( $J_i$ ) and the rate of geometric depreciation ( $\delta_i$ ):

$$(4) \quad \dot{k}_i = J_i - \delta_i k_i$$

Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969) we assume that the investment process is subject to rising marginal costs of installation. To formalize this we adopt Uzawa's approach by assuming that in order to install  $J$  units of capital a firm must buy a larger quantity,  $I$ , that depends on its rate of investment ( $J/k$ ):

$$(5) \quad I_i = \left( 1 + \frac{\phi_i J_i}{2 k_i} \right) J_i$$

where  $\phi_i$  is a non-negative parameter. The difference between  $J$  and  $I$  may be interpreted various ways; we will view it as installation services provided by the capital-goods vendor. Differences in the sector-specificity of capital in different industries will lead to differences in the value of  $\phi_i$ .

The goal of each firm is to choose its investment and inputs of labor, materials and energy to maximize intertemporal net-of-tax profits. For analytical tractability, we assume that this problem is deterministic (equivalently, the firm could be assumed to believe its estimates of future variables with subjective certainty). Thus, the firm will maximize:<sup>11</sup>

$$(6) \quad \int_t^{\infty} (\pi_i - (1 - \tau_4) p^I I_i) e^{-(R(s) - n)(s-t)} ds$$

where all variables are implicitly subscripted by time. The firm's profits,  $\pi$ , are given by:

$$(7) \quad \pi_i = (1 - \tau_2)(p_i^* Q_i - w_i x_{il} - p_i^e x_{ie} - p_i^m x_{im})$$

where  $\tau_2$  is the corporate income tax,  $\tau_4$  is an investment tax credit, and  $p^*$  is the producer price of

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<sup>11</sup> The rate of growth of the economy's endowment of effective labor units,  $n$ , appears in the discount factor because the quantity and value variables in the model have been scaled by the number of effective labor units. These variables must be multiplied by  $\exp(nt)$  to convert them back to their original form.

the firm's output.  $R(s)$  is the long-term interest rate between periods  $t$  and  $s$ :

$$(8) \quad R(s) = \frac{1}{s-t} \int_t^s r(v) dv$$

Because all real variables are normalized by the economy's endowment of effective labor units, profits are discounted adjusting for the rate of growth of population plus productivity growth,  $n$ . Solving the top tier optimization problem gives the following equations characterizing the firm's behavior:

$$(9) \quad x_{ij} = \delta_{ij}^o (A_i^o)^{\sigma_i^o - 1} Q_i \left( \frac{p_i^*}{p_j} \right)^{\sigma_i^o} \quad j \in \{l, e, m\}$$

$$(10) \quad \lambda_i = (1 + \phi_i \frac{J_i}{k_i}) (1 - \tau_4) p^I$$

$$(11) \quad \frac{d\lambda_i}{ds} = (r + \delta_i) \lambda_i - (1 - \tau_2) p_i^* \frac{dQ_i}{dk_i} - (1 - \tau_4) p^I \frac{\phi_i}{2} \left( \frac{J_i}{k_i} \right)^2$$

where  $\lambda_i$  is the shadow value of an additional unit of investment in industry  $i$ .

Equation (9) gives the firm's factor demands for labor, energy and materials and equations (10) and (11) describe the optimal evolution of the capital stock. Integrating (11) along the optimum trajectory of investment and capital accumulation,  $(\hat{J}(t), \hat{k}(t))$ , gives the following expression for  $\lambda_i$ :

$$(12) \quad \lambda_i(t) = \int_t^\infty \left( (1 - \tau_2) p_i^* \frac{dQ_i}{dk_i} \Big|_{\hat{J}, \hat{k}} + (1 - \tau_4) p^I \frac{\phi_i}{2} \left( \frac{\hat{J}_i}{\hat{k}_i} \right)^2 \right) e^{-(R(s) + \delta)(s-t)} ds$$

Thus,  $\lambda_i$  is equal to the present value of the after-tax marginal product of capital in production (the first term in the integral) plus the savings in subsequent adjustment costs it generates. It is related



to  $q$ , the after-tax marginal version of Tobin's Q (Abel, 1979), as follows:

$$(1) \quad q_i = \frac{\lambda_i}{(1-\tau_4)p^I}$$

Thus we can rewrite (10) as:

$$(2) \quad \frac{J_i}{k_i} = \frac{1}{\phi_i}(q_i - 1)$$

Inserting this into (5) gives total purchases of new capital goods:

$$(3) \quad I_i = \frac{1}{2\phi_i}(q_i^2 - 1)k_i$$

Based on Hayashi (1979), who showed that actual investment seems to be partly driven by cash flows, we modify (3) by writing  $I_i$  as a function not only of  $q$ , but also of the firm's current cash flow at time  $t$ ,  $\pi_i$ , adjusted for the investment tax credit:

$$(4) \quad I_i = \alpha_2 \frac{1}{2\phi_i}(q_i^2 - 1)k_i + (1 - \alpha_2) \frac{\pi_i}{(1 - \tau_4)p^I}$$

This improves the model's ability to mimic historical data and is consistent with the existence of firms that are unable to borrow and therefore invest purely out of retained earnings.

So far we have described the demand for investment goods by each sector. Investment goods are supplied, in turn, by a third industry that combines labor and the outputs of other industries to produce raw capital goods. We assume that this firm faces an optimization problem identical to those of the other two industries: it has a nested CES production function, uses inputs of capital, labor, energy and materials in the top tier, incurs adjustment costs when changing its capital stock, and earns zero profits. The key difference between it and the other sectors is that we use the investment column of the input-output table to estimate its production parameters.

### Households

Households have three distinct activities in the model: they supply labor, they save, and they consume goods and services. Within each region we assume household behavior can be modeled by a representative agent with an intertemporal utility function of the form:

$$(1) \quad U_t = \int_t^{\infty} (\ln c(s) + \ln g(s)) e^{-\theta(s-t)} ds$$

where  $c(s)$  is the household's aggregate consumption of goods and services at time  $s$ ,  $g(s)$  is government consumption at  $s$ , which we take to be a measure of public goods provided, and  $\theta$  is the rate of time preference.<sup>12</sup> The household maximizes (1) subject to the constraint that the present value of consumption be equal to the sum of human wealth,  $H$ , and initial financial assets,  $F$ :<sup>13</sup>

$$(1) \quad \int_t^{\infty} p^c(s) c(s) e^{-(R(s)-n)(s-t)} = H_t + F_t$$

Human wealth is defined as the expected present value of the future stream of after-tax labor income plus transfers:

$$(1) \quad H_t = \int_t^{\infty} (1 - \tau_1)(W(L^G + L^C + L^I + \sum_{i=1}^{12} L^i) + TR) e^{-(R(s)-n)(s-t)} ds$$

where  $\tau_1$  is the tax rate on labor income,  $TR$  is the level of government transfers,  $L^C$  is the quantity of labor used directly in final consumption,  $L^I$  is labor used in producing the investment good,  $L^G$  is government employment, and  $L^i$  is employment in sector  $i$ . Financial wealth is the sum of real money balances,  $MON/P$ , real government bonds in the hand of the public,  $B$ , net holding of claims against foreign residents,  $A$ , the value of capital in each sector:

$$(2) \quad F = \frac{MON}{p} + B + A + q^I k^I + q^c k^c + \sum_{i=1}^{12} q^i k^i$$

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<sup>12</sup> This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable.

<sup>13</sup> As before,  $n$  appears in (1) because the model's scaled variables must be converted back to their original basis.

Solving this maximization problem gives the familiar result that aggregate consumption spending is equal to a constant proportion of private wealth, where private wealth is defined as financial wealth plus human wealth:

$$(1) \quad p^c c = \theta(F + H)$$

However, based on the evidence cited by Campbell and Mankiw (1990) and Hayashi (1982) we assume some consumers are liquidity-constrained and consume a fixed fraction  $\gamma$  of their after-tax income (*INC*).<sup>14</sup> Denoting the share of consumers who are not constrained and choose consumption in accordance with (1) by  $\alpha_8$ , total consumption expenditure is given by:

$$(2) \quad p^c c = \alpha_8 \theta(F_t + H_t) + (1 - \alpha_8) \gamma INC$$

The share of households consuming a fixed fraction of their income could also be interpreted as permanent income behavior in which household expectations about income are myopic.

Once the level of overall consumption has been determined, spending is allocated among goods and services according to a CES utility function.<sup>15</sup> The demand equations for capital, labor, energy and materials can be shown to be:

$$(3) \quad p_i x_i^c = \delta_i^c y \left( \frac{p^c}{p_i} \right)^{\sigma_c^o - 1}, \quad i \in \{k, l, e, m\}$$

where  $y$  is total expenditure,  $x_i^c$  is household demand for good  $i$ ,  $\sigma_c^o$  is the top-tier elasticity of substitution and the  $\delta_i^c$  are the input-specific parameters of the utility function. The price index for consumption,  $p^c$ , is given by:

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14 There has been considerable debate about the empirical validity of the permanent income hypothesis. In addition the work of Campbell, Mankiw and Hayashi, other key papers include Hall (1978), and Flavin (1981). One side effect of this specification is that it prevents us from computing equivalent variation. Since the behavior of some of the households is inconsistent with (1), either because the households are at corner solutions or for some other reason, aggregate behavior is inconsistent with the expenditure function derived from our utility function.

15 The use of the CES function has the undesirable effect of imposing unitary income elasticities, a restriction usually rejected by data. An alternative would be to replace this specification with one derived from the linear expenditure system.

$$(1) \quad p^c = \left( \sum_{j=k,l,e,m} \delta_j^c p_j^{\sigma_c^o - 1} \right)^{\frac{1}{\sigma_c^o - 1}}$$

Household capital services consist of the service flows of consumer durables plus residential housing. The supply of household capital services is determined by consumers themselves who invest in household capital,  $k^c$ , in order to generate a desired flow of capital services,  $c^k$ , according to the following production function:

$$(1) \quad c^k = \alpha k^c$$

where  $\alpha$  is a constant. Accumulation of household capital is subject to the condition:

$$(2) \quad \dot{k}^c = J^c - \delta^c k^c$$

We assume that changing the household capital stock is subject to adjustment costs so household spending on investment,  $I^c$ , is related to  $J^c$  by:

$$(3) \quad I^c = \left( 1 + \frac{\phi^c}{2} \frac{J^c}{k^c} \right) J^c$$

Thus the household's investment decision is to choose  $I^c$  to maximize:

$$(4) \quad \int_t^{\infty} (p^{ck} \alpha k^c - p^I I^c) e^{-(R(s)-n)(s-t)} ds$$

where  $p^{ck}$  is the imputed rental price of household capital. This problem is nearly identical to the investment problem faced by firms and the results are very similar. The only important differences are that no variable factors are used in producing household capital services and there is no investment tax credit for household capital. Given these differences, the marginal value of a unit of household capital,  $\lambda_C$ , can be shown to be:

$$(1) \quad \lambda_c(t) = \int_t^{\infty} \left( p^{ck} \alpha + p^I \frac{\phi_c}{2} \left( \frac{\hat{J}_c}{\hat{k}_c} \right)^2 \right) e^{-(R(s)+\delta)(s-t)} ds$$

where the integration is done along the optimal path of investment and capital accumulation,  $(\hat{J}_c(t), \hat{k}_c(t))$ . Marginal  $q$  is:

$$(1) \quad q_c = \frac{\lambda_c}{p^I}$$

and investment is given by:

$$(1) \quad \frac{J_c}{k_c} = \frac{1}{\phi_c} (q_c - 1)$$

### ***The Labor Market***

We assume that labor is perfectly mobile among sectors within each region but is immobile between regions. Thus, wages will be equal across sectors within each region, but will generally not be equal between regions. In the long run, labor supply is completely inelastic and is determined by the exogenous rate of population growth. Long run wages adjust to move each region to full employment. In the short run, however, nominal wages are assumed to adjust slowly according to an overlapping contracts model where wages are set based on current and expected inflation and on labor demand relative to labor supply. The equation below shows how wages in the next period depend on current wages; the current, lagged and expected values of the consumer price level; and the ratio of current employment to full employment:

$$(1) \quad w_{t+1} = w_t \left( \frac{p_{t+1}^c}{p_t^c} \right)^{\alpha_5} \left( \frac{p_t^c}{p_{t-1}^c} \right)^{1-\alpha_5} \left( \frac{L_t}{\bar{L}} \right)^{\alpha_6}$$

The weight that wage contracts attach to expected changes in the price level is  $\alpha_5$  while the weight assigned to departures from full employment ( $\bar{L}$ ) is  $\alpha_6$ . Equation (1) can lead to short-run

unemployment if unexpected shocks cause the real wage to be too high to clear the labor market. At the same time, employment can temporarily exceed its long run level if unexpected events cause the real wage to be below its long run equilibrium.

### ***The Government***

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among inputs in fixed proportions, which we set to 1996 values. Total government outlays include purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales taxes, corporate and personal income taxes, and from sales of new government bonds. In addition, there can be taxes on externalities such as carbon dioxide emissions. The government budget constraint may be written in terms of the accumulation of public debt as follows:

$$(1) \quad \dot{B}_t = D_t = r_t B_t + G_t + TR_t - T_t$$

where  $B$  is the stock of debt,  $D$  is the budget deficit,  $G$  is total government spending on goods and services,  $TR$  is transfer payments to households, and  $T$  is total tax revenue net of any investment tax credit.

We assume that agents will not hold government bonds unless they expect the bonds to be paid off eventually and accordingly impose the following transversality condition:

$$(2) \quad \lim_{s \rightarrow \infty} B(s) e^{-(R(s)-n)s} = 0$$

This prevents per capita government debt from growing faster than the interest rate forever. If the government is fully leveraged at all times, (2) allows (1) to be integrated to give:

$$(3) \quad B_t = \int_t^{\infty} (T - G - TR) e^{-(R(s)-n)(s-t)} ds$$

Thus, the current level of debt will always be exactly equal to the present value of future budget

surpluses.<sup>16</sup>

The implication of (3) is that a government running a budget deficit today must run an appropriate budget surplus at some point in the future. Otherwise, the government would be unable to pay interest on the debt and agents would not be willing to hold it. To ensure that (3) holds at all points in time we assume that the government levies a lump sum tax in each period equal to the value of interest payments on the outstanding debt.<sup>17</sup> In effect, therefore, any increase in government debt is financed by consols, and future taxes are raised enough to accommodate the increased interest costs. Other fiscal closure rules are possible, such as requiring the ratio of government debt to GDP to be unchanged in the long run. These closures have interesting implications but are beyond the scope of this paper.

### ***Financial Markets and the Balance of Payments***

The eight regions in the model are linked by flows of goods and assets. Flows of goods are determined by the import demands described above. These demands can be summarized in a set of bilateral trade matrices which give the flows of each good between exporting and importing countries.

Trade imbalances are financed by flows of assets between countries. Each region with a current account deficit will have a matching capital account surplus, and vice versa.<sup>18</sup> We assume asset markets are perfectly integrated across regions.<sup>19</sup> With free mobility of capital, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations of the following form:

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<sup>16</sup> Strictly speaking, public debt must be less than or equal to the present value of future budget surpluses. For tractability we assume that the government is initially fully leveraged so that this constraint holds with equality.

<sup>17</sup> In the model the tax is actually levied on the difference between interest payments on the debt and what interest payments would have been if the debt had remained at its base case level. The remainder, interest payments on the base case debt, is financed by ordinary taxes.

<sup>18</sup> Global net flows of private capital are constrained to be zero at all times – the total of all funds borrowed exactly equals the total funds lent. As a theoretical matter this may seem obvious, but it is often violated in international financial data.

<sup>19</sup> The mobility of international capital is a subject of considerable debate; see Gordon and Bovenberg (1994) or Feldstein and Horioka (1980).

$$(1) \quad i_k + \mu_k = i_j + \mu_j + \frac{\dot{E}_k^j}{E_k^j}$$

where  $i_k$  and  $i_j$  are the interest rates in countries  $k$  and  $j$ ,  $\mu_k$  and  $\mu_j$  are exogenous risk premiums demanded by investors (calibrated in the baseline to make the model condition hold exactly with actual data), and  $E_k^j$  is the exchange rate between the currencies of the two countries.

Capital flows may take the form of portfolio investment or direct investment but we assume these are perfectly substitutable *ex ante*, adjusting to the expected rates of return across economies and across sectors. Within each economy, the expected returns to each type of asset are equated by arbitrage, taking into account the costs of adjusting physical capital stock and allowing for exogenous risk premiums. However, because physical capital is costly to adjust, any inflow of financial capital that is invested in physical capital will also be costly to shift once it is in place. This means that unexpected events can cause windfall gains and losses to owners of physical capital and *ex post* returns can vary substantially across countries and sectors. For example, if a shock lowers profits in a particular industry, the physical capital stock in the sector will initially be unchanged but its financial value will drop immediately.

### ***Money Demand***

Finally, we assume that money enters the model via a constraint on transactions.<sup>20</sup> We use a money demand function in which the demand for real money balances is a function of the value of aggregate output and short-term nominal interest rates:

$$(1) \quad MON = PY i^\varepsilon$$

where  $Y$  is aggregate output,  $P$  is a price index for  $Y$ ,  $i$  is the interest rate, and  $\varepsilon$  is the interest elasticity of money demand. The supply of money is determined by the balance sheet of the central bank and is exogenous.

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<sup>20</sup> Unlike other components of the model we simply assume this rather than deriving it from optimizing behavior. Money demand can be derived from optimization under various assumptions: money gives direct utility; it is a factor of production; or it must be used to conduct transactions. The distinctions are unimportant for our purposes.



*Assessing the Model*

All models have strengths and weaknesses and G-Cubed is no exception. Its most important strength is that it distinguishes between financial and physical capital and includes a fully integrated treatment of intertemporal optimization by households, firms and international portfolio holders. This allows the model to do a rigorous job of determining where physical capital ends up, both across industries and across countries, and of determining who owns the physical capital and in what currency it is valued. Overall, the key feature of G-Cubed is its treatment of capital, and that is also what most distinguishes it from other models in either the macro, trade or CGE literatures.

G-Cubed also has other strengths. All budget constraints are satisfied at all times, including both static and intertemporal budget constraints on households, governments and countries. Short-run behavior captures the effects of slow wage adjustment and liquidity constraints, while long-run behavior is consistent with full optimization and rational expectations. In addition, wherever possible the model's behavioral parameters are determined by estimation, which is discussed further in Chapter 4 of McKibbin and Wilcoxon (2001).

For the 2 country model used in the remainder of this paper, the parameter estimates are aggregated from the underlying 12 sectors to 2 sectors using output shares as weights. Also the initial values of foreign debt of each country are set to zero in the prototype model to preserve symmetry.

Figure 1 : Permanent Versus Temporary OECD wide Equity Risk Premium Shocks

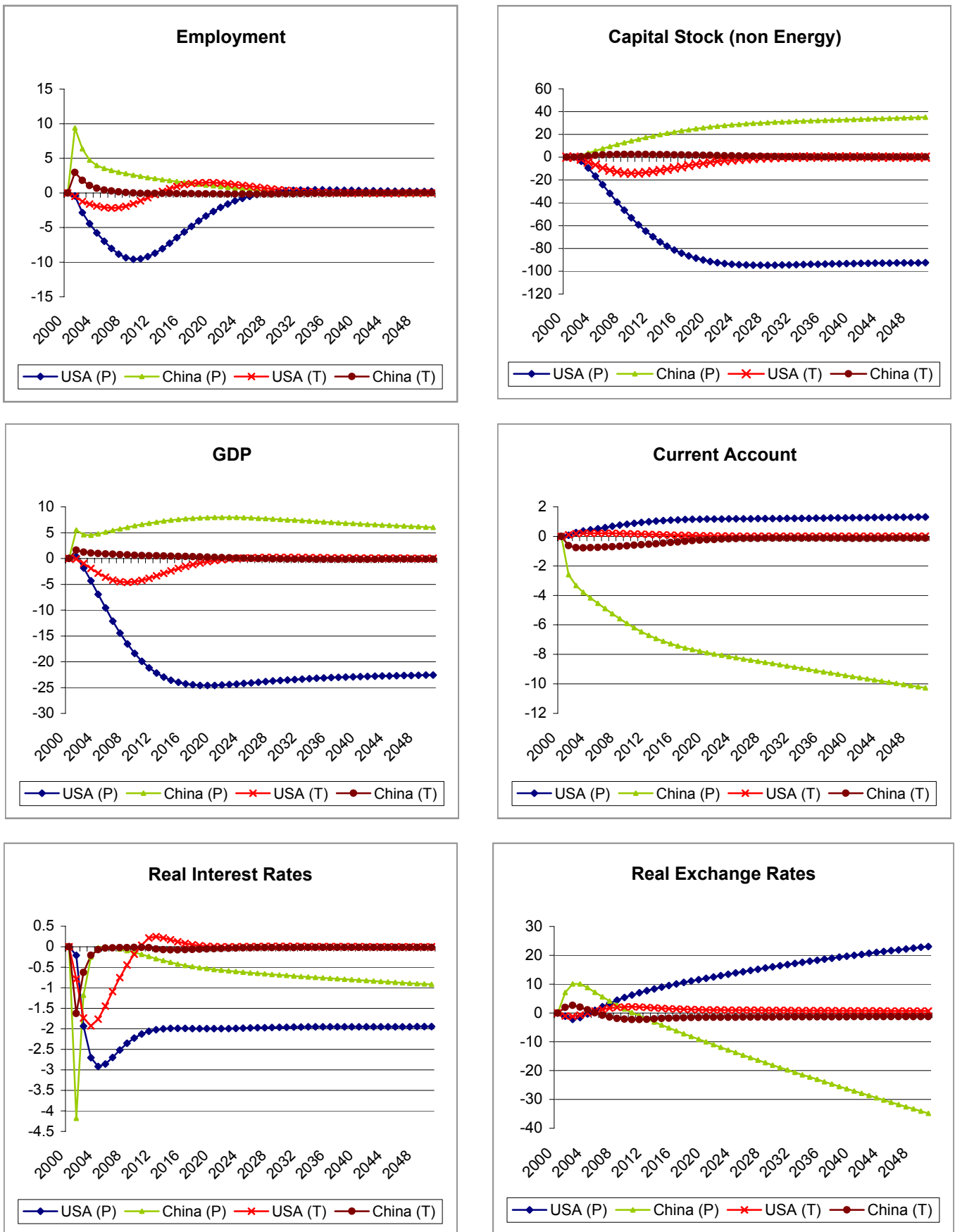


Figure 2: US versus OECD-Wide Equity Risk Premium Shocks - Results for US and China

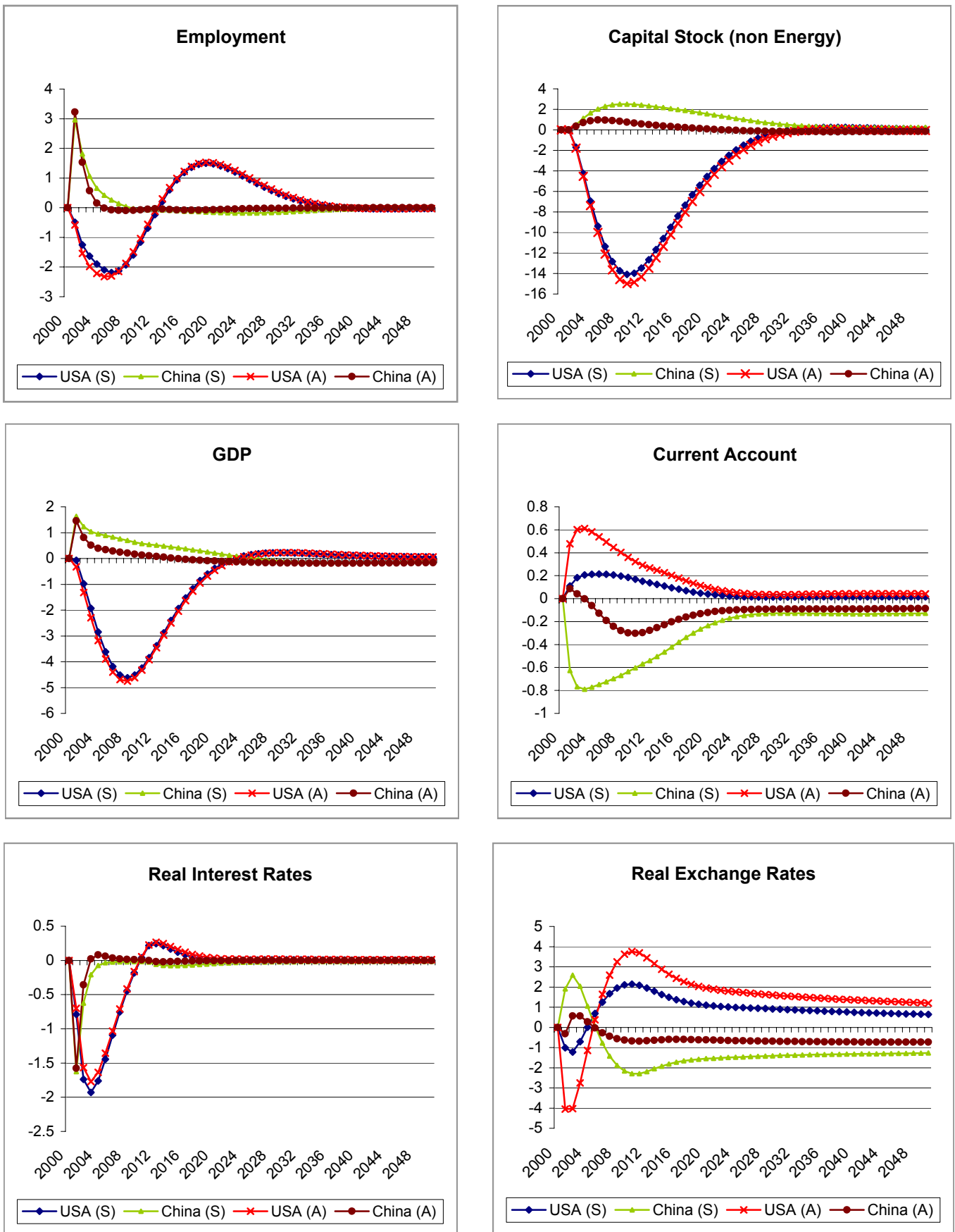


Figure 3 : Detailed Results for the US for OECD Wide Temporary Risk Premium Shocks

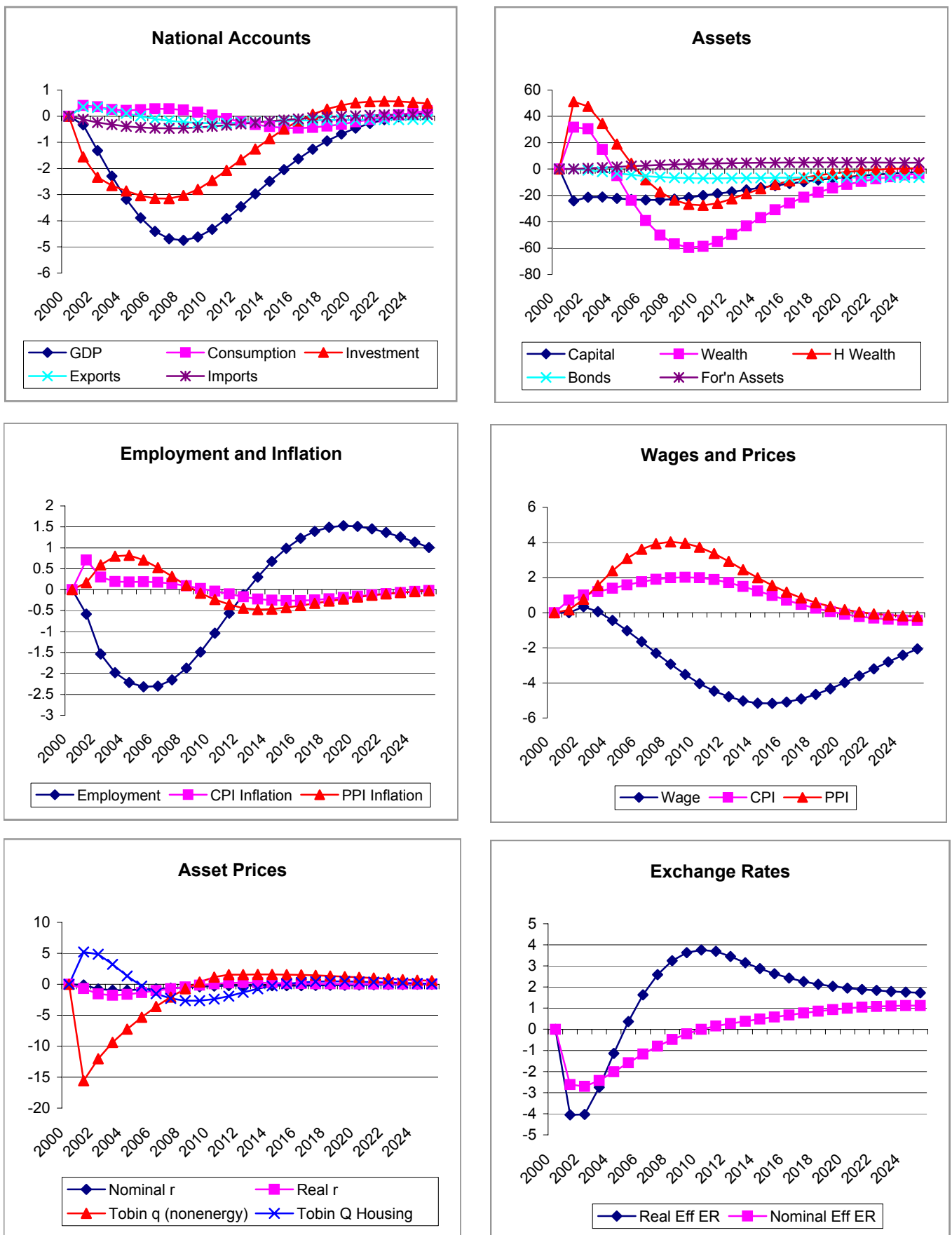
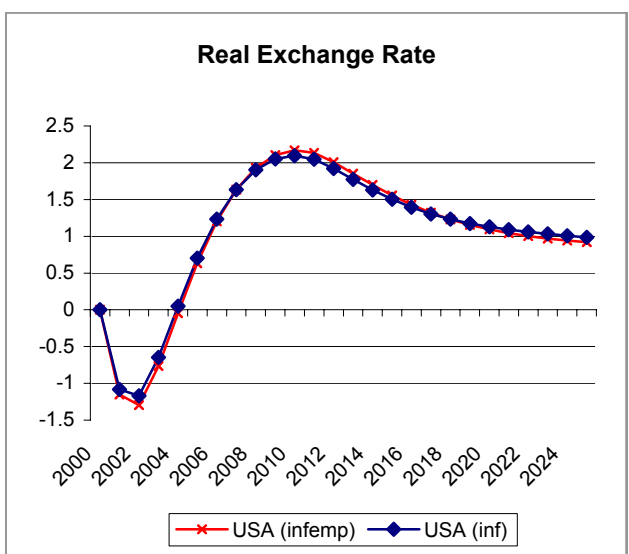
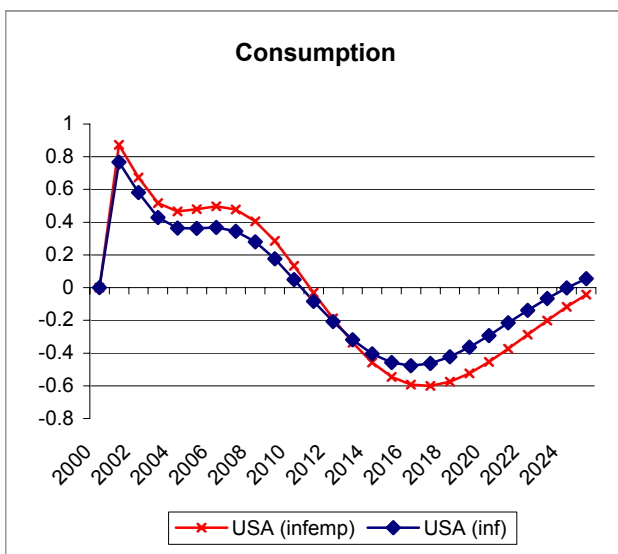
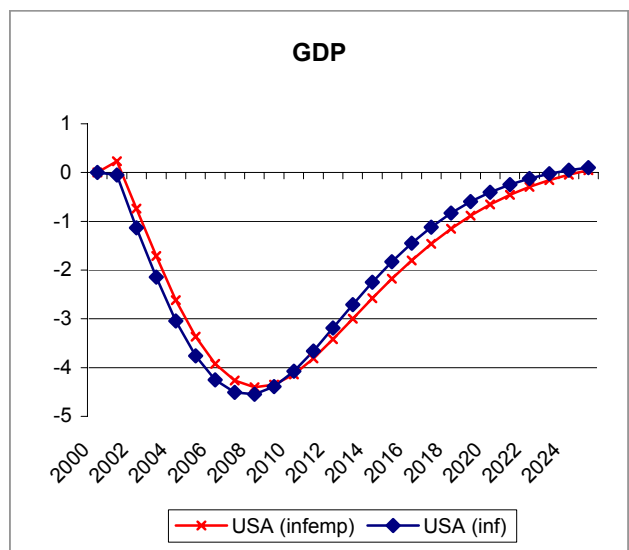
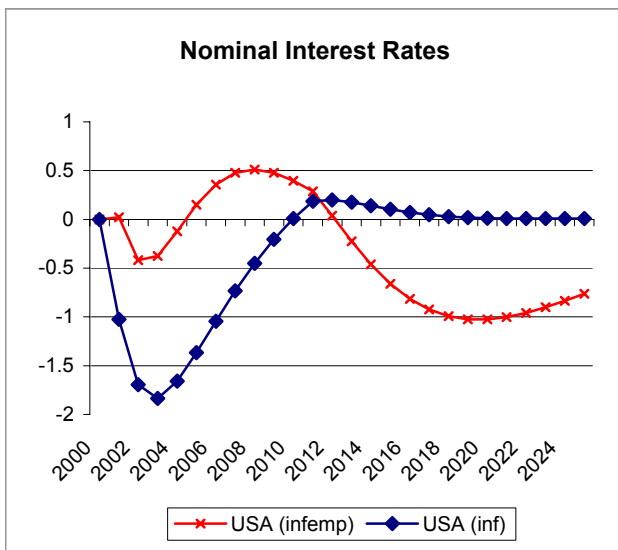
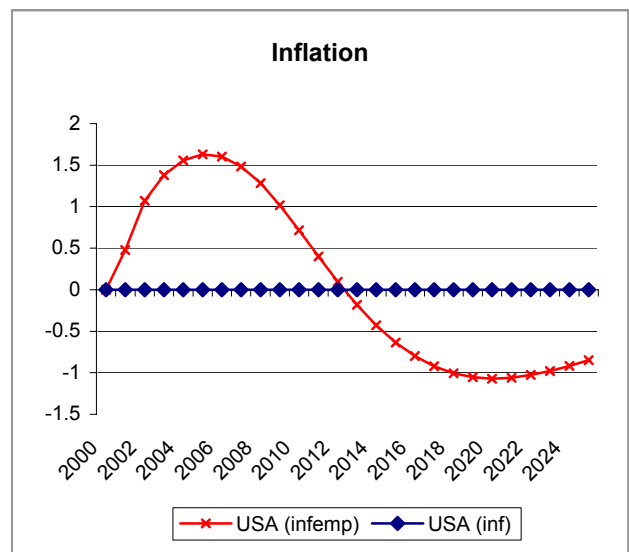
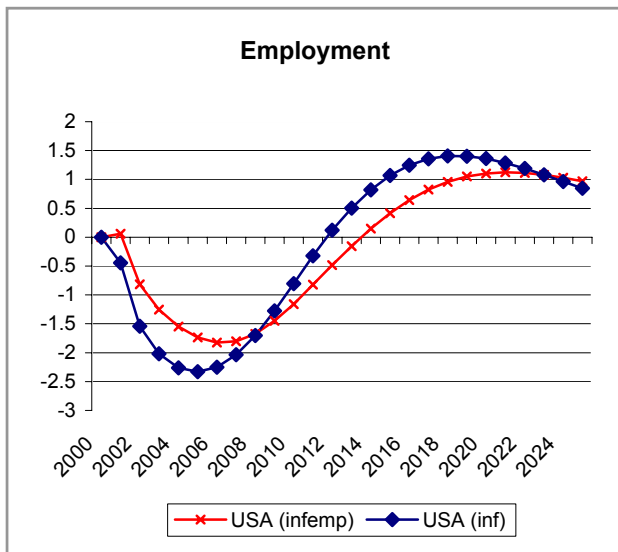


Figure 4: Optimal Policy Response in United States to OECD risk Shock : Inflation/Employment versus Inflation



Source: MSG3 Model version O50

Figure 5: Results for France for OECD-wide Temporary Risk Premium Shocks with optimal policy

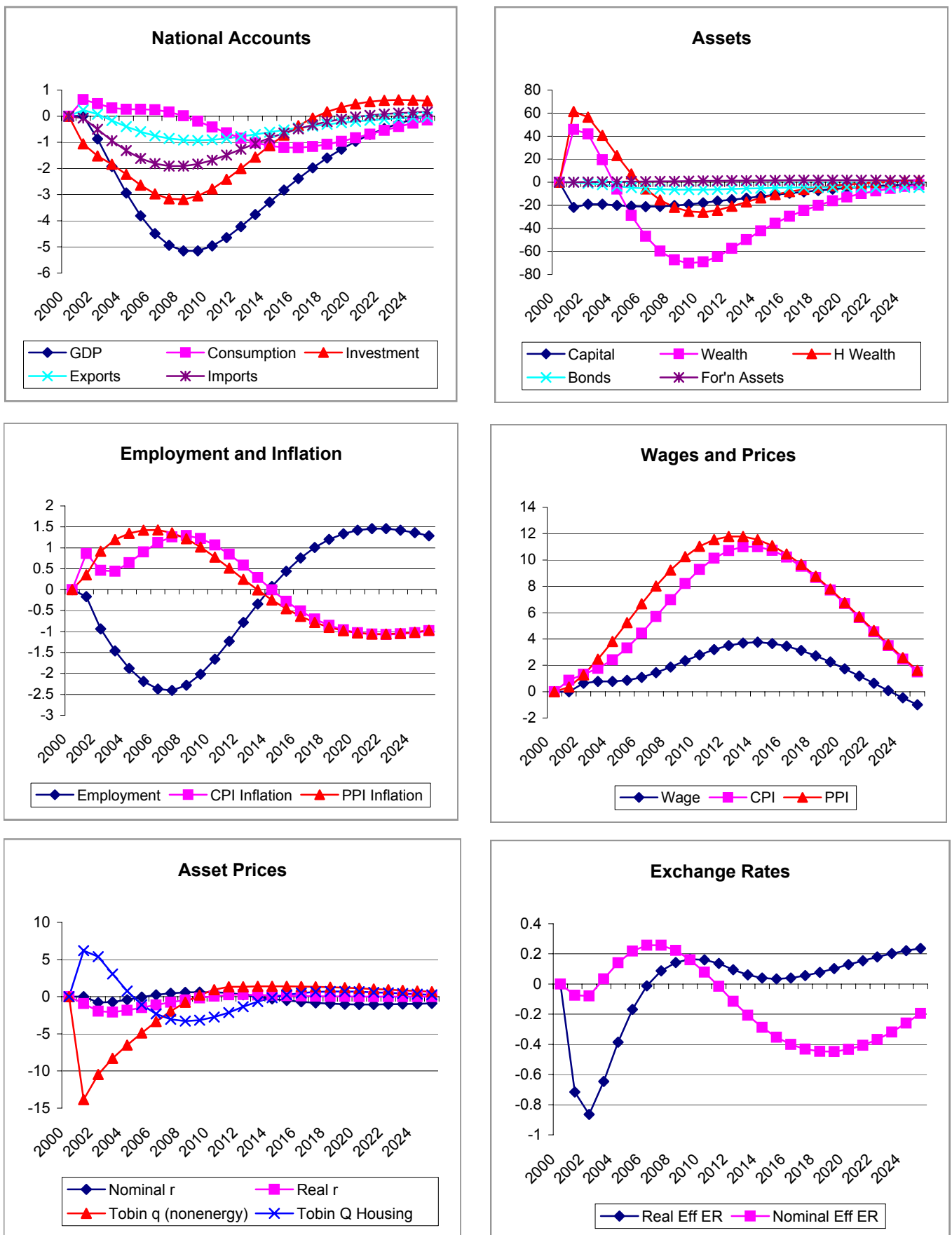


Figure 6: Results for France for Temporary US Risk Premium Shocks with optimal policy

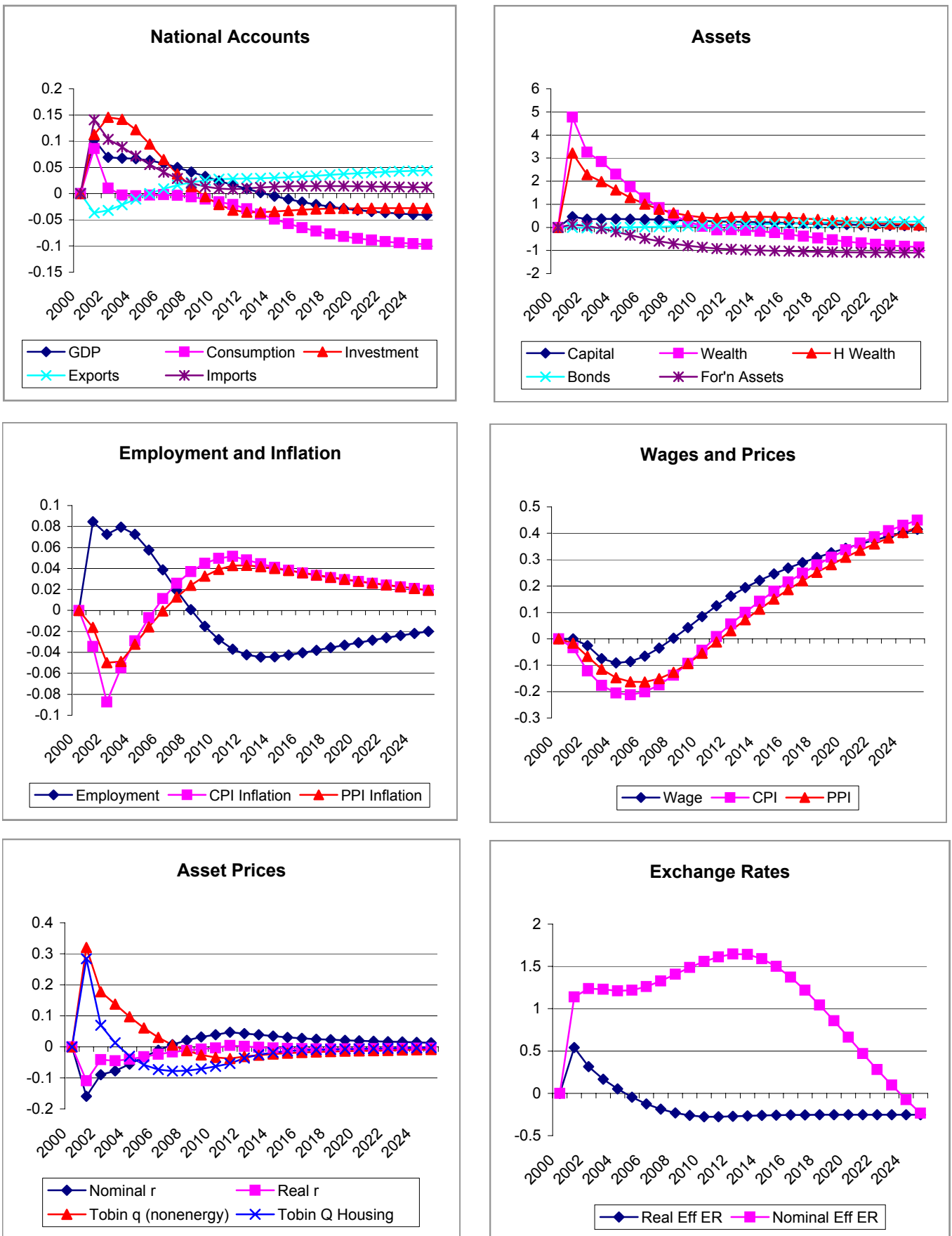
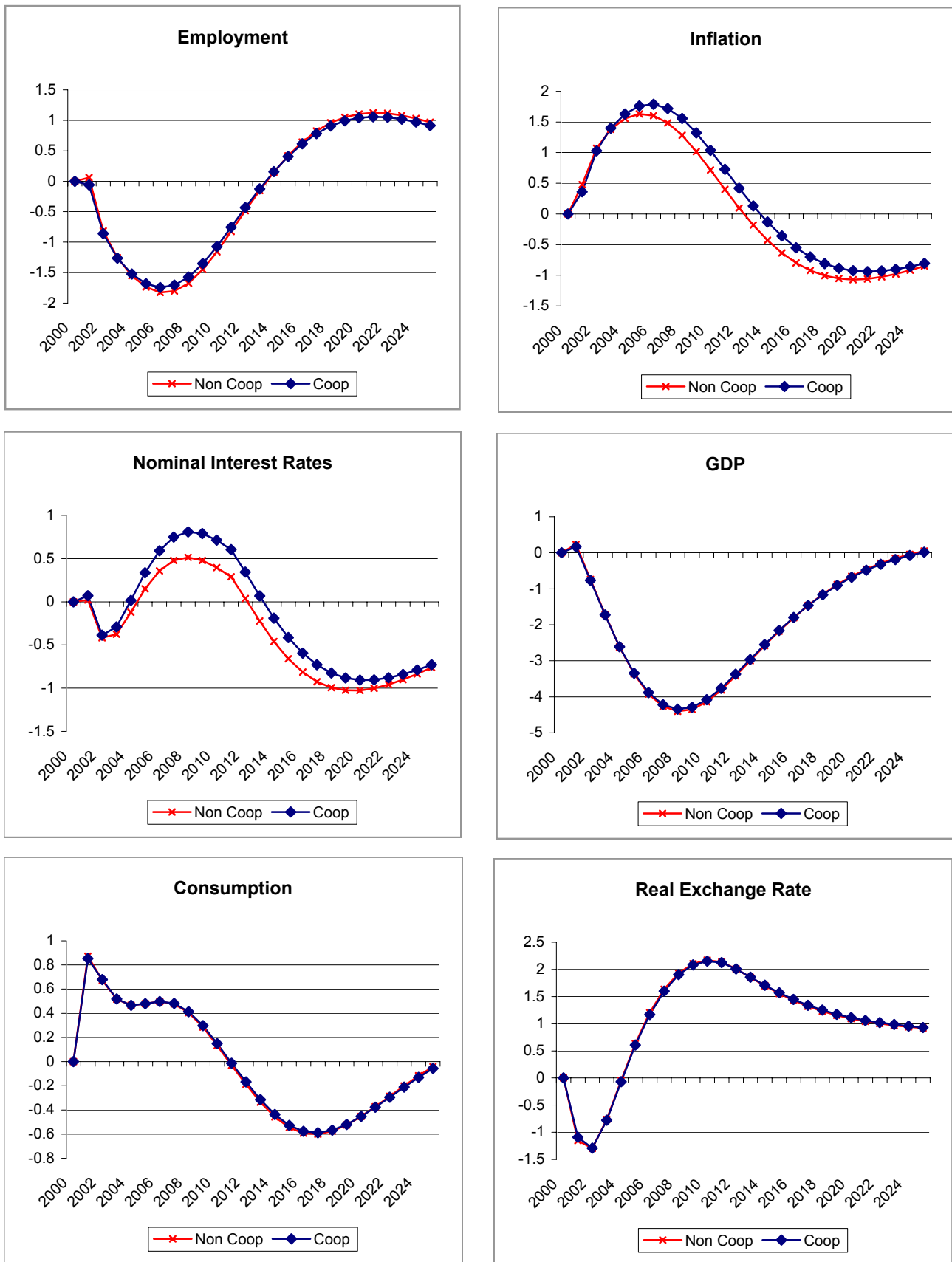


Figure 7: NonCooperative Versus Cooperative Policy Response in United States to OECD risk shock



Source: MSG3 model version O50



Figure 8: NonCooperative Versus Cooperative Policy Response in Europe to OECD Risk Shock

