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An Open Economy Real Business Cycle Model for the UK‡

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ABSTRACT

The objective of this paper is to specify a fully articulated model of a medium-sized open economy which we subsequently calibrate using quarterly data for the UK. We construct a dynamic general equilibrium open economy model based on optimising decisions of rational agents, incorporating money, government and distortionary taxes. The first order conditions from the household and firm's optimisation problem are used to derive the behavioural equations of the model. As we model a medium-sized open economy, we take the world economy as given. We keep the model in its non-linear form and hence solve it numerically. The interaction with the rest of the world comes in the form of UIP and current account both of which are explicitly micro-founded. Finally, the paper discusses simulation results for both demand and supply shocks with calibrated parameters which were used to assess the overall properties of the model. The results are consistent with our theoretical priors. Given the well-specified micro foundations of the model it can be used for evaluating welfare implications of nontrivial policy changes without the use of an ad-hoc objective function.

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1 Introduction

`The term \business cycle" refers to joint time-series behaviour of a wide range of economic variables such as prices, output, employment, consumption and investment. In actual economies this behaviour seems to be characterised by at least two broad regularities:

(1) Measured as deviations from trend, the ups and downs in individual series exhibit a considerable amount of persistence.

(2) Measures of various economic activities (e.g.outputs in di®erent sectors) move together.'

Long and Plosser (1983)

According to Lucas (1977) `One exhibits understanding of business cycles by constructing a model in the most literal sense: a fully articulated arti¯cial economy which behaves through time so as to imitate closely the time series behaviour of actual economics.'

The Keynesian Macroeconomic models of the 1940's were the ¯rst to attain this level of explicitness and empirical accuracy. Yet the ability of these models to imitate actual economies, has almost nothing to do with their ability to make accurate conditional forecasts, to evaluate how behaviour would have di®ered had certain policies been di®erent in speci¯ed ways. This ability requires invariance of the parameters of the model under policy variation, i.e. the celebrated Lucas Critique. Now invariance of model parameters is not a property that can be assured in advance, however it seems reasonable to assume that neither tastes nor technology vary systematically with variations in policies. In contrast, agents' decision rules will change with the change in economic environment. Any disequilibrium model, like the Keynesian models, constructed by simply codifyng the decision rules that agents found useful over some previous sample period, without explaining why these rules are used, will be of no use in predicting the consequences of nontrivial policy changes.

One of the most striking development in macroeconomic in the early 1980's was the emergence of a substantial body of literature devoted to the \real business cycle" approach to the analysis economics °uctuations. This approach originated in the pioneering work of Kydland and Prescott (1982) and Long and Plosser (1983). This literature was an outgrowth of the equilibrium strategy for business cycle analysis initiated by Lucas (1972,1973,1975) and extended by Barro (1976,1981), but di®ers from them in two critical aspects. First, RBC models place much more emphasis on mechanisms involving cycle propagation, that is, spreading over time of the e®ects of a shock. Second, RBC models emphasize the extent to which shocks that initiate the cycles are real-as opposed to- monetary in origin. Comprehensive reviews of the RBC research by McCallum (1989) and Plosser (1989) have illustrated that despite a number of unresolved issues, the approach successfully explains some of the key empirical regularities that characterise economic °uctuations. In the prototype real-business-cycle model, productivity disturbances motivate rational agents to adjust savings and investment to smooth consumption, and to adjust employment in response to changes in relative price of leisure and the productivity of labour. This behaviour is consistent with some of the stylised facts because: (a) it generates procyclical °uctuations in consumption, investment and employment, (b) it causes investment to exhibit greater variability than output or consumption, and (c) it produces positive persistence in all major macro-aggregates.

The greatest advantage of the RBC approach is in that the structural equations of the model have been derived via an optimization, so that the parameters of the model (preferences and technology) can be regarded as truly \structural". It is an equilibrium model, which is by de¯nition constructed to predict how agents with stable tastes and technology will chose to respond to a new situation and can be used: (1) to analyze how key macroeconomic variables are likely to respond to known economic shocks or changes in the economic structure, and (2) to identify the economic shocks and changes in economic structure underlying the observed movements in economic data. Both of these functions are important in central banks' economic analysis, as for instance the Bank of England (1999) recognizes to be for the conduct of its monetary policy. In the RBC framework alternative policies can be compared on the basis of measures of the utility bene¯ts or costs, rather than on the basis of ad hoc objectives. Further it allows for the analysis of policy and other shocks in the dynamic-stochastic context of a fully speci¯ed system, as called for by rational-expectations reasoning.

The early models in the RBC literature [1] were closed economy models that assumed no externalities, taxes, government expenditure or monetary variables. Theirs was a competitive theory of economic °uctuations and thus the equilibria were Pareto optimal. However, as Long and Plosser (1983) states `models of this type provide useful, well-de¯ned benchmark for evaluating the importance of other factors (e.g. monetary disturbances) in actual business-cycle episodes.' Many extentions have been made to the traditional RBC models, particularly the role of government[2], role of money[3], incorporation of distortionary taxes[4] and open economy extensions[5].

In the world economy, most countries exhibit well-de¯ned empirical regularities not only in the domestic indicators of economic activity, but also in key international indicators. Backus and Kehoe (1989) and Backus, Kehoe and Kydland (1994) well document the historical evidence on the international aspects of the business cycle. The signi¯cant stylised facts typical of modern open economies are: (1) national savings and investment are positively correlated, (2) after an increase in output, the country's net foreign asset position deteriorates, and (3) the current account and the trade balance tend to move counter cyclically.

More recently, e®orts have been made to develop a new workhorse model for open-economy macroeconomic analysis. Obstfeld and Rogo® (1995) is commonly recognised as the contribution that launched this new wave of research. The unifying feature of this emerging literature is the introduction of nominal rigidities and market imperfections into a dynamic general equilibrium model with well-speci¯ed microfoundations. The presentation of explicit and pro¯t maximising problems provides welcome clarity and

[1] Like Kydland and Prescott (1982), Long and Plosser (1983) and Hansen (1985)

[2] See Mankiw (1989), Christiano and Eichenbaum (1992), McGrattan (1994), Cooper (1997).

[3] See King and Plosser (1984), Cooley and Hansen (1989).

[4] See Braun (1994). However, McGrattan (1994) found that capital and income tax rate shocks do not contribute much to business cycle variability.

[5] See Mendoza (1991), Lundvik (1992), Correia et al. (1995).

analytic rigor. Moreover, it allows the researcher to conduct welfare analysis, hence laying the groundwork for credible policy evaluation. The presence of nominal rigidities and market imperfections alters the transmission mechanism for shocks and also provides a more potent role for monetary policy. One of the goals of this new strand of literature is to provide an analytic framework that is relevant for policy analysis and offers a superior alternative to the Mundell-Fleming model that is still widely employed in policy circles as a theoretical reference point.

The choice of the exchange rate regime is a special case of the general issue of optimal monetary policy in an open economy. Researchers have been prolific using the stochastic general equilibrium paradigm to investigate the performance of alternative open economy monetary policy rules, Benigno and Benigno (2000), analysis of alternative exchange rate regimes in terms of macroeconomic and welfare properties, Collard and Dellas (2002), Dellas and Tavlas (2002), Devereux and Engel (2001) and the welfare implications of different degrees on international policy coordination, Corsetti and Pesenti (2001a, 2001b), Canzoneri, Cumby and Diba (2002), Obsfeld and Rogoff (2001), Pappa (2001), to name a few. The message emerging from this literature regarding the value of the exchange rate instrument is mixed. The results depend on the currency denomination of trade, the structure of financial markets, the type of policy rule considered and the difference in size across countries.

As Lucas (1980) notes, "One of the functions of theoretical economics is to provide fully articulated, artificial economic systems that can serve as laboratories in which policies that would be prohibitively expensive to experiment with in actual economies can be tested out at much lower cost." However, incorporating more and more features of the real world increases the complexity of models exponentially. Most of the open economy dynamic general equilibrium models of today are highly non-linear. These models cannot be solved analytically, and most do not have closed form solutions. The usual approach is either to take linear approximation[6] around the steady-state-growth path or to solve them numerically, i.e. use algorithms to

[6]Unfortunately many 'linearised' versions of non-linear models have properties that are different from the original non-linear model. If these differences are due to the non-linearity itself, an important element of the original model is discarded

simulate the model economy. Economists prefer parsimonious models. As Friedman (1995) notes, repeated experience has shown that progress in economic science is possible only with heroic simplification. The reason is that the phenomena that economists attempt to study are very complex in comparison to the tools available at their disposal.

The challenge for modelers, therefore, has been to construct fully transparent macro models that pass the simplicity test and at the same time are reliable for forecasting and policy analysis. The model discussed in this paper is a micro founded general equilibrium open economy model based on optimising decisions of rational agents, incorporating money, government and distortionary taxes. The first order conditions are used to derive the behavioural equations of the model. However, we are modelling a medium-sized open economy so have a full blown model only for the domestic economy taking the world economy as given[7]. The interaction with the rest of the world comes in the form of UIP and current account which are explicitly micro-founded.

by linearisation.

[7] This assumtion is usually made for a small open economy.

2 The Model

Consider an economy populated by identical infinitely lived agents who produce a single good as output and use it both for consumption and investment. To simplify the notation we abstract from population growth and represent all variables in per capita terms. We assume that there are no market imperfections i.e., no frictions or transactions costs. At the beginning of each period `t', the representative agent chooses (a) the commodity bundle necessary for consumption during the period, (b) the total amount of leisure that she would like to enjoy during the period, and (c) the total amount of factor inputs necessary to carry out production during the period. All of these choices are constrained by the fixed amount of time available and the aggregate resource constraint that agents face. During the period `t', the model economy is influenced by various random shocks.

In an open economy goods can be traded but for simplicity it is assumed that these do not enter in the production process but are only exchanged as final goods. The consumption, C_t in the utility function below is composite per capita consumption, made up of agents consumption of domestic goods, C_t^d and their consumption of imported goods, C_t^f. [8] The composite consumption function can be represented as an Armington aggregator of the form

$$C_t = \left[\omega \left(C_t^d \right)^{-\rho} + (1 - \omega) \left(C_t^f \right)^{-\rho} \right]^{\left(\frac{-1}{\rho} \right)} \qquad (1)$$

where ω is the weight of home goods in the consumption function and σ, the elasticity of substitution is equal to $\frac{1}{1+\rho}$.[9]

The consumption-based price index that corresponds to the above specification of preference[10], denoted

[8] It is to be noted C_t^f is the same as IM_t

[9] The derivation of σ, the elasticity of substitution can be found in the foreign sector section of the paper.

[10] The consumption-based price index P_t is defined as the minimum expenditure that is necessary to buy one unit of the composite good C_t, given the price of the domestic good and foreign good.

P_t is derived as

$$P_t = \left[\omega^{\frac{1}{1+\rho}} \left(P_t^d \right)^{\frac{\rho}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}} \left(P_t^F \right)^{\frac{\rho}{1+\rho}} \right] \tag{2}$$

where P_t^d is the domestic price level and P_t^F [11] is the foreign price level in domestic currency.

Given the specification of the consumption basket, the agent's demand for home and foreign goods are a function of their respective relative price and the composite consumption

$$C_t^d = \left(\frac{P_t^d}{\omega P_t} \right)^{-\left(\frac{1}{1+\rho}\right)} C_t \tag{3}$$

$$C_t^f = \left(\frac{P_t^F}{(1-\omega) P_t} \right)^{-\left(\frac{1}{1+\rho}\right)} C_t \tag{4}$$

In a stochastic environment a consumer is expected to maximise her expected utility subject to her budget constraint. Each agent's preferences are given by

$$U = Max E_0 \left[\sum_{t=0}^{\infty} \beta^t u(C_t; L_t) \right] ; \qquad 0 < \beta < 1 \tag{5}$$

where β is the discount factor, C_t is consumption in period `t'[12], $L_t$ is the amount of leisure time consumed in period `t' and E_0 is the mathematical expectations operator. The essential feature of this structure is that the agent's tastes are assumed to be constant over time and is not influenced by exogenous

[11] $P_t^F = S_t P_t^f$ where S_t is the nominal exchange rtae and P_t^f is the foreign price level in foreign prices. So, P_t^F is the foreign price level in domestic prices.

[12] For the sake of convenience we shall use consumption in place of composite consumption through out the paper.

stochastic shocks. The preference ordering of consumption subsequences $[(C_t; L_t); (C_{t+1}; L_{t+1}); \ldots]$ does not depend on `t' or on consumption prior to time `t'. We assume that $u(C; L)$ is increasing in $(C; L)$ and concave- $u'(C; L) > 0$; $u''(C; L) < 0$. We also assume that $u(C; L)$ satisfies Inada-type conditions: $u'(C; L) \rightarrow \infty$ as $c \rightarrow 0$, and $u'(C; L) \rightarrow 0$ as $c \rightarrow \infty$; $u'(C; L) \rightarrow \infty$ as $l \rightarrow 0$, and $u'(C; L) \rightarrow 0$ as $l \rightarrow \infty$.

In a prototype RBC model with complete markets and the absence of any form of externality there is no role for the government. Still, one could think of a government providing public goods from the tax revenue it collects, although this is not really a stabilization role for the government. Incorporation of government expenditure (fiscal policy) into the RBC framework introduces a potential source of demand side disturbance to the basic model which is otherwise governed by supply side disturbances.

Following Lucas (1980, 1987), our model assumes money has value in exchange. In order to give value to money we need to introduce trading in decentralised markets. Here, to motivate the use of money a subset of consumption goods must be paid for with currency acquired in advance.[13] The cash-in-advance model is a convenient way for representing the aspects of classical monetary theory in the context of an intertemporal model.

The objective of this paper is to specify a fully articulated model of an open economy which we propose to calibrate/estimate using data for the UK. The model presented here is an enriched variant of a prototype RBC model embodying a representative agent framework as in McCallum (1989).

This paper is organised as follows. Section 2.1 specifies the optimisation problem faced by a representative household., Section 2.2 describes the governments' role in the model economy, Section 2.3 specifies the optimisation problem of the representative firm and Section 2.4 describes the foreign sector of the economy. Section 3 delineates the calibration of the model together with an explanation the solution algorithm used to solve the model numerically, Section 4 goes on to show the simulation results of the model. Finally,

[13] In cash-in-advance models, the market structure and households' constraint are altered vis-à-vis an Arrow-Debreu model in that at least some goods can be purchased only with currency accumulated in advance of shopping.

Section 5 states the main findings of the paper.

2.1 The Representative Household

The model economy is populated by a large number of identical household's who make consumption, investment, and labour supply decisions overtime. Each households objective is to choose sequences of consumption and hours of leisure that maximise its expected discounted stream of utility.[14] We assume a time-separable utility function of the form

$$U(C_t; 1 - N_t) = \theta_0 (1 - \rho_0)^{-1} C_t^{(1 - \rho_0)} + (1 - \theta_0)(1 - \rho_2)^{-1}(1 - N_t)^{(1 - \rho_2)} \tag{6}$$

where $0 < \theta_0 < 1$, and ρ_0, $\rho_2 > 0$ are the substitution parameters. This sort of functional form is common in the literature for example McCallum and Nelson, (1999a).The advantage of using this specification is that it does not restrict elasticity of substitution between consumption and leisure to unity.[15] Barro and King (1984) note that time-separable preference ordering of this form would not restrict the sizes of intertemporal substitution effects. However, time-separability constrains the relative size of various responses such as those of leisure and consumption to relative-price and income effects. As the authors argue, for the purpose of business cycle analysis, the presumption that departures from separability matters only for days and weeks and not for months or years is wholly justified. Macroeconomic analysis is primarily concerned with time periods such as quarters or years. Hence, time-separability of preferences is a reasonable approximation in this context.

Individual economic agents view themselves as playing a dynamic stochastic game. Changes in expectations about future events would generally affect current decisions. Individual choices at any given point

[14] The utility function is assumed to possess the following properties. The representative agent is assumed to derive positive, but diminishing marginal utility from the consumption of goods and leisure. The utility function is further assumed to be strictly concave in its arguments i.e., consumption and leisure. In addition we postulate that consumption and leisure are normal goods, meaning that they both increase with wealth.

[15] The Cobb-Douglas utility function is a special case of the CES utility function when $\rho_0 = \rho_2 = 0$.

in time are likely to be influenced by what agents believe would be their available opportunity set in the future. Each agent in our model is endowed with a fixed amount of time which she spends on leisure L_t and/or work N_t. If H_t, total endowment of time is normalised to unity, then it follows that

$$N_t + L_t = 1 \text{ or } L_t = 1 - N_t \tag{7}$$

Let us assume that ($\bar{l}$) is the normal amount of leisure which is necessary for an agent to sustain her productivity over a period of time. If an agent prefers more than normal amount of leisure say `$U_t$' she is assumed to be unemployed $\left(U_t = (1 - N_t) - \bar{l}\right)$ in this framework. An agent who chooses $U_t$ is entitled to an unemployment benefit `μ_t' from the state. It is assumed that $\mu_t < v_t$ (i.e., the consumer real wage as defined below) so that there is an incentive for the agent to search for a job. With the introduction of unemployment benefits substitution between work and leisure is higher.

The representative agents budget constraint is

$$\begin{gathered} (1+\phi_t)C_t + \frac{b_{t+1}}{1+r_t} + \frac{Q_t b^f_{t+1}}{(1+r^f_t)} + \frac{p_t S^p_t}{P_t} = \\ (1-\tau_{t-1})v_{t-1}N_{t-1} + \mu_{t-1}\left[(1-N_{t-1}) - \bar{l}\right] + b_t + Q_t b^f_t + \frac{(p_t+d_t)S^p_t}{P_t} \end{gathered} \tag{8}$$

where p_t denotes the present value of share, $v_t = \frac{W_t}{P_t}$[16] is the real consumer wage, $w_t = \frac{W_t}{P^d_t}$ is the producer real wage[17]. Consumption and labour income are taxed at rates ϕ_t and τ_t respectively, both of which are assumed to be stochastic processes. Also, $(1+\phi_t)C^d_t = \frac{M^{dp}_t}{P^d_t}$ i.e., representative agent's real

[16] $P_t = \left[\omega^{\frac{1}{1+\rho}}\left(P^d_t\right)^{\frac{\rho}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}}\left(P^F_t\right)^{\frac{\rho}{1+\rho}}\right]$

and W_t is nominal wage.

[17] Please note that consumers take into account domestic and foreign prices while evaluating their real wages. However, producers do not, this is because they do not use imported intermediate goods.

demand for domestic money is equal to consumption of domestic goods inclusive of sales tax. In a similar way, the agent's real demand for foreign money is equal to consumption of foreign goods inclusive of sales tax, $(1+\phi_t)C_t^f = \frac{M_t^{Fp}}{P_t^F}$.[18] This follows from the fact that consumption in this framework is treated as a 'cash good' i.e., the cash-in-advance constraint is binding only in the case of consumption. Investment is treated as a credit good. b_t^f denotes foreign bonds, b_t domestic bonds, S_t^p demand for domestic shares and Q_t is the real exchange rate.

One way of looking at the representative household's budget constraint is to think of time being divided into two subperiod. In the first subperiod the household receives labour income (net-of-tax) $(1-\tau_{t-1})v_{t-1}N_{t-1}$, bond income due from previous period, both domestic b_t, and foreign $Q_t b_t^f$, unemployment benefits from the government, $\mu_{t-1}\left[(1-N_{t-1})-\bar{l}\right]$ and dividends, d_t from its investment in shares, S_t^p, i.e., $\left(\frac{p_t+d_t}{P_t}\right)S_t^p$. In the second subperiod she buys goods with the help of currency carried forward from the first subperiod and undertakes financial transaction i.e., purchases shares and government bonds.

In a stochastic environment the representative agent maximizes her expected discounted stream of utility subject to her budget constraint. The Lagrangian associated with this problem is:

$$U = \operatorname{Max} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\theta_0 (1-\rho_0)^{-1} C_t^{(1-\rho_0)} + (1-\theta_0)(1-\rho_2)^{-1}(1-N_t)^{(1-\rho_2)} \right] \right\} \tag{9}$$
$$+\lambda_t \left\{ \begin{array}{c} (1-\tau_{t-1})v_{t-1}N_{t-1} + \mu_{t-1}\left[(1-N_{t-1})-\bar{l}\right] + b_t + Q_t b_t^f + \frac{(p_t+d_t)S_t^p}{P_t} - \\ (1+\phi_t)C_t - \frac{b_{t+1}}{1+r_t} - \frac{Q_t b_{t+1}^f}{(1+r_t^f)(1-rp)} - \frac{p_t S_t^p}{P_t} \end{array} \right\}$$

where 'λ' is the Lagrangian multiplier, $0 < \beta < 1$ is the discount factor, and $E(\bullet)$ is the mathematical expectations operator. The first order conditions with respect to C_t, N_t, b_t, b_t^f and S_t^p are:

[18] $M_t^{Fp} = S_t M_t^{fp}$

$$(1-\rho_0)\theta_0(1-\rho_0)^{-1}C_t^{-\rho_0} = \lambda_t(1+\phi_t) \tag{10}$$

$$(1-\rho_2)(1-\theta_0)(1-\rho_2)^{-1}(1-N_t)^{-\rho_2} = \beta E_t\lambda_{t+1}[(1-\tau_t)v_t - \mu_t] \tag{11}$$

$$\frac{\lambda_t}{1+r_t} = \beta E_t\lambda_{t+1} \tag{12}$$

$$\frac{\lambda_t Q_t}{(1+r_t^f)} = \beta E_t\lambda_{t+1}Q_{t+1} \tag{13}$$

$$\frac{\lambda_t p_t}{P_t} = \beta E_t\lambda_{t+1}\left(\frac{p_{t+1}+d_{t+1}}{P_{t+1}}\right) \tag{14}$$

The first of the above equations equates the marginal utility of domestic consumption to the shadow price of output. Note that sales tax impinges on this equation. The second equates the marginal disutility of labour to labour's marginal product - the real wage. The marginal product of labour is affected both by tax on labour and the unemployment benefit. From the representative household's first-order condition we know that supply of labour is positively related to the net-of-tax real wage and negatively related to the unemployment benefit. If the after-tax real wage is temporarily high, substitution effect overpowers the income effect. The increase in work effort raises employment and output. On the other hand unemployment benefits negatively impinge upon supply of work effort. These equations which are the stochastic analogue of the well known Euler equations which characterizes the expected behavior of the economy, determine the time path of the economy's values of labour, consumption, and investments (in financial assets).

Substituting equation (8) in (6) yields [19] :

$$(1 + r_t) = \left(\frac{1}{\beta}\right)\left(\frac{C_t}{C_{t+1}}\right)^{-\rho_0}\left(\frac{1+\phi_{t+1}}{1+\phi_t}\right) \tag{15}$$

Now substituting (6) and (8) in (7) yields

$$(1 - N_t) = \left\{\frac{\theta_0 C_t^{-\rho_0}\left[(1-\tau_t)\,v_t - \mu_t\right]}{(1-\theta_0)(1+\phi_t)(1+r_t)}\right\}^{\frac{-1}{\rho_2}} \tag{16}$$

where v_t (consumer real wage) enters the labour supply equation, so that

$$\log v_t^* = \log W^* - \left[\frac{\omega^{\frac{1}{1+\rho}}}{\omega^{\frac{1}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}}}\log P_t^d + \frac{(1-\omega)^{\frac{1}{1+\rho}}}{\omega^{\frac{1}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}}}\log P_t^F\right]$$

Also given that $\log W_t = \log w_t + \log P_t^d$, (producer real wage) and using $\log Q_t = \log P_t^F - \log P_t$, then $\log v_t^* = \log w_t^* - \frac{(1-\omega)^{\frac{1}{1+\rho}}}{\omega^{\frac{1}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}}}\log Q_t$. Therefore (12) becomes

$$(1 - N_t) = \left\{\frac{\theta_0 C_t^{-\rho_0}\left[(1-\tau_t)\exp\left(\log w_t^* - \frac{(1-\omega)^{\frac{1}{1+\rho}}}{\omega^{\frac{1}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}}}\log Q_t\right) - \mu_t\right]}{(1-\theta_0)(1+\phi_t)(1+r_t)}\right\}^{\frac{-1}{\rho_2}} \tag{17}$$

If each household can borrow an unlimited amount at the going interest rate, then it has an incentive

[19] All future values are expected - for convenience expectations operator is dropped.

to pursue a Ponzi game. The household can borrow to finance current consumption and then use future borrowing to roll over the principal and pay all of the interest. To prevent the household from playing a Ponzi game it is further assumed that the household's decision rule is subject to a transversality condition,

$$Y_{T-1} - r_T D_T - \phi_T C_T - \tau_T v_T N_T^s - T_T = C_T \tag{18}$$

Substituting (8) in (10) yields

$$p_t = \left(\frac{p_{t+1} + d_{t+1}}{(1 + r_t)} \right) \frac{P_t}{P_{t+1}} \tag{19}$$

Using $p_{t+1} = \frac{p_{t+2} + d_{t+2}}{(1+r_{t+1})} \frac{P_{t+1}}{P_{t+2}}$ in above, yields

$$p_t = \left(\frac{p_{t+2} + d_{t+2}}{(1 + r_t)(1 + r_{t+1})} \right) \left(\frac{P_t}{P_{t+2}} \right) + \left(\frac{d_{t+1}}{1 + r_t} \right) \left(\frac{P_t}{P_{t+1}} \right) \tag{20}$$

Using the arbitrage condition and by forward substituting the above yields to

$$p_t = \sum_{i=1}^{\infty} \frac{d_{t+i}}{(1 + r_t)^i} \left(\frac{P_t}{P_{t+i}} \right) \tag{21}$$

The above equation states that the present value of a share is simply discounted future dividends.

In small open economy models the domestic real interest rate is equal to the world real interest rate, which is taken as given. Further, it is assumed that the economy has basically no effect on the world rate because, being a small part of the world, its affect on the world savings and investment is negligible. These assumptions imply that the real exchange rate for the small open economy is constant. However, we are modelling a medium sized economy. In our set up the economy is small enough to continue with the assumption that world interest rates are exogenous but large enough for the domestic rate to deviate from the world rate. Hence, in our model real exchange rates are constantly varying.

To derive the uncovered interest parity condition equation (3) is substituted into (9)

$$\left(\frac{1+r_t}{1+r_t^f}\right) = \frac{Q_{t+1}}{Q_t} \tag{22}$$

In logs this yields to

$$r_t = r_t^f + E_t \Delta \log Q_{t+1} \tag{23}$$

3 The Government

In this framework it is assumed that the government spends current output according to a non-negative stochastic process that satisfies $G_t \le Y_t$ for all `t'. The variable $G_t$ denotes per capita government expenditure at `t'. It is also assumed that government expenditure does not enter the agents objective function. In the case of equilibrium business cycle models embodying rational expectations, output is always at its `desired' level. Given the information set, agents are maximizing their welfare subject to their constraints. Since there are no distortions in this set-up government expenditure may not improve welfare through its stabilization program. This is why government expenditure has been excluded from the representative agent's utility function. As stated above the state also pays out unemployments benefits μ_t which leads to higher substitution between work and leisure.

The government finances its expenditure by collecting taxes on labour income, τ_t, and taxes on consumption, ϕ_t, which are assumed to be stochastic processes. Also, it issues debt, bonds (b_t) each period which pays a return next period. Then, it collects seigniorage, i.e., $\frac{M^d_{t+1} - M^d_t}{P^d_t}$ which is assumed to act as a lump-sum tax, leaving real asset prices and allocation unaltered and is assumed to be a stochastic process.

Tax on labour income , since it reduces the after-tax return accruing to an agent from supplying labour in the market, is likely to affect her choice as to how much of labour to supply at a given point in time. By reducing the take-home wage, the labour income tax reduces the opportunity cost of leisure, and there is a tendency to substitute leisure for work. This is the substitution effect, and it tends to decrease labour supply. At the same time, the tax reduces the individual's income. Given that leisure is a normal good, this loss in income leads to a reduction in consumption of leisure, *ceteris paribus*. The income effect tends to induce an individual to work more. It is the relative strengths of the income and substitution effects which would ultimately determine whether an agent would work more or less.

Tax on consumption are similar to income tax in the sense that they are imposed on flows generated in the production of current output. However, income tax is imposed on the net income received by agents whereas sales tax is imposed by the state on the sales of business firms.

The government budget constraint is:

$$G_t + b_t + \mu_t\left[(1 - N_t) - l\right] = \tau_{t-1}v_{t-1}N_{t-1} + \chi_{t-1}C_{t-1} + \frac{b_{t+1}}{1 + r_t} + \frac{M^d_{t+1} - M^d_t}{P^d_t} \qquad (24)$$

where b_t is real bonds and P^d_t is the domestic price level. Note that $\tau_{t-1}v_{t-1}N_{t-1} + \chi_{t-1}C_{t-1}$ is the total tax revenue collected by the state. Also, the government faces a cash-in advance constraint, i.e.:

$$P^d_t G_t \leq M^{dg}_t \qquad (25)$$

where M^{dg}_t is government's demand for domestic money. Here we assume that the government has home bias, i.e. it consumes only domestic goods.

3.1 The Representative Firm

Firms rent labour and buy capital inputs from households[20] and transform them into output according to a production technology and sell consumption and investment goods to households and government. The interaction between firms and household is crucial, as it provides valuable insights for understanding the fluctuations of macroeconomic aggregates such as output, consumption and employment. The technology available to the economy is described by a constant-returns-to scale production function:

$$Y_t = Z_t f(N_t; K_t) \tag{26}$$

or

$$Y_t = Z_t N_t^{\alpha} K_t^{1-\alpha}$$

where $0 \leq \alpha \leq 1$, Y_t is aggregate output per capita, K_t is capital carried over from previous period $(t-1)$, and Z_t reflects the state of technology.

Proponents of RBC theory argue that technology shock displays considerable serial correlation, with their first differences nearly serially uncorrelated. In order to introduce high persistence, they assume that technology follows a stationary Markov process, meaning that its probability distribution is independent of anything prior to time $(t-1)$. Alternatively, one can think of technology evolving as a random walk motion without drift. The productivity term Z_t reflects the state of technology. As emphasized by Lucas and Stokey (1989), the timing of information and actions taken by agents in each period is important in this context. At the beginning of period `t' the current value of Z_t is realized. It follows that the agents already know the value of total output based on which they take consumption and investment (end-of-period stock of capital) decisions.

It is assumed that $f(N; K)$ is smooth and concave and it satisfies Inada-type conditions i.e., the marginal

[20] Households own shares in the firms and therefore own them.

product of capital (or labour) approaches infinity as capital (or labour) goes to 0 and approaches 0 as capital (or labour) goes to infinity.

$$
\begin{aligned}
\lim_{K \to 0} (F_K) &= \lim_{N \to 0} (F_N) = \infty \\
\lim_{K \to \infty} (F_K) &= \lim_{N \to \infty} (F_N) = 0
\end{aligned}
$$

The capital stock evolves according to:

$$
K_{t+1} = (1 - \delta) K_t + I_t \tag{27}
$$

where δ is the depreciation rate and I_t is gross investment.

In a stochastic environment the firm maximizes present discounted stream, V, of cash flows, subject to the constant-returns-to-scale production technology, i.e.

$$
\mathrm{Max} V = E_t \sum_{i=0}^{\infty} d_{it}^{i} (Y_t - K_t(r_t + \delta) - w_t N_t^d) \tag{28}
$$

subject to (26). Here r_t and w_t are the rental rates of capital and labour inputs used by the firm, both of which are taken as given by the firm. Output of the firm depends not only on capital and labour inputs but also on Z_t. The firm optimally chooses capital and labour so that marginal products are equal to the price per unit of input. The first order conditions with respect to K_t and N_t^d are as follows:

$$
K_t = \frac{(1 - \alpha) Y_t}{r_t + \delta} \tag{29}
$$

$$
N_t^d = \left(\frac{w_t}{\alpha Z_t} \right)^{\left(\frac{1}{\alpha - 1}\right)} K_t \tag{30}
$$

The non-negativity constraint applies i.e., $K_t \geq 0$.Firms own the capital stock and choose investment and domestic labour.

3.2 The Foreign Sector

As Obstfeld and Rogoff (1996) argue, relative prices are a central feature of open economy macroeconomics.

In particular the response of the trade balance to shocks on the terms of trade has preoccupied trade theorists for decades. In open economies a country's investment and consumption plans are no longer constrained by its own production frontier. As in Armington (1969), demand for products in this framework are distinguished not only by their kind but also by their place of production. The Armington assumption that home and foreign goods are differentiated purely because of their origin of production has been a workhorse of empirical trade theory.

In a stochastic environment the representative agent maximizes her expected discounted stream of utility subject to her budget constraint. In order to derive the real exchange rate and hence the balance of payments explicitly from micro-foundations we take into account the consumption constraint on the agent

$$P_t C_t = P_t^d C_t^d + P_t^F C_t^f \tag{31}$$

As noted earlier the consumption function is an Armington aggregator of the form

$$C_t = \left[\omega \left(C_t^d\right)^{-\rho} + (1-\omega)\left(C_t^f\right)^{-\rho}\right]^{-\left(\frac{1}{\rho}\right)} \tag{32}$$

where C_t is composite per capita consumption, made up of C_t^d, agents consumption of domestic goods and C_t^f, their consumption of imported goods and ω is the weight of home goods in the consumption function. The utility-based price index corresponding to the above consumption function is of the form

$$P_t = \left[\omega^{\frac{1}{1+\rho}} \left(P_t^d\right)^{\frac{\rho}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}} \left(P_t^F\right)^{\frac{\rho}{1+\rho}} \right] \tag{33}$$

Now the Lagrangian associated with the agent's maximisation subject to the budget as well as consumption constraint is :

$$\begin{aligned} U \;=\; & \operatorname{Max} E_0 \left\{ \sum_{t=0} \beta^t \left[\theta_0 (1-\rho_0)^{-1} C_t^{(1-\rho_0)} + (1-\theta_0)(1-\rho_2)^{-1} (1-N_t)^{(1-\rho_2)} \right] \right\} \\ & + \lambda_t \left\{ \begin{array}{c} (1-\tau_{t-1}) v_{t-1} N_{t-1} + \mu_{t-1} \left[(1-N_{t-1}) - \bar{l} \right] + b_t + Q_t b_t^f + \frac{(p_t+d_t) S_t^p}{P_t} - \\ (1+\phi_t) C_t - \frac{b_{t+1}}{1+r_t} - \frac{Q_t b_{t+1}^f}{(1+r_t^f)(1-rp)} - \frac{p_t S_t^p}{P_t} \end{array} \right\} \\ & + \lambda_t^c \left\{ P_t^d C_t^d + P_t^F C_t^f - P_t C_t \right\} \end{aligned} \tag{34}$$

The first order conditions with respect to C_t^d and C_t^f are

$$\theta_0 C_t^{-\rho_0} \frac{\partial C_t}{\partial C_t^d} - \lambda_t (1+\phi_t) \frac{\partial C_t}{\partial C_t^d} - \lambda_t^c P_t^d + \lambda_t^c P_t \frac{\partial C_t}{\partial C_t^d} \tag{35}$$

$$\theta_0 C_t^{-\rho_0} \frac{\partial C_t}{\partial C_t^f} - \lambda_t (1+\phi_t) \frac{\partial C_t}{\partial C_t^f} - \lambda_t^c P_t^F + \lambda_t^c P_t \frac{\partial C_t}{\partial C_t^f} \tag{36}$$

Dividing equation (36) by equation (35), we have[21]

[21] In equilibrium, terms of trade can be computed from the intra-temporal marginal rate of substitution between goods in the Armington aggregator function, see Backus, Kehoe and Kydland (1994). The marginal rate of substitution, i.e., the slope of the indifference curve is given by

$$\frac{P_t^F}{P_t^d} = \frac{\frac{\partial C_t}{\partial C_t^f}}{\frac{\partial C_t}{\partial C_t^d}} = \left(\frac{1-\omega}{\omega}\right) \left(\frac{C_t^d}{C_t^f}\right)^{1+\rho}$$

$$\frac{P_t^F}{P_t^d} = \frac{\frac{\partial C_t}{\partial C_t^f}}{\frac{\partial C_t}{\partial C_t^d}} \tag{37}$$

or

$$\frac{P_t^F}{P_t^d} = \left(\frac{1 - \omega}{\omega}\right)\left(\frac{C_t^d}{C_t^f}\right)^{1+\rho} \tag{38}$$

Now we can write equation (38) as

$$Q_t = \left(\frac{1 - \omega}{\omega}\right)(F)^{(1+\rho)} \tag{39}$$

where $Q_t = \frac{P_t^F}{P_t^d}$ and $F = \frac{C_t^d}{C_t^f}$

Elasticity of substitution between home goods and imported foreign goods is given by

$$\sigma = \left(\frac{\partial F}{\partial Q}\right)\left(\frac{Q}{F}\right) = \frac{1}{1+\rho} \tag{40}$$

Substituting (40) in (39) we have the real exchange rate

$$Q_t = \left(\frac{1 - \omega}{\omega}\right)\left(\frac{C_t^d}{C_t^f}\right)^{(\frac{1}{\sigma})} \tag{41}$$

To the extent that home and imported goods are not perfect substitutes, σ will take some finite value.

The lower the estimated σ means the less the substitution between the two goods. In other words the greater the degree of product differentiation, the smaller the elasticity of substitution between the products.

From the real exchange rate equation we can derive import equation for our economy. Taking logs of equation (41) we have

$$\log IM_t = \sigma \log \left(\frac{1 - \omega}{\omega} \right) + \log C_t^d - \sigma \log Q_t \tag{42}$$

Note that $IM_t = C_t^f$.

To derive the import function we need to substitute out for $\log C_t^d$ From the household's expenditure minimisation we know

$$C_t^d = \left(\frac{P_t^d}{\omega P_t} \right)^{-\left(\frac{1}{1+\rho}\right)} C_t \tag{43}$$

Taking logs

$$\log C_t^d = \sigma \log \omega + \sigma \log P_t - \sigma \log P_t^d + \log C_t \tag{44}$$

Now substituting equation (44) in equation (42), we have

$$\log IM_t = \sigma \log (1 - \omega) + \log C_t - \sigma A \log Q_t \tag{45}$$

$$A = \frac{\omega^{\frac{1}{1+\rho}}}{\omega^{\frac{1}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}}} \tag{46}$$

The equation states that imports into the country are positively related to the total consumption in the home country and negatively related to the real exchange rate, i.e. as Q_t increases that is the currency depreciates, import demand falls.

Now an Armington aggregator consumption function and a corresponding real exchange rate equation exists for the foreign country as well.

$$C_t^F = \left[\omega^f \left(C_t^{df}\right)^{-\rho_3} + \left(1-\omega^f\right)\left(C_t^{ff}\right)^{-\rho_3}\right]^{-\frac{1}{\rho_3}} \tag{47}$$

$$Q_t^f = \left(\frac{1-\omega^f}{\omega^f}\right)\left(\frac{C_t^{df}}{C_t^{ff}}\right)^{\frac{1}{\sigma_1}} \tag{48}$$

where C_t^F is the composite consumption of the foreign country, C_t^{df} is the foreign country's consumption of own goods, C_t^{ff} is the foreign country's consumption of home goods, ω^f is the weight of foreign country's own goods in its composite consumption function, Q_t^f is the real exchange rate for the foreign country[22], $\sigma_1 = \frac{1}{1+\rho_3}$ is the elasticity of substitution between home goods i.e. home exports and foreign country's own goods.

Taking logs of equation (48)

[22] Please note $Q_t^f = \frac{1}{Q_t}$

$$\log EX_t = \sigma_1 \log \left(\frac{1 - \omega^f}{\omega^f} \right) + \log C_t^{df} + \sigma_1 \log Q_t \tag{49}$$

Note that $EX_t = C_t^{ff}$ and $Q_t^f = \frac{1}{Q_t}$.

To derive the export function we need to substitute out for $\log C_t^{df}$. As before, from the foreign household's expenditure minimisation we know

$$C_t^{df} = \left(\frac{P_t^{df}}{\omega^f P_t^{*}} \right)^{-\left(\frac{1}{1+\rho}\right)} C_t^F \tag{50}$$

where P_t^{*}, is the foreign C.P.I of the form

$$P_t^{*} = \left[\left(\omega^f\right)^{\frac{1}{1+\rho}} \left(P_t^{df}\right)^{\frac{\rho}{1+\rho}} + \left(1 - \omega^f\right)^{\frac{1}{1+\rho}} \left(P_t^D\right)^{\frac{\rho}{1+\rho}} \right] \tag{51}$$

where P_t^{df} is the foreign country's own price level and P_t^D [23] is the domestic price level in foreign currency.

Taking logs of equation (50)

$$\log C_t^{df} = \sigma_1 \log \omega^f + \sigma_1 \log P_t^{*} - \sigma_1 \log P_t^{df} + \log C_t^F \tag{52}$$

Substituting equation (52) in equation (49)

[23] $P_t^D = \frac{P_t^d}{S_t}$ where S_t is the nominal exchange rate and P_t^d is the domestic price level in domestc prices. So, P_t^D is the domestic price level in foreign prices.

$$\log EX_t = \sigma_1 \log\left(1 - \omega^f\right) + \log C_t^F + \sigma_1 A^f \log Q_t \tag{53}$$

$$A^f = \frac{\left(\omega^f\right)^{\frac{1}{1+\rho}}}{(\omega^f)^{\frac{1}{1+\rho}} + (1 - \omega^f)^{\frac{1}{1+\rho}}} \tag{54}$$

The equation states that exports of the home country are a positive function of the total consumption in the foreign country and also a positive function of the real exchange rate. If Q_t increases, i.e. the home currency depreciates then exports will increase.

In the model home and foreign agents need foreign and home money respectively, in order to transact with each other. The foreign agents need home money to buy our exports, but get home money for imports as well as our purchase of foreign bonds. So their net supply of foreign money is equal to net exports plus sales of foreign bonds i.e. the balance of payments surplus. This surplus is equal to the home agents net demand for foreign money, who get foreign money from firms exporting to foreign agents and need foreign money for imports and purchases of foreign bonds. So if home agents adjust their sales of foreign bonds then all balances. In equilibrium it is assumed that exports and imports are equal and hence the agents would have no tendency to change their asset position. In disequilibrium the changes between domestic and foreign bonds will depend upon net exports.

$$NX_t = EX_t - IM_t \tag{55}$$

Foreign bonds thus evolve over time according to the following equation

$$b_{t+1}^{f} = (1 + r_t^{f})b_t^{f} + NX_t \tag{56}$$

4 Calibration and Solution Algorithm

Macroeconomic analysis has come a long way since the optimizing behavior of economic agents was explicitly incorporated in models attempting to explain fluctuations and growth. Initial work dealt with dynamic but deterministic models which admitted analytical solutions, at least for the case of homogeneous agents. Then came the need to use stochastic control techniques to try to explain fluctuations in a linear quadratic setup, again allowing for an analytical solution. Later on the requirement to work in a general equilibrium environment led to models with no analytical solution. For a number of years a variety of numerical methods to simulate model economies have been proposed and reviewed in the literature. This section discusses the issues related to calibration and to the method used to solve our macro-models.

4.1 Calibration

In order to carry out model simulations, numerical values should be assigned to the structural parameters of the models.[24] These value, such as for example the output elasticity of the production factors, the degree of risk-aversion or the elasticity of intertemporal substitution, are taken from micro data estimates or from some casual empirical characteristics for the economy which is to be studied. For instance Kydland and Prescott (1982) derive values for some of the remaining structural parameters so that their steady-state levels match sample averages observed in actual time series data.

The exogenous stochastic processes should also be calibrated. However, it is hard to find information from a real economy concerning the stochastic structure of technology shocks, shocks to preferences, error of controlling money growth or tax revenues, or the correlations among them. For this purpose, persistence properties in actual time series data can be used to calibrate some aspects of the model. For instance, in the simplest business cycle model, an AR(1) model is assumed for productivity shocks, with the coefficient generally chosen so that the simulated output series exhibits persistence similar to the GNP series in actual

[24] See appendix to the paper to see values of the parameters used.

economies.

A quite di®erent strategy seeks to use the simulated time series to estimate some or all structural parameters through a formal method like the Maximum Likelihood Method (MLM). These more standard econometric procedures choose values for all parameters by optimizing a given criterion - the likelihood of the data, in the case of MLM. This procedure has two main advantages: it avoids a possibly arbitrary selection of parameter values, and it provides a measure of dispersion that can be used to evaluate the goodness of ¯t of model to data.

As initial starting value the parameters in each models have been calibrated to match historical data. This method has found to produce low bias.

4.2 Model Solution and Algorithm

In solving our model, we are forced by its complexity and non-linearity to use a computer algorithm. We must note at the outset that in a rational expectations models, the forward expectations terms tend to induce unstable roots and it is therefore necessary for a model to have a stable well-defined long run, or saddlepath, if a solution to the model is to be obtained. The solving procedure must be therefore be subject to the terminal conditions that beyond some terminal date, N, all the expectational variables are set to their equilibrium values, this ensures that the algorithm will pick the unique stable path. In any case, it is necessary for the terminal date to be "large", in order to reduce the sensitivity of the model to variations in the terminal date. The justification for this is that non-convergent behaviour of the system would provoke behaviour by economic agents different from that assumed in the model (Minford, 1979). It is also of interest to know if the model settles down to a new equilibrium following a shock. As pointed out by Matthews and Marwaha (1979), the actual value of the terminal condition can be derived from the long run equilibrium condition of the model. In some cases, the steady-state properties of the model can be used to choose the terminal conditions of the model, although several other method can be easily used (see Whitley 1994 for a review).

There are several of iterarive methods, but the most common is the Gauss-Seidel method. This iterative method[25] is built in the program developed by Matthews (1979) and Minford et al. (1984) called RATEXP which has been used to get the model solution. The computer programme typically uses a backward-solving (dynamic programming) technique. However, unlike the classical dynamic programming, the solution vector is approached simultaneously for all $t = 1; 2; ...T$; but convergence follows a backward process. The problem lies in that the model must firstly obtain a dynamic solution for a given time span using initial 'guess' values of the expectational variables. These initial values are then adjusted in an iterative manner until convergence is obtained. After checking for equality between expectations and the solved forecasts, the

[25] The programme also has the option of using the Powell (1964) conjugate quadratic convergence. Despite its robustness this routine usually requires more function evaluations than the Jacobi method.

initial expectations set is gradually altered until convergence is obtained. In effect this endogenises the expectational variables in that period. Our model is highly non-linear, consequently a larger number of iterations are required compared to linear models.[26]

In order to understand how the algorithm works, consider a set of simultaneous non-linear structural equations written in implicit form:

$$F\{y(t);\ y(t-1);\ x(t);\ u(t)\} = 0 \tag{44}$$

where, as before $y(t)$ is a vector of endogenous variables, $y(t-1)$ is a vector of lagged endogenous variables, $x(t)$ is a vector of exogenous variables, and $u(t)$ is a vector of stochastic shocks with mean zero and constant variances. $F(\cdot)$ represents a set of functional forms. Setting the disturbance terms equal to their expected values and solving for the reduced form, we have

$$y_t = H\{x(t);\ y(t-1)\} \tag{45}$$

where $H(\cdot)$ is the reduced form functional form. Partitioning equation (45) so as to distinguish between endogenous variables on which expectations are formed $y(2)$ and the others $y(1)$, we have

$$y1(t) = h1\{x(t);\ y1(t-1)\} \tag{46a}$$

$$y2(t) = h2\{x(t);\ y2(t-1);\ E[y2(t+j)/t]\} \tag{46b}$$

where $E[y2(t+j)/t]$ denotes the rational expectation of $y(2)$ formed in period $t+j$ based on information available at t. Our programme uses starting values for the vector $E[y2(t+j)/t]$ which, together with values

[26] It should be noted that in general a non-linear model does not have a unique reduced form. Further, when a non-linear model is solved in a deterministic manner the solution values of the endogenous variables are not in general equal to their expected values. A correct solution requires stochastic simulation.

for the `fully' exogenous variables, are assumed to extend over the whole solution period. The algorithm ensures that the expectational values stored in the vector $E[y2(t+j)/t]$ converge to the values predicted by the model for $y(2)$ in period $t+j$.

For simplicity, let us assume that the solution period extends from $t = 1, \ldots, T$, and that expectations are formed for one period ahead only. Equation (4.4.2) can therefore be written as

$$y2(t) = f\{x(t);\ y2(t-1);\ E[y2(t+1)/t]\} \tag{46c}$$

where $f(\cdot)$ equals $h2(\cdot)$ and $t = 1, \ldots, T$.

The convergence of the expectational values towards the model's predicted values follows a Jacobi algorithm, which can be described as

$$\begin{aligned} E[y2(t;\ k+1)/t-1] &= E[y2(t;k)/t-1] + q\{y2(t;k) - E[y2(t;k)/t-1]\} \\ 0 &< q < 1;\ t = 1, 2, \ldots, T \end{aligned} \tag{47}$$

for the k^{th} iteration, with the objective of minimising the residual vector $R(t)$, defined as

$$R(t) = \text{abs}\{y2(t) - E[y2(t)/t-1]\} < L; \qquad t = 1, 2, \ldots, T \tag{48}$$

where q is the step length and L is some pre-assigned tolerance level.

Since $E[y2(t)/t-1]$ is stored in period $t-1$, the end period expectational variable remains undetermined. We require a value for $y2(T+1)$ which lies outside the domain of the solution period. The technique used in our programme consists of imposing a set of terminal conditions on the rationally expected variables.[27]

[27] In a rational expectations model, the forward expectations terms tend to induce unstable roots. The use of terminal conditions has the effect of setting the starting values of the unstable roots to zero asymptotically, thereby ruling out unstable paths.

Terminal conditions are a necessary constraint from the point of view of numerical solution and can be rigorously justified in optimisation models where transversality conditions form part of the solution (see Sargent, 1987). It is necessary for the terminal date to be large, in order to reduce the sensitivity of the model to variations in the terminal date. For models which possess a long run steady state solution, the expectational variables must be set to their long run equilibrium values. This ensures that the algorithm will pick the unique stable path.

In sum, the complete algorithm can be described in the following series of steps;

Step1. Solve the model given initial values for the expectational variables.

Step 2. Check for convergence.

Step 3. Adjust expectational variables.

Step 4. Re-solve the model given the new iterated values of the expectational variables.

4.3 Steady State Equations of the model

$\beta = \frac{1}{1+r_t}$

$\overline{M} = (1+\phi)CP + GP$

$p = \frac{d}{1+r}$

$Y = ZN^{\alpha}K^{(1-\alpha)}$

$N = \frac{\alpha Y}{w^*}$

$K = \frac{(1-\alpha)Y}{r+\delta}$

$Y = C + I + G + NX$

$I = \delta K$

$w = w^*$

$rb = -PD$

$1 - N = \left(\frac{\theta_0 C^{-\rho_0}[(w^* - (1-h)Q)(1-\tau) - \mu]}{(1-\theta_0)(1+\phi)(1+r)} \right)^{-\frac{1}{\rho_2}}$

$d = \frac{Y - w^*N - (r+\delta)K}{\overline{S}}$

$PD = G + \mu(1 - N - \bar{l}) - \tau\nu N - \phi C - T$

$r = r^f$

$r^f b^f = NX$

$\log Q = \log S$

$Y - (1+\phi)C - \tau\nu N - T = rD$

5 Simulations

Once the model has been solved numerically, one can analyse the characteristics of the transition of the model to its steady-state. This may arise either because initially the economy is outside steady-state or because some structural change is introduced (it could be a policy intervention) altering the steady-state. This type of analysis is crucial, among other things, to evaluate the possible e®ects of change in policy rules i.e., of policy interventions and to assess the overall properties of the model.

Standard simulation methods consist of comparing the solution of the model with one where one or more of the exogenous variables are perturbed. Comparing the base and perturbed solutions gives an estimate of the policy multiplier(s) if the exogenous variable perturbed is a policy instrument. In other words, comparing the results of simulation experiments with those obtained in the base run provides valuable information regarding the e®ects of policy changes on the economy.

There is also the question of selection of the length of the simulation period. The period should be long enough for the e®ects of changes to work through the model. This is especially important in models which contain long lags or slow rate of adjustment. Darby et al. (1999) lists two advantages of having a long simulation period. First, when solving non-linear rational expectations models it is important to ensure that the terminal date for the simulation is su±ciently far in the future so that the simulation is una®ected by the choice of terminal date. Second, simulating the model over a long period makes it easier to observe the long-run solution of the model.

Our simulations start in 1986 (quarter 2 in the appendix) and end in 2000 using quarterly UK data. Results of our simulation exercise are reported in graphical form in the appendix.[28] The charts show the percentage deviation of a particular variable - real output, price level, and so on - from the baseline path except in the case of interest rates where it shows percentage point deviations from the baseline.

[28] The base run solution for our model is reported in appendix 4.0.

5.1 Results

The effects of both demand and supply shocks on the behaviour of output, consumption, capital stock, investment, employment, price level, real wage, real interest rate, imports, exports, and real exchange rate is examined by deterministically simulating the calibrated model using the extended path method discussed earlier. In addition to providing quantitative input to policy analysis these deterministic simulations provide useful insights into the dynamic properties of the model. These insights prove helpful when interpreting more complex stochastic simulations.

For the baseline simulation - that is, the simulation with no change in policy instruments - the endogenous variables are set so as to track the actual historical values perfectly. This is done by adding residuals to each equation. The residuals are computed as if the future expectations of the endogenous variables that appear in the model are equal to the actual values. These residuals therefore include not only the shocks to the equations, but also the forecast errors.

5% Permanent increase in Money Supply[29]

Consider the case of an unanticipated 5% permanent increase in the level of the money supply relative to the historical baseline. The predictions of the model for the case of an increase in the money supply are shown in Fig 1 in the appendix. Although unanticipated at the time of the initial increase, the entire path of the money supply is assumed to be incorporated into agent's forecasts as of the first quarter of the simulation. In particular, people know that the increase in money is permanent. In the very first quarter of the simulation price level increases by 5% and the nominal exchange rate also increases by 5%. Real output, the components of real spending, real interest rates, real exchange rate, imports, exports and bond holdings of agents are unaffected by the money expansion. In the model money is neutral, as there are no nominal rigidities enabling agents to make instantaneous adjustments.

[29]Notice that at times there is a jump at the end of the simulation period. This is where the terminal condition cuts in and so variables are forced to close their path down fast.

1% p.a. Productivity Growth Shock

Consider the case of an unanticipated 1% per annum growth shock to productivity till year five and then 5% permanent increase in the level of productivity relative to the base from the fifth year onwards. So productivity grows at 1% in the first year, 2% in the second year and so on till the fifth year when it grows at 5%. After that it is permanently 5% above the base. Although unanticipated at the time of the initial increase, the entire path of productivity spurt is assumed to be incorporated into agent's forecasts as of the first quarter of the simulation. The predictions of the model for the case of an increase in productivity are shown in Fig 2 in the appendix.

The productivity burst raises permanent income and also stimulates a stream of investments to raise the capital stock in line. Output however cannot be increased without increased labour supply and extra capital, which is slow to arrive. Thus the real interest rate must rise to reduce demand to the available supply. The rising real interest rate violates Uncovered Real Interest Parity (URIP) which must be restored by a rise in the real exchange rate relative to its expected future value. This rise is made possible by the expectation that the real exchange rate will fall back steadily, so enabling URIP to be established consistently with a higher real interest rate. As real interest rates fall with the arrival on stream of sufficient capital and so output, the real exchange rate also moves back to equilibrium.

5% Permanent increase in Unemployment Benefits

Consider the case of an unanticipated 5% permanent increase in unemployment benefits. The predictions of the model are shown in Fig 3 in the appendix. A permanent unanticipated increase in unemployment benefits reduces labour supply, reduces the level of output from first the simulation period. Also investment declines causing capital stock to fall. Prices rise and currency depreciates, canceling each other and hence having no impact on real exchange rate, imports and exports.

Benefits systems affect the decision of private agents to participate in the labour market. Unemployment benefits act as a floor on wage demands creating a downward rigidity in wages. This reduction in wage

°exibility prevents adjustment, and so the labour market in response to new shocks which require wage falls - instead generates falling employment and rising unemployment. In other words, unemployment bene¯ts have the e®ect of reducing the downward pressure on wages that normally would accompany an increase in unemployment.

5% Permanent increase in Labour Income Tax

Consider the case of an unanticipated 5% permanent increase in labour income tax. The predictions of the model are shown in Fig 4 in the appendix. An unanticipated permanent increase in income tax reduces labour supply (raises the level of unemployment), which leads to a fall in the level of output and an increase in the price level from the ¯rst simulation period. As output falls, investment in the economy reduces, leading to declining capital stock. The initial fall in the interest rates causes a real and nominal depreciation leading to improvement of the trade balance. However, as wages start declining, after the initial jump in the light of increment in labour income tax, labour supply, output and investment expand. This pushes up the real interest rates, leading ultimately to a real appreciation and a deteriorating trade balance.

An increase in income tax produces a substitution e®ects which outweighs the income e®ect of the tax. The increase in tax tends to discourage supply of labor because of the wedge it creates between pre and post-tax return on labor. Further, the impact of changes in income taxes depends on how these tax changes are perceived. If a tax increase in the current time period is deemed permanent agents would react with the expectation that current disposable income would be lesser and thus alter consumption plans, an inward shift in the household budget constraint.

5% Permanent increase in Consumption Tax (VAT)

Consider the case of an unanticipated 5% permanent increase in consumption tax. The predictions of the model are shown in Fig 5 in the appendix. An unanticipated permanent increase in consumption tax raises the level of unemployment and reduces the level of output. With the fall in output, investment in the economy declines and hence capital stock also reduces. In both consumption and labour income tax simulations labour supply falls as a result of substitution effect outweighing income effect. Consumption tax discourages spending and hence we observe a fall in the price level. As price level falls, the currency appreciates.

5% Permanent increase in the Foreign Interest Rate

Consider the case of an unanticipated 5% permanent increase in the foreign price level. The predictions of the model are shown in Fig 6 in the appendix. An unanticipated permanent increase in the foreign interest rate, through the uncovered interest rate parity leads to a depreciation of the real as well as nominal exchange rate. This of course leads to a fall in imports and rise in exports as domestic goods are now more competitive in the world markets. As domestic interest rates catch up with the foreign rates, real and nominal exchange rates appreciate leading ultimately to a small deterioration in the trade balance. With the increase in the cost of capital, investment receives a big blow, falling by nearly 13% in the first period and then gradually coming back to equilibrium. Capital stock falls, output falls and price level increases. Movements in consumption are a mirror image of the movements in the price level.

5% Permanent increase in the Foreign Price Level

Consider the case of an unanticipated 5% permanent increase in the foreign price level. The predictions of the model are shown in Fig 7 in the appendix. An unanticipated permanent increase in foreign prices leads to an immediate 5% appreciation of the pound sterling. The appreciation is instantaneous due to the model having a flexible exchange rate together with absolutely no nominal rigidity. The price level does not change as the movement in opposite direction of foreign prices and nominal exchange rate cancel each other out.

6 Conclusion

In this paper we have built a micro founded general equilibrium open economy model based on optimising decisions of rational agents, incorporating money, government and distortionary taxes. The ¯rst order conditions of the household and ¯rm optimisation problem are used to derive the behavioural equations of the model. We are modelling medium-sized open economy, so have a full blown model only for the domestic economy taking the world economy as given. The interaction with the rest of the world comes in the form of uncovered-interest rate-parity and current account, both of which are explicitly micro-founded.

The objective of this paper is to specify a fully articulated model of an open economy which we propose to calibrate/estimate using data for the UK. The model presented here is an enriched variant of a prototype RBC model embodying a representative agent framework as in McCallum (1989).

The paper has also explained the solution method used to solve our dynamic stochastic general equilibrium model. We have also discussed in detail an algorithm developed by the Liverpool Research Group which we have used to solve our complex non-linear model. Finally, the paper has discussed the simulation results for both demand and supply shocks with calibrated parameters which were used to assess the overall properties of the model. The results are consistent with our theoretical priors.

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6.1 Appendix: Behavioral Equations of the RBC Model - Exogenous Processes - Numbering of Variables - Values of Coefficients - Base Run - Simulations

(1) Consumption C_t ; solves for r_t:

$$(1 + r_t) = \frac{1}{\beta}\left(\frac{C_t}{E_t\left[C_{t+1}\right]}\right)^{-\rho_0}\left(\frac{1 + \phi_{t+1}}{1 + \phi_t}\right)$$
$$r_t = \frac{1}{\beta}\left(\frac{C_t}{E_t\left[C_{t+1}\right]}\right)^{-\rho_0}\left(\frac{1 + \phi_{t+1}}{1 + \phi_t}\right) - 1$$

where $C_t = \left[\omega\left(C_t^d\right)^{-\rho} + (1 - \omega)\left(C_t^f\right)^{-\rho}\right]^{(\frac{-1}{\rho})}$

(2) Money supply $\overline{M}_t^d$; solves for P_t^d:

$$\overline{M}_t^d = (1 + \phi_t)C_t^d P_t^d + \overline{G}_t P_t^d$$
$$P_t^d = \frac{\overline{M}_t^d}{(1 + \phi_t)C_t^d + \overline{G}_t}$$

where $P_t = \left[\omega^{\frac{1}{1+\rho}}\left(P_t^d\right)^{\frac{\rho}{1+\rho}} + (1 - \omega)^{\frac{1}{1+\rho}}\left(P_t^F\right)^{\frac{\rho}{1+\rho}}\right]$

(3) Demand for shares, S_{t+1}^p :

$$S_{t+1}^p = \overline{S}_t \; ; \; b_{t+1} = b_{t+1}^p \text{ implied.}$$

(4) Present value of share :

$$p_t = E_t\sum_{i=1}^{\infty}\frac{d_{t+i}}{(1 + r_t)^i}\left(\frac{P_t}{P_{t+i}}\right)$$

where d_t (dividend per share), p_t (present value of shares in nominal terms).

(5) Production function Y_t:

$$Y_t = Z_t N_t^{\alpha} K_t^{(1-\alpha)}$$

(6) Demand for labour :

$$N_t^d = \left(\frac{\alpha Z_t}{w_t}\right)^{\left(\frac{1}{1-\alpha}\right)} K_t$$

(7) Capital :

$$K_t = (1-\alpha)\frac{Y_t}{r_t + \delta}$$

(8) GDP identity, Y_t; solves for C_t:

$$Y_t = C_t + I_t + G_t + NX_t$$

where NX_t is net exports.

(9) Investment :

$$K_{t+1} = (1-\delta)K_t + I_{t+1}$$

(10) W_t ; currently this variable is not defined.

(11) Wage w_t :

$$w_t = w_t^*$$

(12) Evolution of b_t; government budget constraint:

$$b_{t+1} = (1+r_t)b_t + PD_t - \frac{\Delta \bar{M}_t}{P_t}$$

(13) Equilibrium wage, w_t^*; w_t^* is derived by equating demand for labour, N_t^d, to the supply of labour N_t^s, where

$$(1-N_t^s) = \left\{ \frac{\theta_0 C_t^{-\rho_0} \left[(1-\tau_t)\exp\left(\log w_t^* - \frac{(1-\omega)^{\frac{1}{1+\rho}}}{\omega^{\frac{1}{1+\rho}}+(1-\omega)^{\frac{1}{1+\rho}}}\log Q_t\right) - \mu_t\right]}{(1-\theta_0)(1+\phi_t)(1+r_t)} \right\}^{-\frac{1}{\rho_2}}$$

where Q_t is the real exchange rate, $(1-\omega)^{\frac{1}{1+\rho}}$ is the weight of domestic prices in the CPI index.

(14) Dividends are surplus corporate cash flow:

$$d_t\bar{S}_t = Y_t - N_t^s w_t - K_t(r_t+\delta)$$

$$d_t = \frac{Y_t - N_t^s w_t - K_t(r_t+\delta)}{\bar{S}_t}$$

(15) Primary deficit PD_t:

$$PD_t = G_t + \mu_t\left(1 - N_t^s - \bar{l}\right) - \tau_{t-1}v_{t-1}N_{t-1}^s - \phi_{t-1}C_{t-1} - T_{t-1}$$

(16) Tax T_t:

$$T_t = T_{t-1} + \gamma^G(PD_{t-1} + b_t r_t) + \varepsilon_t$$

(17) Exports EX_t:

$$\log EX_t = \sigma_1 \log\left(1 - \omega^f\right) + \log C_t^F + \sigma_1 A^f \log Q_t$$

where $A^f = \frac{(\omega^f)^{\frac{1}{1+\rho}}}{(\omega^f)^{\frac{1}{1+\rho}} + (1-\omega^f)^{\frac{1}{1+\rho}}}$

(18) Imports IM_t:

$$\log IM_t = \sigma \log(1 - \omega) + \log C_t - \sigma A \log Q_t$$

where $A = \frac{\omega^{\frac{1}{1+\rho}}}{\omega^{\frac{1}{1+\rho}} + (1-\omega)^{\frac{1}{1+\rho}}}$

(19) UIP condition:

$$r_t = r_t^f + E_t \Delta \log Q_{t+1} + \varepsilon_{UIP}$$

where r^f defined the foreign real interest rate.

(20) Net exports:

$$NX_t = EX_t - IM_t$$

(21) Evolution of foreign bonds b_t^f:

$$b_{t+1}^f = (1 + r_t^f) b_t^f + NX_t$$

(22) Nominal exchange rate, S_t:

$$\log S_t = \log Q_t - \log P_t^f + \log P_t$$

where P_t^f is foreign price and S_t the nominal exchange rate.

(23) Evolution of household debt D_{t+1}:

$$D_{t+1} = (1 + r_t) D_t - Y_{t-1} + (1 + \phi_t) C_t + \tau_t v_t N_t^s + T_t$$

(24) Household transversality condition:

$$Y_{T-1} - r_T D_T - \phi_T C_T - \tau_T v_T N_T^s - T_T = C_T$$

(25) Government transversality condition:

$$G = 0.30$$

Exogenous processes

(1) $¢ \ln Z_t = "_{1;t}$

(2) $¢ ¿_t = "_{2;t}$

(3) $¢ Á_t = "_{3;t}$

(4) $¢ ¹_t = "_{4;t}$

(5) $¢ \ln \overline{M}_t = "_{5;t}$

(6) $¢ \ln P_t^f = "_{6;t}$

(7) $¢ \ln C_t^F = "_{7;t}$

(8) $¢ \ln r_t^f = "_{8;t}$

Numbering of variables and coe±cients used in model - Endogenous variables

No.	Name in program	Description	Initial value
1	r	Real interest rate	0.05266
2	P	Price level	0.803528
3	S^p	Demand for shares	1
4	p	Present value of share	4.6
5	Y	Output	0.867945
6	N^d	Demand for labour	0.840382
7	K	Capital	11.71725436
8	C	Composite consumption	0.542171914
9	I	Investment	0.129193
10	v	Consumer real wage	0.941375
11	w	Producer real wage	0.925483
12	b	Domestic bonds	1.804726
13	G	Government expenditure	0.196944
14	$w^{¤}$	Equilibrium real wage	0.925483
15	d	Dividend per share	0.285
16	D	Household debt	4.313317
17	PD	Primary de¯cit	-0.000731
18	T	Tax (lump sum)	-0.012945

Endogenous variables (cont.)

19	EX	Export	0.199159
20	IM	Import	0.197175
21	Q	Real exchange rate	0.971767
22	b^f	Foreign bonds	0.621545
23	S	Nominal exchange rate	1.05855
24	NX	Net exports	0.001984

Exogenous variables

Notes : α_i are parameters for defining exogenous random processes; $E_t[Y_{t+i}]$, etc., are i-period ahead expectations. The latter are set equal to the initial starting values.

No.	Name in program	Initial value
1	Z Productivity	0.999105
2	τ (tau) Labour income tax	0.34738
3	ϕ (phi) Consumption Tax, VAT	0.15346
4	μ (mu) Unemployment benefits	0.2608
5	M Money	0.107535
6	$\bar{S}$ Supply of shares	1
7	$\bar{I}$	0
8	$\bar{M}$	0.107535
9	α_1	1
10	α_2	0
11	α_3	0
12	α_4	0
13	α_5	1
14	α_6	0
15	$E_t[C_{t+1}]$	0.542171914
16	r_base	0.05266
17	P_base	0.803528
18	Y_base	0.867945
19	N_base	0.840382
20	K_base	11.71725436

Exogenous variables (cont.)

21	w¤_base	0.925483
22	d_base	0.285
23	PD_base	-0.000731
24	I_base	0.129193
25	Q-base	0.971767
26	EX-base	0.199159
27	IM-base	0.197175
28	G-base	0.196944
29	P^f Foreign Price Level	0.737074
30	POP	28.009
31	C^F Foreign Consumption	16.830648
32	r^f Foreign Interest Rate	0.045
33	E[Q]	0.971767
34	C-base	0.542171914

Values of coe±cients

Note: the values of the coe±cients used in the model have been calibrated from the recent literature.

Coe±cient	Value - Single equation
®	0.70
¯	0.97
±	0.0125
$½_0$	1.20
$µ_0$	0.50
$°^G$	0.05
$½_2$	1.00
!	0.70
½	-0.50
$!^f$	0.70
h	0.80
$½_3$	-0.50
¾	2
$¾_1$	2

Base Run Simulation from 3 to 60

GROUP 1 ENDOGENOUS VARIABLES

	2	3	4	5	6	7	8	9	10	11
r	0.0430	0.0541	0.0680	0.0579	0.0724	0.0849	0.0647	0.0610	0.0529	0.0546
P	0.8127	0.8219	0.8297	0.8428	0.8467	0.8544	0.8647	0.8758	0.8894	0.9015
Sp	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
p	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000
Y	0.8784	0.8878	0.8997	0.9034	0.9136	0.9324	0.9437	0.9574	0.9637	0.9778
N_d	0.8397	0.8392	0.8407	0.8429	0.8429	0.8508	0.8595	0.8598	0.8665	0.8730
K	11.7098	11.7100	11.7157	11.7110	11.7176	11.7313	11.7506	11.7752	11.8060	11.8438
C	0.5491	0.5495	0.5536	0.5607	0.5699	0.5836	0.5957	0.6091	0.6160	0.6294
I	0.1391	0.1466	0.1520	0.1418	0.1530	0.1602	0.1659	0.1715	0.1780	0.1854
v	0.9449	0.5064	0.5026	0.5013	0.5076	0.5134	0.5159	0.5105	0.5169	0.5228
w	0.9341	0.9398	0.9337	0.9316	0.9436	0.9546	0.9601	0.9509	0.9619	0.9731
b	1.8564	1.9557	2.0717	2.2074	2.3376	2.5047	2.7080	2.8722	3.0331	3.1589
G	0.1950	0.1951	0.1948	0.1937	0.1959	0.1965	0.1953	0.1966	0.1951	0.1941
w*	0.9341	0.9398	0.9337	0.9316	0.9436	0.9546	0.9601	0.9509	0.9619	0.9731
d	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
D	4.5015	4.5420	4.6223	4.7743	4.8931	5.1036	5.4107	5.6383	5.8723	6.0756
PD	0.0204	0.0118	-0.0028	0.0031	-0.0013	-0.0071	-0.0092	-0.0117	-0.0322	-0.0295
T	0.0637	0.0700	0.0776	0.0839	0.0925	0.1031	0.1115	0.1198	0.1272	0.1342
EX	0.2019	0.2022	0.2076	0.2132	0.2110	0.2185	0.2174	0.2139	0.2181	0.21909
IM	0.2041	0.2054	0.2083	0.2060	0.2163	0.2263	0.2306	0.2338	0.2435	0.2500
Q	1.0049	0.9937	1.0043	1.0069	1.0103	1.0144	1.0221	1.0321	1.0212	1.0235
b_fr	0.6515	0.6774	0.7108	0.7584	0.8096	0.8629	0.9284	0.9752	1.0148	1.0431
S	1.0644	0.9939	0.9373	0.9595	1.0002	1.0011	1.0215	1.0301	1.0692	1.0573
NX	-0.0021	-0.0033	-0.0007	0.0072	-0.0053	-0.0078	-0.0132	-0.0199	-0.0254	-0.0310
P_d	0.4374	0.4429	0.4466	0.4536	0.4555	0.4595	0.4647	0.4702	0.4779	0.4844

	12	13	14	15	16	17	18	19	20	21
r	0.0688	0.0840	0.0748	0.0742	0.0781	0.0794	0.0735	0.0740	0.0571	0.0780
P	0.9121	0.9281	0.9395	0.9534	0.9696	0.9878	0.9864	1.0040	1.0217	1.0377
Sp	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
p	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000
Y	0.9861	0.9871	0.9920	0.9942	0.9955	1.0040	1.0086	0.9963	0.9911	0.9908
N_d	0.8794	0.8858	0.8922	0.8933	0.8945	0.8957	0.8969	0.8914	0.8859	0.8967
K	11.8981	11.9422	11.9868	12.0305	12.0620	12.0960	12.1325	12.1554	12.1672	12.1807
C	0.6367	0.6415	0.6445	0.6437	0.6472	0.6523	0.6534	0.6476	0.6453	0.6428
I	0.2023	0.1929	0.1939	0.1935	0.1818	0.1848	0.1877	0.1745	0.1637	0.1657
v	0.5284	0.5233	0.5291	0.5360	0.5402	0.5284	0.5342	0.5420	0.5496	0.5516
w	0.9837	0.9744	0.9850	0.9969	1.0043	0.9828	0.9931	1.0057	1.0184	1.0224
b	3.2977	3.4943	3.7581	4.0104	4.2924	4.6171	4.9687	5.3430	5.7285	6.0524
G	0.1971	0.1962	0.1959	0.1999	0.1986	0.2005	0.2006	0.2027	0.2042	0.2049
w*	0.9837	0.9744	0.9850	0.9969	1.0043	0.9828	0.9931	1.0057	1.0184	1.0224
d	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
D	6.3154	6.6636	7.1466	7.6204	8.1321	8.7295	9.4071	10.0937	10.8453	11.4941
PD	-0.0295	-0.0289	-0.0273	-0.0132	-0.0078	-0.0136	0.0109	-0.0096	-0.0031	-0.0024
T	0.1441	0.1573	0.1699	0.1834	0.1995	0.2175	0.2351	0.2554	0.2712	0.2947
EX	0.2143	0.2249	0.2207	0.2262	0.2327	0.2384	0.2382	0.2377	0.2394	0.2308
IM	0.2643	0.2684	0.2630	0.2692	0.2648	0.2721	0.2712	0.2663	0.2615	0.2535
Q	1.0264	1.0274	1.0266	1.0165	1.0113	1.0166	1.0120	0.9922	0.9791	0.9810
b_fr	1.0690	1.0925	1.1408	1.1838	1.2287	1.2926	1.3616	1.4287	1.5058	1.5697
S	1.0700	1.0753	1.0364	1.0153	0.9703	0.9669	0.9736	1.0350	1.0276	1.0247
NX	-0.0500	-0.0435	-0.0423	-0.0429	-0.0321	-0.0336	-0.0330	-0.0286	-0.0221	-0.0227
P_d	0.4899	0.4985	0.5046	0.5126	0.5216	0.5311	0.5306	0.5411	0.5514	0.5599

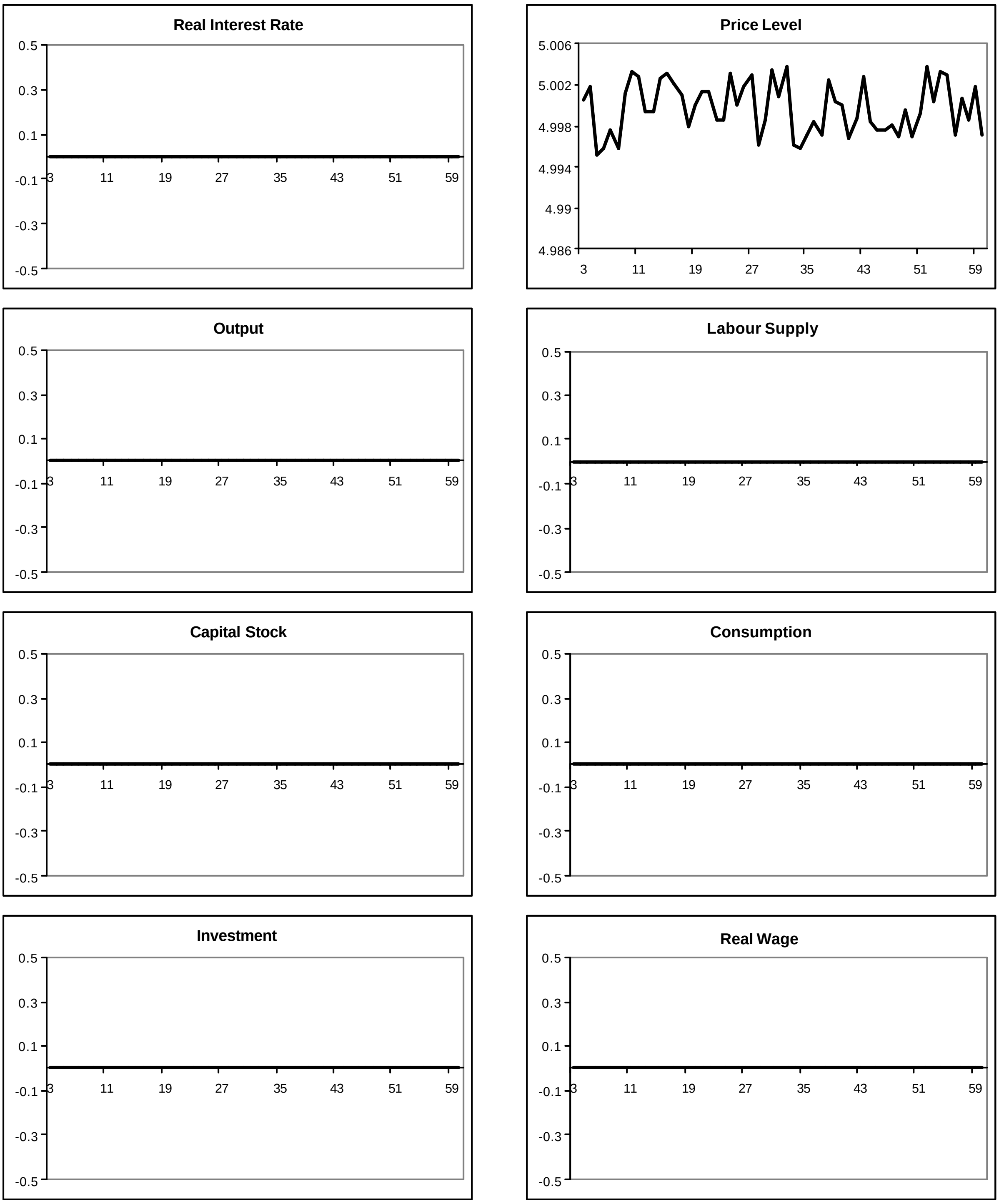
	22	23	24	25	26	27	28	29	30	31
r	0.0760	0.0750	0.0720	0.0822	0.0600	0.0530	0.0306	0.0342	0.0393	0.0395
P	1.0723	1.0883	1.1013	1.1120	1.1276	1.1333	1.1429	1.1523	1.1632	1.1738
Sp	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
p	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000
Y	0.9850	0.9837	0.9854	0.9864	0.9839	0.9896	0.9940	1.0011	1.0066	1.0168
N_d	0.8950	0.8899	0.8859	0.8708	0.8687	0.8771	0.8688	0.8631	0.8672	0.8708
K	12.1827	12.1815	12.1898	12.2023	12.2095	12.2192	12.2266	12.2369	12.2503	12.2627
C	0.6363	0.6374	0.6348	0.6330	0.6411	0.6464	0.6465	0.6520	0.6566	0.6671
I	0.1542	0.1511	0.1606	0.1649	0.1597	0.1623	0.1602	0.1631	0.1663	0.1656
v	0.5592	0.5659	0.5730	0.5422	0.5607	0.5638	0.5717	0.5744	0.5958	0.6036
w	1.0354	1.0470	1.0593	1.0029	1.0363	1.0420	1.0563	1.0606	1.1003	1.1135
b	6.5210	7.0340	7.5843	8.1498	8.8508	9.4266	9.9777	10.3513	10.7717	11.2614
G	0.2103	0.2089	0.2082	0.2088	0.2096	0.2097	0.2104	0.2084	0.2065	0.2089
w*	1.0354	1.0470	1.0593	1.0029	1.0363	1.0420	1.0563	1.0606	1.1003	1.1135
d	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
D	12.4477	13.4665	14.5841	15.7698	17.2316	18.4664	19.6813	20.5298	21.5022	22.6393
PD	0.0187	0.0232	0.0204	0.0310	0.0455	0.0528	0.0697	0.0688	0.0676	0.0700
T	0.3194	0.3467	0.3751	0.4097	0.4377	0.4650	0.4829	0.5041	0.5287	0.5543
EX	0.2384	0.2420	0.2412	0.2441	0.2501	0.2452	0.2542	0.2579	0.2547	0.2588
IM	0.2542	0.2557	0.2595	0.2645	0.2766	0.2740	0.2773	0.2803	0.2776	0.2835
Q	0.9705	0.9632	0.9578	0.9620	0.9548	0.9541	0.9517	0.9457	0.9473	0.9374
b_fr	1.6694	1.7805	1.9004	2.0190	2.1646	2.2679	2.3593	2.4085	2.4684	2.5425
S	1.0061	1.0009	1.0015	0.9929	1.0151	0.9841	0.8773	0.8735	0.8902	0.9052
NX	-0.0158	-0.0137	-0.0182	-0.0203	-0.0265	-0.0288	-0.0230	-0.0224	-0.0229	-0.0247
P_d	0.5792	0.5883	0.5956	0.6012	0.6101	0.6132	0.6185	0.6240	0.6299	0.6363

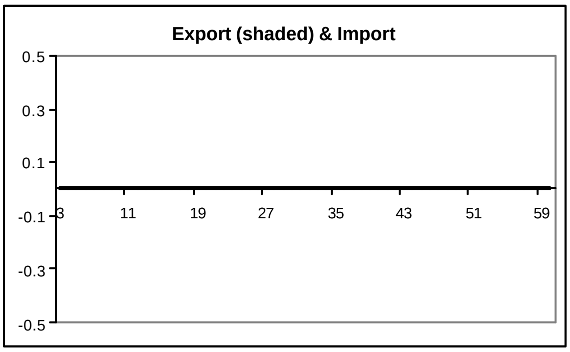
	32	33	34	35	36	37	38	39	40	41
r	0.0383	0.0313	0.0283	0.0367	0.0383	0.0400	0.0467	0.0502	0.0496	0.0472
P	1.1811	1.1849	1.1910	1.1967	1.2044	1.2167	1.2194	1.2299	1.2360	1.2468
Sp	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
p	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000
Y	1.0278	1.0410	1.0538	1.0686	1.0778	1.0843	1.0883	1.0921	1.0994	1.1110
N_d	0.8747	0.8718	0.8777	0.8891	0.8885	0.8859	0.8925	0.9050	0.8997	0.9000
K	12.2773	12.2924	12.3202	12.3464	12.3834	12.4068	12.4433	12.4725	12.5014	12.5394
C	0.6725	0.6815	0.6803	0.6869	0.6896	0.6901	0.6935	0.7018	0.7051	0.7129
I	0.1679	0.1686	0.1815	0.1802	0.1914	0.1782	0.1916	0.1847	0.1849	0.1943
v	0.6107	0.6126	0.6302	0.6344	0.6449	0.6407	0.6473	0.6549	0.6715	0.6601
w	1.1270	1.1333	1.1623	1.1743	1.1940	1.1860	1.1983	1.2122	1.2401	1.2182
b	11.7744	12.2952	12.7554	13.1698	13.7061	14.2791	14.9084	15.6555	16.4943	17.3567
G	0.2087	0.2084	0.2107	0.2111	0.2110	0.2129	0.2148	0.2133	0.2148	0.2163
w*	1.1270	1.1333	1.1623	1.1743	1.1940	1.1860	1.1983	1.2122	1.2401	1.2182
d	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
D	23.8591	25.1185	26.2739	27.3942	28.7982	30.3164	31.9672	33.9339	36.1600	38.5203
PD	0.0727	0.0769	0.0559	0.0555	0.0504	0.0596	0.0516	0.0554	0.0461	0.0377
T	0.5803	0.6032	0.6251	0.6521	0.6811	0.7122	0.7500	0.7918	0.8355	0.8788
EX	0.2658	0.2765	0.2777	0.2854	0.2930	0.3049	0.3011	0.3119	0.3170	0.3241
IM	0.2871	0.2940	0.2965	0.2949	0.3072	0.3018	0.3126	0.3195	0.3224	0.3365
Q	0.9402	0.9623	0.9359	0.9682	0.9701	0.9694	0.9697	0.9686	0.9473	0.9406
b_fr	2.6182	2.6971	2.7641	2.8235	2.9176	3.0152	3.1391	3.2740	3.4308	3.5957
S	0.9004	0.9065	0.8908	0.8803	0.8902	0.8728	0.8438	0.8438	0.8358	0.8358
NX	-0.0213	-0.0175	-0.0188	-0.0095	-0.0141	0.0031	-0.0116	-0.0076	-0.0054	-0.0124
P_d	0.6401	0.6405	0.6457	0.6465	0.6506	0.6572	0.6587	0.6644	0.6693	0.6756

	42	43	44	45	46	47	48	49	50	51
r	0.0410	0.0386	0.0400	0.0430	0.0490	0.0530	0.0555	0.0550	0.0430	0.0520
P	1.2503	1.2593	1.2684	1.2726	1.2766	1.2865	1.2948	1.2981	1.3008	1.3122
Sp	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
p	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000
Y	1.1161	1.1214	1.1301	1.1444	1.1534	1.1634	1.1716	1.1795	1.1892	1.1972
N_d	0.9236	0.9245	0.9280	0.9081	0.9139	0.9186	0.9247	0.9206	0.9258	0.9224
K	12.5721	12.6030	12.6300	12.6654	12.7103	12.7597	12.8168	12.8823	12.9493	13.0231
C	0.7201	0.7276	0.7368	0.7398	0.7524	0.7530	0.7634	0.7707	0.7780	0.7837
I	0.1894	0.1880	0.1845	0.1933	0.2032	0.2083	0.2166	0.2257	0.2280	0.2356
v	0.6391	0.6461	0.6514	0.6556	0.6611	0.6657	0.6717	0.6751	0.6750	0.6749
w	1.1762	1.1887	1.1984	1.2065	1.2159	1.2267	1.2379	1.2445	1.2445	1.2445
b	18.2105	18.9913	19.7588	20.5738	21.4765	22.5859	23.8113	25.1151	26.4540	27.6294
G	0.2167	0.2160	0.2170	0.2194	0.2152	0.2153	0.2166	0.2160	0.2199	0.2211
w*	1.1762	1.1887	1.1984	1.2065	1.2159	1.2267	1.2379	1.2445	1.2445	1.2445
d	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
D	40.9455	43.2691	45.6274	48.1841	51.0290	54.3557	58.1208	62.2981	66.7461	70.6945
PD	0.0364	0.0358	0.0277	0.0201	0.0605	0.0299	-0.0147	-0.0402	0.0389	-0.0034
T	0.9180	0.9565	0.9978	1.0434	1.0970	1.1599	1.2274	1.2958	1.3506	1.4244
EX	0.3298	0.3365	0.3462	0.3514	0.3586	0.3675	0.3698	0.3691	0.3752	0.3744
IM	0.3399	0.3468	0.3543	0.3594	0.3759	0.3807	0.3948	0.4020	0.4119	0.4176
Q	0.9177	0.9150	0.9146	0.9171	0.9119	0.9280	0.9284	0.9309	0.9328	0.9337
b_fr	3.7528	3.8966	4.0370	4.1902	4.3622	4.5585	4.7870	5.0276	5.2712	5.4612
S	0.8485	0.8558	0.9149	0.9699	0.9969	1.0260	1.0320	1.0550	1.0540	1.0450
NX	-0.0101	-0.0102	-0.0081	-0.0081	-0.0173	-0.0132	-0.0250	-0.0329	-0.0367	-0.0432
P_d	0.6793	0.6844	0.6894	0.6915	0.6941	0.6982	0.7026	0.7042	0.7055	0.7116

	52	53	54	55	56	57	58	59	60
r	0.0470	0.0360	0.0350	0.0410	0.0360	0.0390	0.0390	0.0380	0.0370
P	1.3310	1.3359	1.3491	1.3512	1.3548	1.3598	1.3644	1.3655	1.3728
Sp	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
p	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000	4.6000
Y	1.2024	1.2050	1.2118	1.2256	1.2408	1.2463	1.2557	1.2630	1.2687
N_d	0.9241	0.9222	0.9518	0.9539	0.9550	0.9246	0.9262	0.9291	0.9276
K	13.1021	13.1756	13.2375	13.3080	13.3863	13.4500	13.5230	13.5957	13.6706
C	0.7897	0.8027	0.8120	0.8170	0.8297	0.8440	0.8534	0.8629	0.8699
I	0.2418	0.2373	0.2265	0.2360	0.2447	0.2311	0.2411	0.2417	0.2448
v	0.6715	0.6977	0.7058	0.7122	0.7191	0.7184	0.7255	0.7317	0.7385
w	1.2377	1.2843	1.2980	1.3097	1.3224	1.3234	1.3361	1.3477	1.3594
b	29.0599	30.4069	31.4508	32.5726	33.8878	35.0784	36.3734	37.6826	39.0927
G	0.2229	0.2251	0.2254	0.2275	0.2288	0.2294	0.2314	0.2330	0.2318
w*	1.2377	1.2843	1.2980	1.3097	1.3224	1.3234	1.3361	1.3477	1.3594
d	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
D	75.5190	80.2851	84.4561	88.7614	93.8169	98.6662	104.0566	109.7262	115.5860
PD	-0.0169	-0.0483	0.0253	-0.0177	-0.0211	-0.0755	-0.1055	-0.0176	-0.0033
T	1.4925	1.5464	1.5990	1.6671	1.7272	1.7945	1.8617	1.9280	1.9994
EX	0.3727	0.3724	0.3845	0.4042	0.4097	0.4169	0.4300	0.4379	0.4455
IM	0.4247	0.4325	0.4366	0.4592	0.4721	0.4751	0.5001	0.5125	0.5233
Q	0.9309	0.9187	0.9114	0.9105	0.9105	0.9252	0.9224	0.9243	0.9187
b_fr	5.7019	5.9179	6.0709	6.2313	6.4319	6.6010	6.8003	6.9953	7.1865
S	1.0070	1.0120	1.0420	1.0390	1.0600	1.0850	1.0780	1.0650	1.0770
NX	-0.0520	-0.0601	-0.0520	-0.0549	-0.0624	-0.0582	-0.0702	-0.0746	-0.0778
P_d	0.7221	0.7258	0.7336	0.7348	0.7367	0.7382	0.7409	0.7414	0.7458

Fig 1. 5% Shock to Money

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0.1
-0.1
-0.3
-0.5
3
11
19
27
35
43
51
59

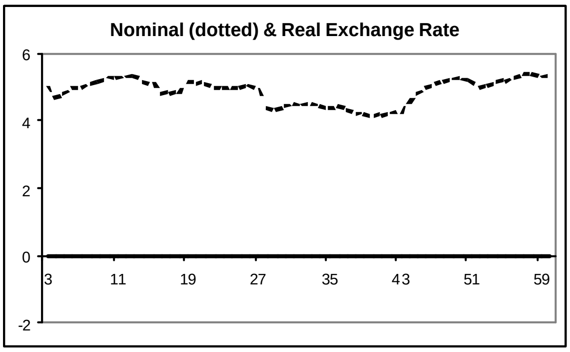
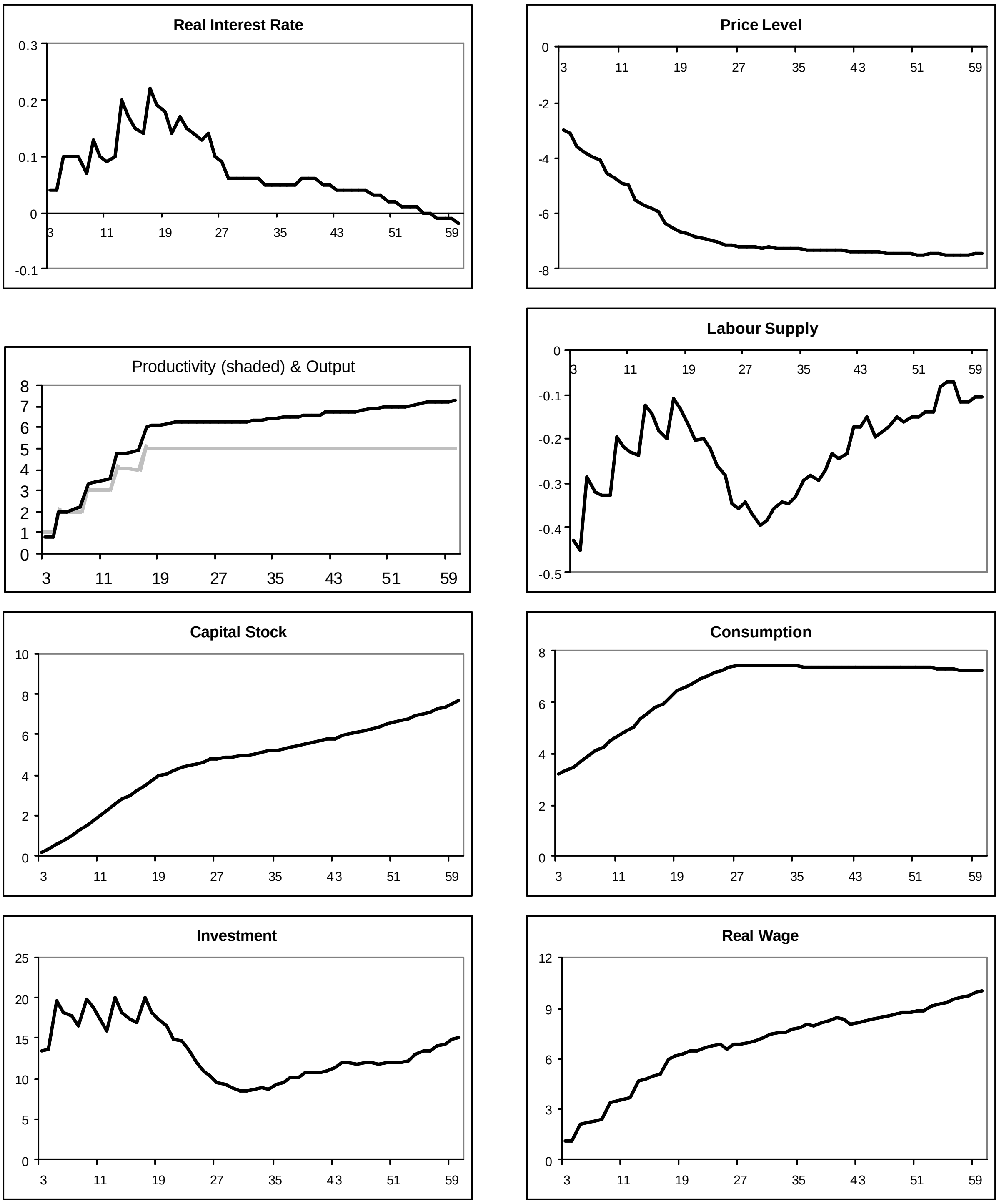
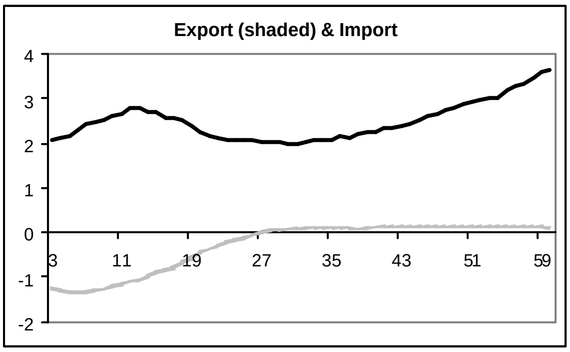

Nominal (dotted) & Real Exchange Rate
6
4
2
0
-2
3
11
19
27
35
43
51
59

Fig 2. 1% p.a.Growth Shock to Productivity




Export (shaded) & Import
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3
2
1
0
-1
-2
3
11
19
27
35
43
51
59

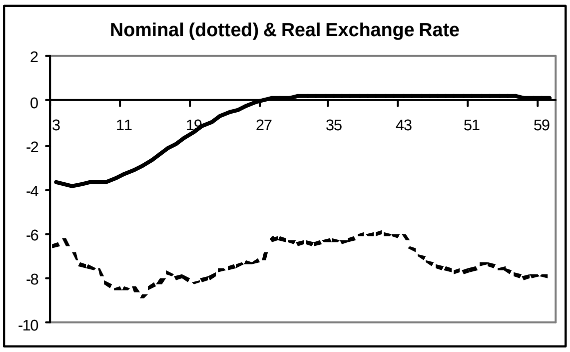
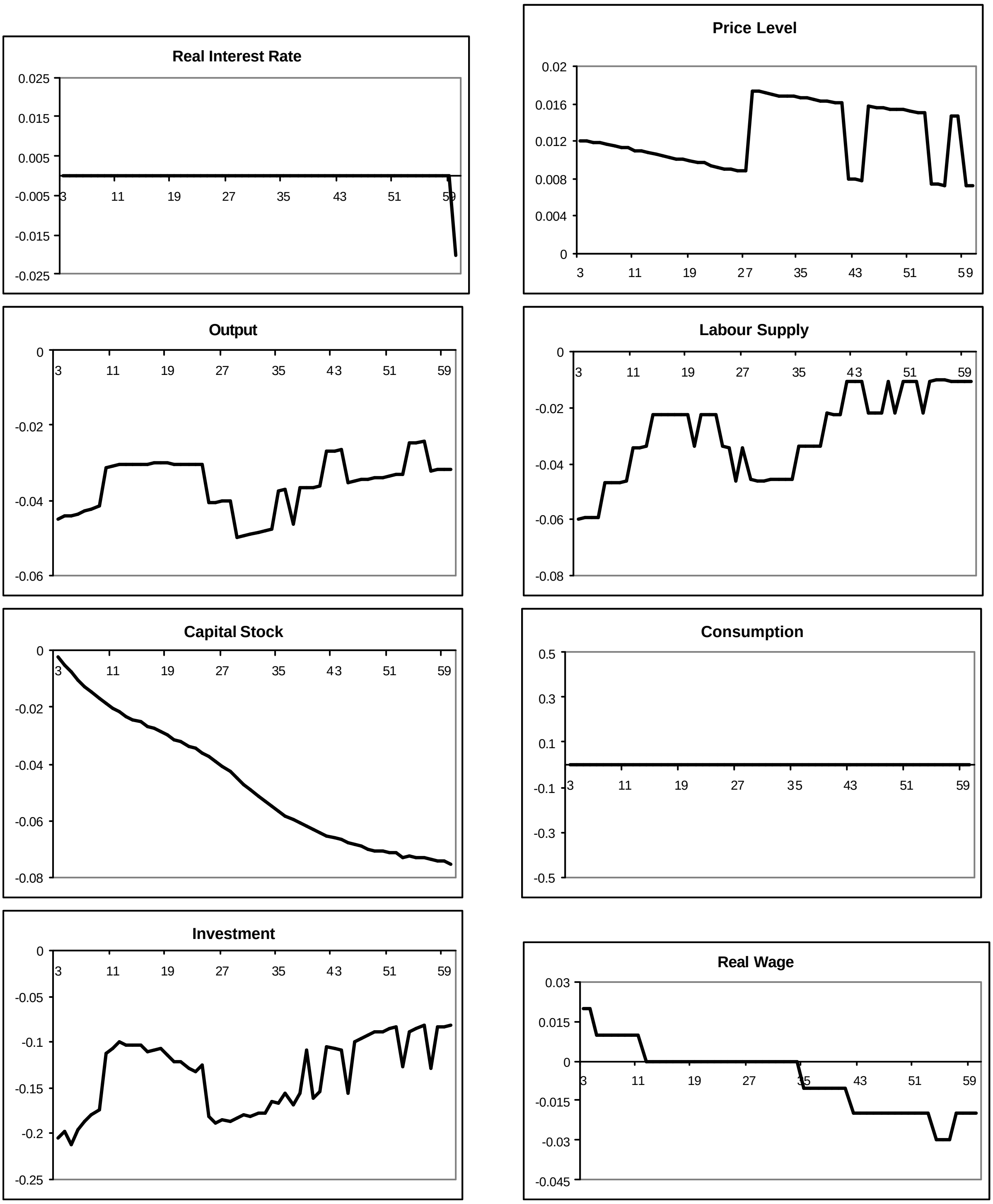
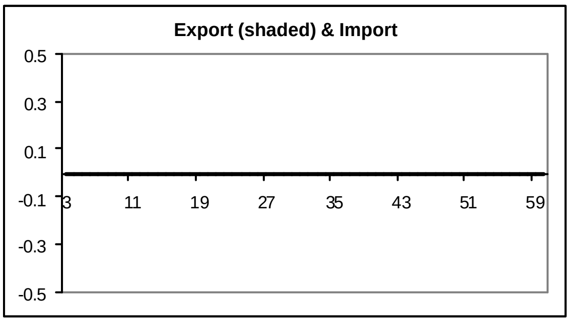

Nominal (dotted) & Real Exchange Rate
2
0
-2
-4
-6
-8
-10
3
11
19
27
35
43
51
59

Fig 3. 5% Shock to Unemployment Bene¯ts




Export (shaded) & Import
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0.1
-0.1
-0.3
-0.5
3
11
19
27
35
43
51
59

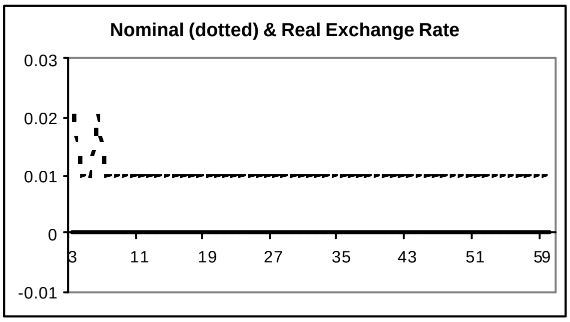
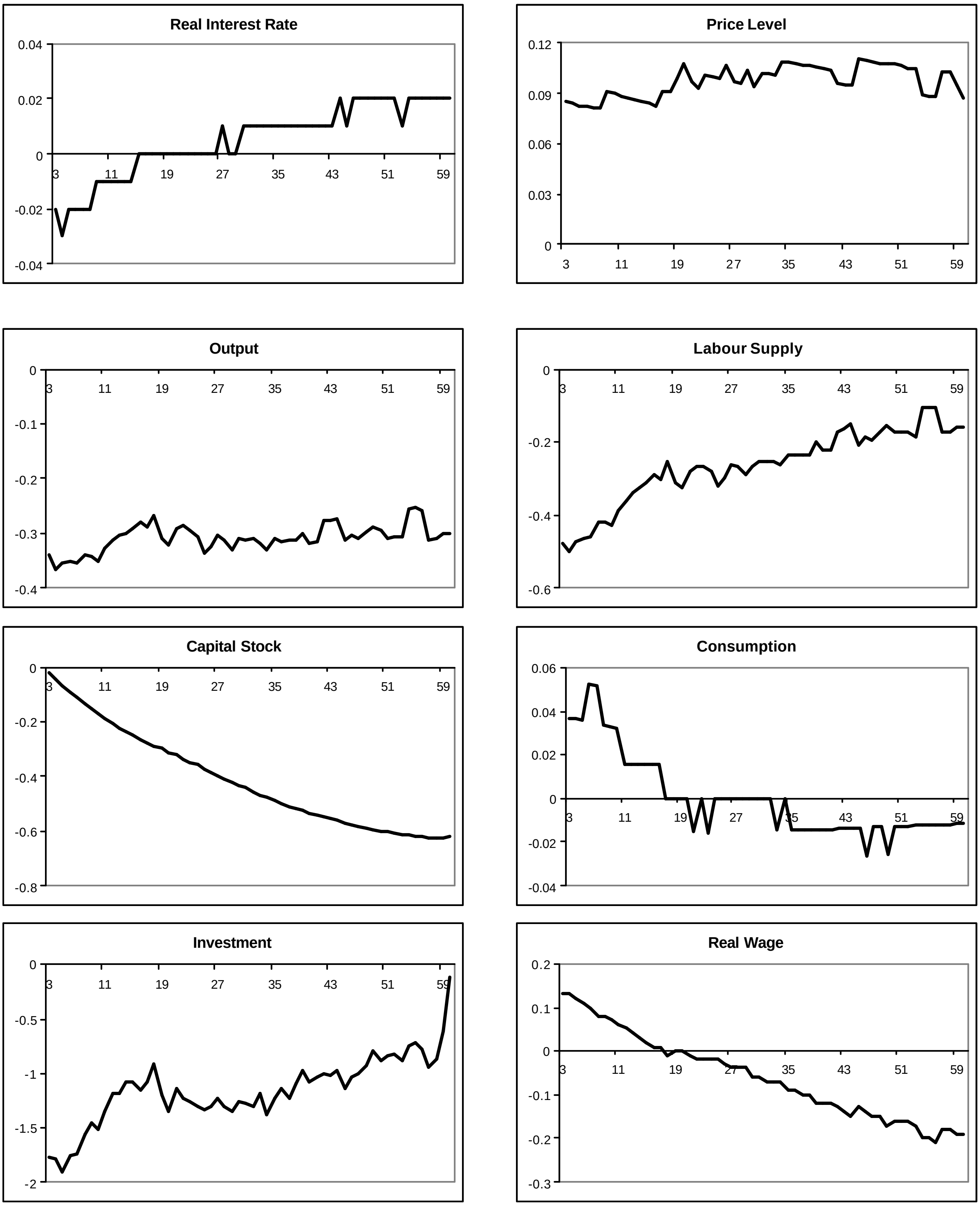
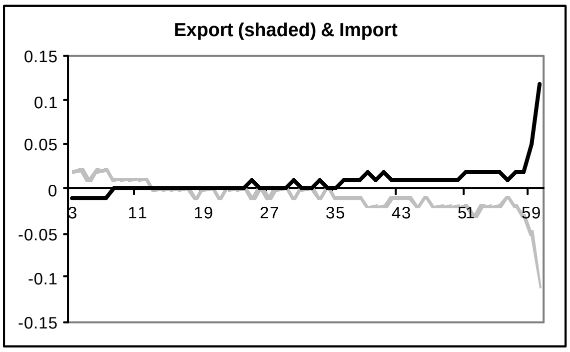

Nominal (dotted) & Real Exchange Rate
0.03
0.02
0.01
0
-0.01
3
11
19
27
35
43
51
59

Fig 4. 5% Shock to Labour Income Tax




Export (shaded) & Import
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0.1
0.05
0
-0.05
-0.1
-0.15
3
11
19
27
35
43
51
59

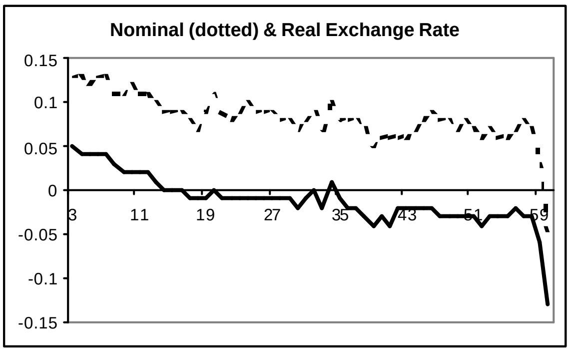
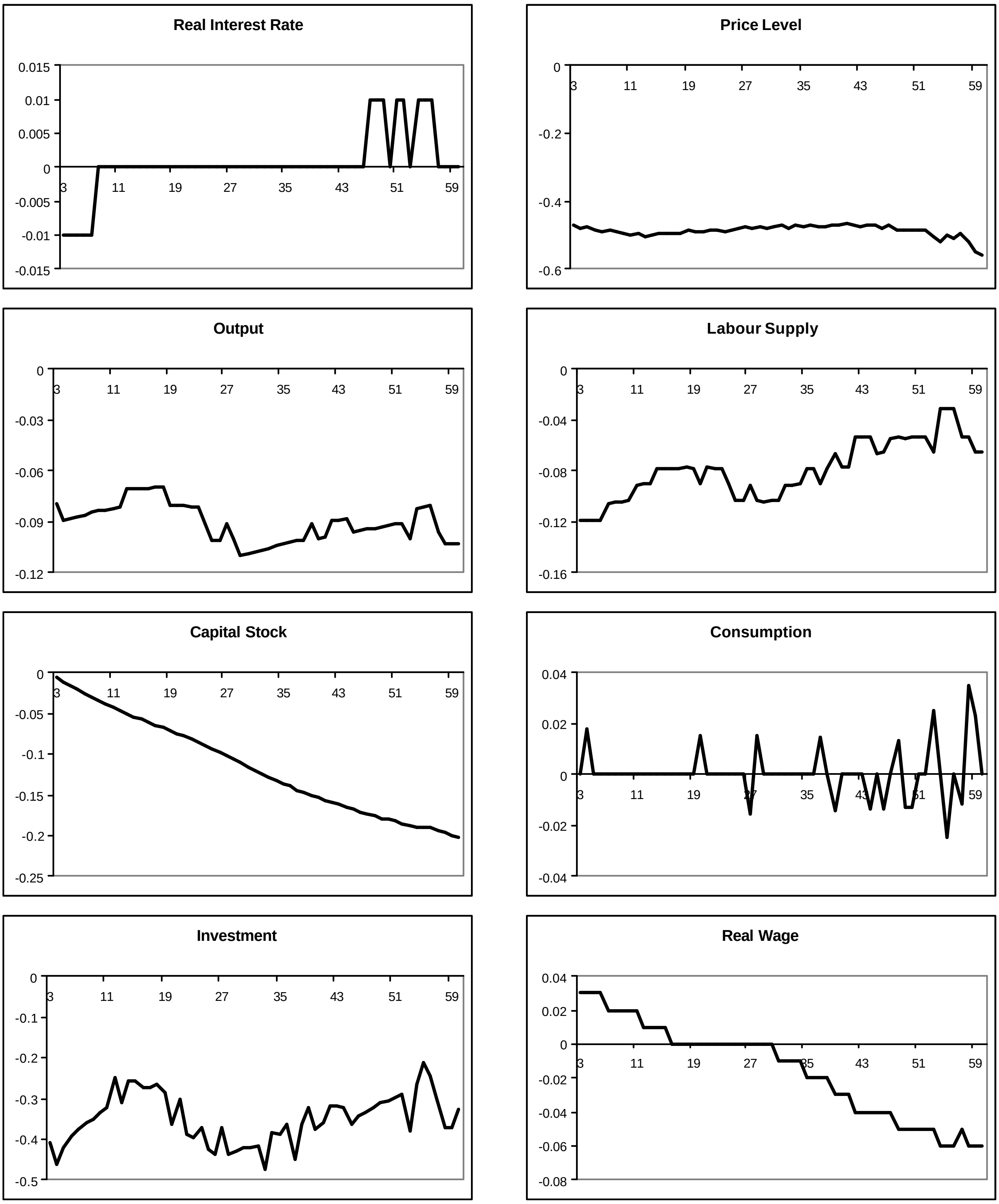
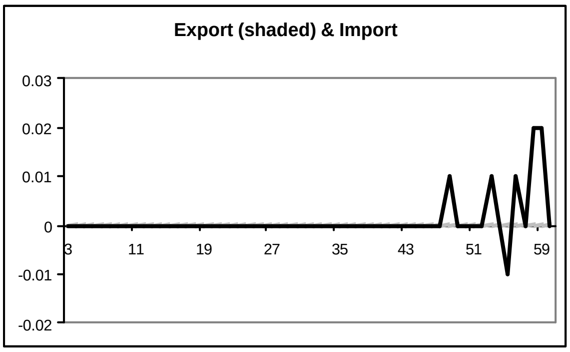

Nominal (dotted) & Real Exchange Rate
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
3
11
19
27
35
43
51
59

Fig 5. Shock to Consumption Tax (VAT)




Export (shaded) & Import
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0.02
0.01
0
-0.01
-0.02
3
11
19
27
35
43
51
59

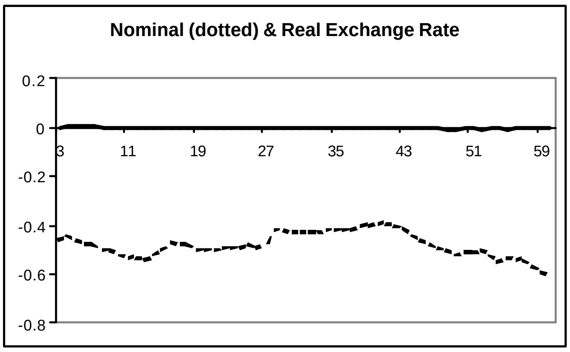
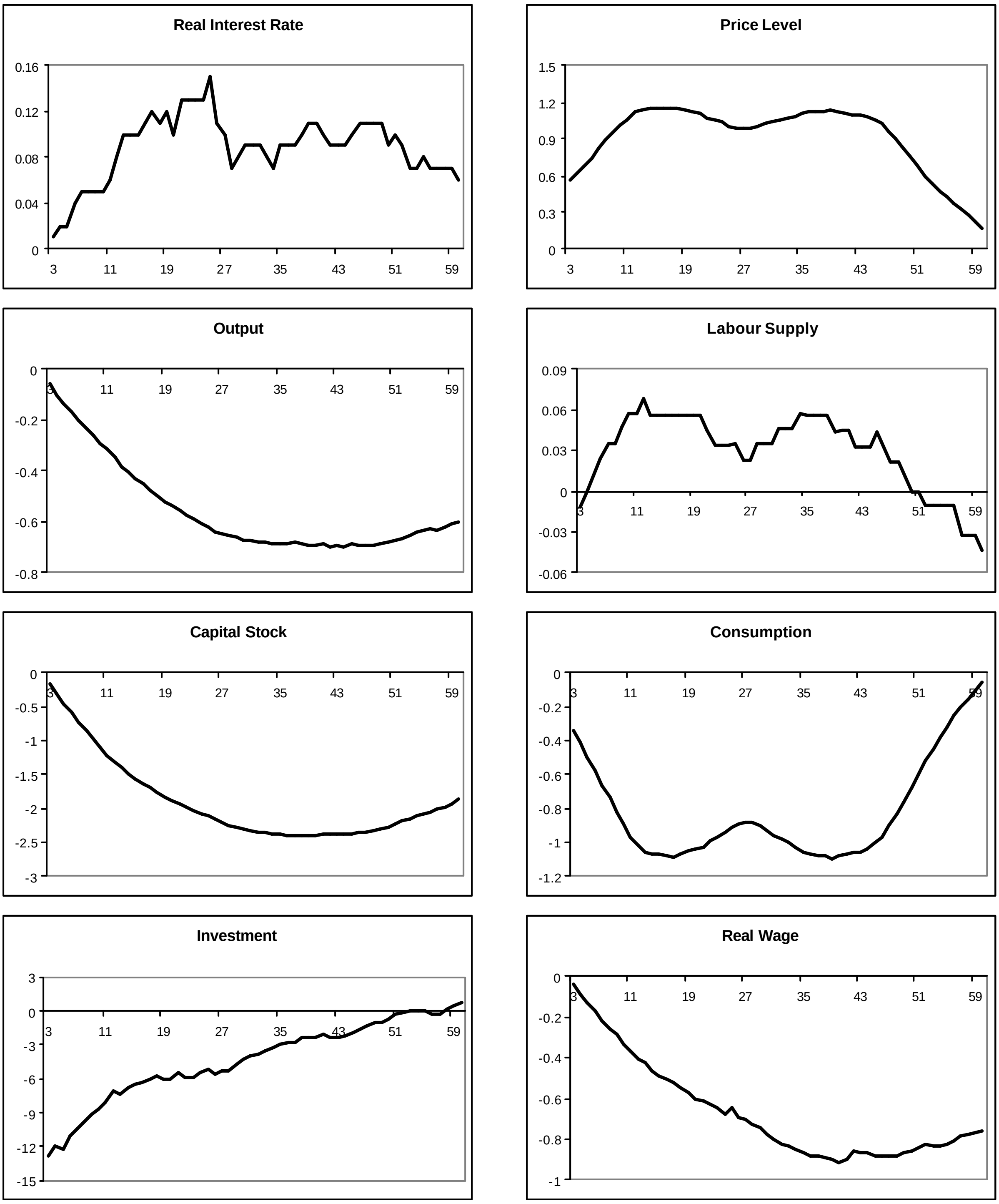
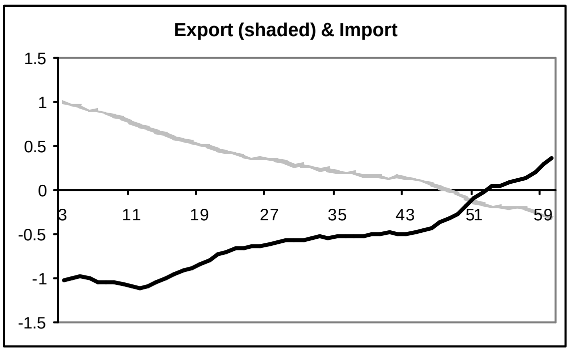

Nominal (dotted) & Real Exchange Rate
0.2
0
-0.2
-0.4
-0.6
-0.8
3
11
19
27
35
43
51
59

Fig 6. 5% Shock to Foreign Interest Rate




Export (shaded) & Import
1.5
1
0.5
0
-0.5
-1
-1.5
3
11
19
27
35
43
51
59

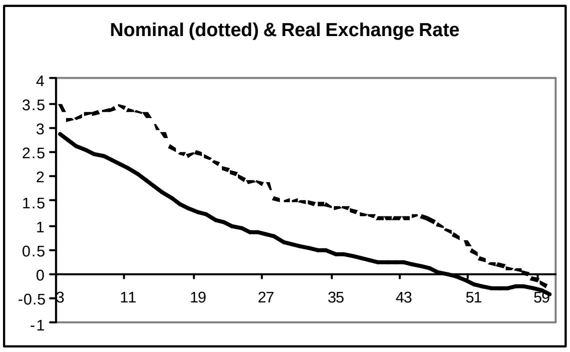
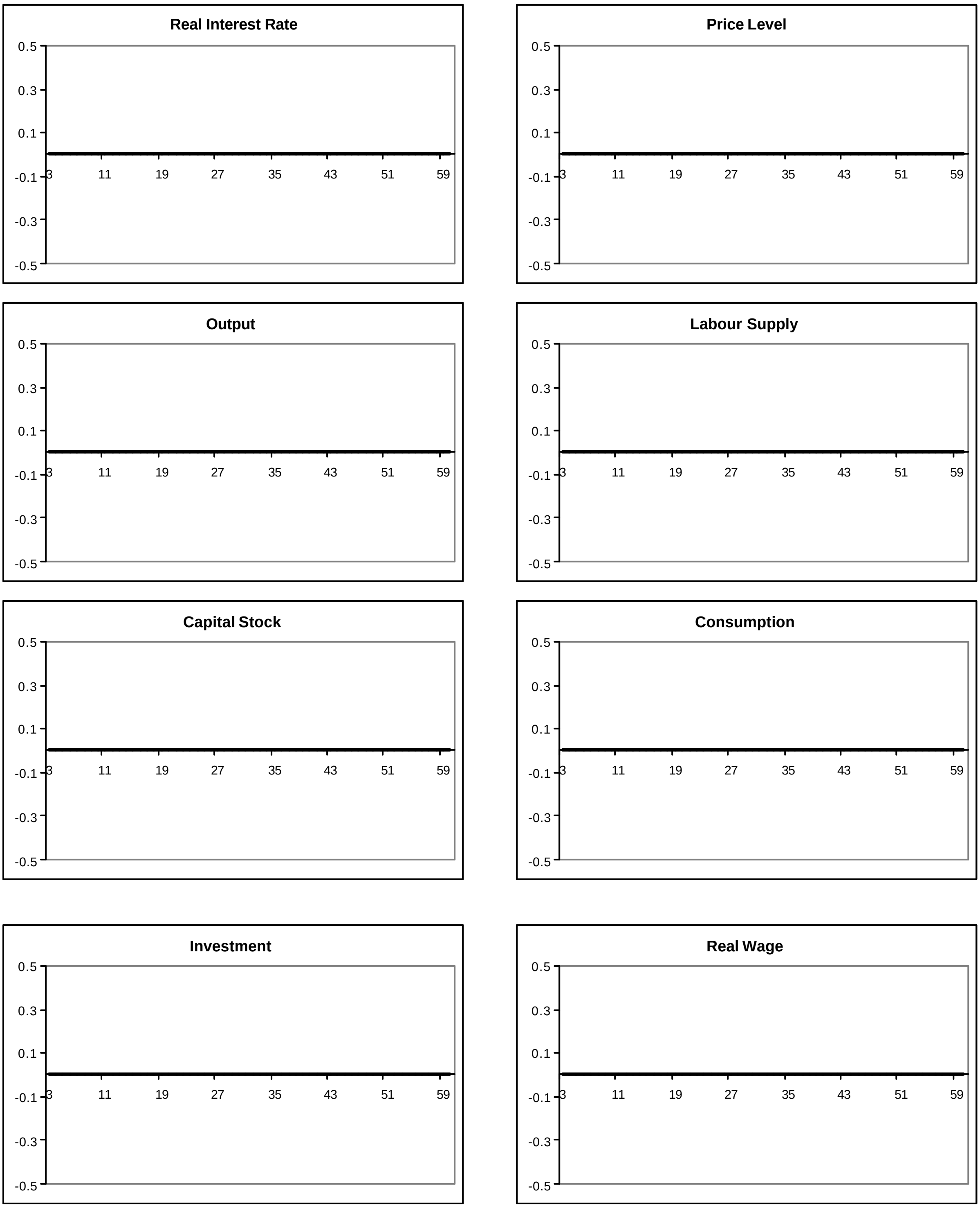
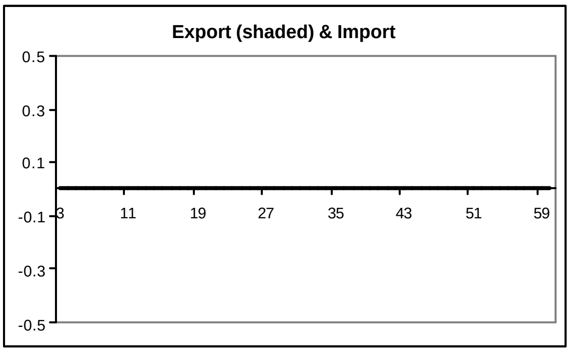

Nominal (dotted) & Real Exchange Rate
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
3
11
19
27
35
43
51
59

Fig 7. 5% Shock to Foreign Prices




Export (shaded) & Import
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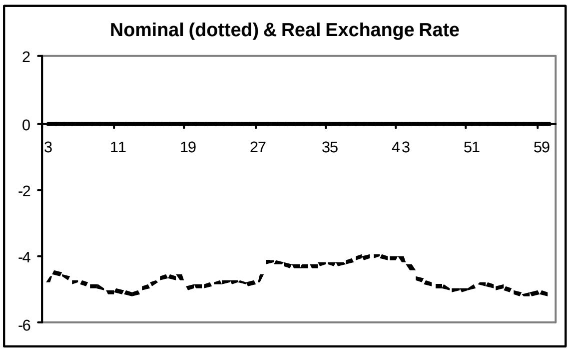
0.3
0.1
-0.1
-0.3
-0.5
3
11
19
27
35
43
51
59


Nominal (dotted) & Real Exchange Rate
2
0
-2
-4
-6
3
11
19
27
35
43
51
59