Nonstationary shocks, crises and policy

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Abstract

A Real Business Cycle model of the UK is developed to account for the behaviour of UK nonstationary macro data. The model, when tested by the method of indirect inference, can explain the behaviour of main variables (GDP, real exchange rate, real interest rate). We use it to explain how ‘crisis’ and ‘euphoria’ are endemic in capitalist behaviour due to nonstationarity; and we draw some policy lessons.

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The recent banking crisis and the contraction that followed it, now generally known as the Great Recession, have led to a spirited debate on whether macroeconomic models of the recent DSGE variety can shed light on the causes of this episode. A wide range of economists — see for example De Grauwe (2010) and Kirman (2010) — have argued in the negative and propose that macroeconomics be reconstituted to allow for behavioural influences such as herd behaviour and projection biases. DSGE modellers have fought back, arguing that these models are useful in tracking data and that the episode must be seen as being the result of a very large shock, which once included in the model has an impulse response function not out of line with with events.

In this paper we take neither of these positions. Instead we argue that a DSGE model of the Real Business Cycle type when driven by non-stationary exogenous shocks is the correct vehicle for understanding such crisis episodes, as well as the behaviour of the economy generally. Thus we are sympathetic to the criticisms of standard DSGE analysis to the extent that this has played down the role of non-stationary shocks, treating the ‘trend’ in a macro model as a separate issue from the business cycle and treating business cycle shocks as stationary with the implication that they fade away in time, leaving no trace of their impact in the longer term. We are also sympathetic to the standard DSGE modeller’s defence since indeed we agree that there is nothing wrong with the structure of these models per se. The model we set out can be analysed in the way previously used for DSGE models, stripping out the ‘trend’ and examining only the stationary components of the shocks; however doing so limits the insights we can obtain from such a model, as we now hope to explain.

Macroeconomic data are generally non-stationary, i.e. a part at least of their movement each quarter is random. This feature is responsible for the considerable uncertainty surrounding the economy’s long-term future. Models of the economy have reacted to this feature by abstracting from it and using some technique for extracting the trend from the data so as to render it stationary. Tests of these models have generally been done on such stationarised data. However the techniques (such as the Band Pass and the Hodrick-Prescott filters) are not based on the theories used in these models; instead they are based on statistical properties of the data and so extract from the data information that could well have a bearing on the models’ fit. It would seem that to test models convincingly one should use the original data in full. That is one aim of this paper: to use a model that has been tested on the original data.

The very uncertainty implied by non-stationary data suggests another way in which a model using this original data could shed light on the economy in an important way that those assuming stationary data do not: they could explain the large deviations from steady time trends that economies experience from time to time, whether long-running booms or ‘crises’. The recent Great Recession is an example of the latter that is fresh in all our minds: in it the OECD economies suffered a severe drop in activity that was impossible to forecast and may also not be reversed, in the sense that output seems set to resume (possibly) its previous growth rate but not recover to its previous trend level. This description has the hallmarks of non-stationarity where random changes in GDP growth lead to permanent changes in the level of GDP. Our suggestion is that in ‘normal times’ such random changes either do not get repeated or partially reverse themselves, but that times of unusual boom or crisis are marked by ‘runs’ of several repeated changes in the same direction.

Models of crisis have been proposed before. Thus in response to currency crises (such as the Mexican and the Asian crises) work was done on open economy models in which a shift of expectations about the economy’s future would trigger a run on the currency; thus these ‘currency crisis’ models invoked expectations shocks, based on game-theoretic models of commitment and reneging — e.g. Obstfeld (1996), Burnside et al (2004). Related to these models are ‘sudden stop’ models where a country faces a collateral constraint and a shock can force it to stop borrowing by pushing it up against this constraint — e.g. Benigno et al (2009). Such models are attractive for developing countries caught in crisis and without access to deep policy instruments; they seem less appropriate to developed countries with deep financial markets, powerful central banks, governments with deep pockets and long-standing conventions of what constitutes good policy behaviour.

In response to the banking crisis of 2007—9 recent work has also built models with a banking sector which may generate crisis through either a shock to the economy which destroys collateral or a shock to the banking sector which destroys credit availability — e.g. Goodhart et al (2009). these models are clearly relevant to the recent banking crisis; as we will argue below, it is desirable to integrate anking into the models we use. However, what these models as presently constituted cannot give is an account of just where these large exogenous banking shocks arose and why. We will argue that it is indeed not these shocks that originate crises but rather more primitive shocks due to the innovatory nature of the capitalis system. Banking then is merely a conduit through which these shocks have further effects.

In addition to these models, which fall into the category of micro-founded rational expectations
we think, be too misleading even about the nature of banking crisis. Crisis behaviour lies in the non-stationary ‘real’ part of the model. Thus focusing on this alone will not, at this stage we find that when this addition is made, it is still true that the bulk of the explanation of source of shocks; this is something we are investigating in other work (eg Liu and Minford, 2012) but
Gilchrist (1999), and this can provide an extra layer of reaction to the crisis, as well as an independent crisis. A banking sector should, as just argued, be added, as for example in Bernanke, Gertler and
macro models we focus on here. The RBC models can be seen as an attempt by modern theorists such as Prescott to turn these ideas into workable mathematical form. It is a model of this type that we use here.

In this paper we propose a different approach based, within a DSGE model, on non-stationarity as briefly explained above. In this model crisis arises from random same-direction sequences of non-stationary shocks to productivity. These models are in the Real Business Cycle tradition, which in turn can be traced to Austrian economists, especially Schumpeter (1939), with their emphasis on long cycles in productivity whether in primary (commodity), secondary (manufacturing) or tertiary (service) industries; these long waves will typically in the upswing generate a capital boom at whose end the capital overhang will deepen the slump that will follow. In addition to these processes of pure innovation, we can invoke ‘supply-side’ policies that have direct and indirect effects on productivity growth; these policies are undertaken by politicians for political economy reasons that involve another class of models from the macro models we focus on here. The RBC models can be seen as an attempt by modern theorists such as Prescott to turn these ideas into workable mathematical form. It is a model of this type that we use here.

In the model here there is no banking; thus it is a model of crisis rather than specifically of banking crisis. A banking sector should, as just argued, be added, as for example in Bernanke, Gertler and Gilchrist (1999), and this can provide an extra layer of reaction to the crisis, as well as an independent source of shocks; this is something we are investigating in other work (eg Liu and Minford, 2012) but at this stage we find that when this addition is made, it is still true that the bulk of the explanation of crisis behaviour lies in the non-stationary ‘real’ part of the model. Thus focusing on this alone will not, we think, be too misleading even about the nature of banking crisis.

Thus we have here a Real Business Cycle model in which the key property (not by any means new but we would suggest underappreciated in recent macroeconomic work) is that non-stationary productivity behaviour produces periods of strong sustained growth and also periods of ‘crisis’. We regard this as a description of ‘capitalism’ at work — crisis being an inevitable ingredient in the process. We therefore reject the idea that crises can be avoided by for example regulatory policy.

The model that we use here as our example is of a medium-sized open economy, the UK; because of the complexity of the UK’s monetary arrangements over the post-war period we examine the UK’s real behaviour only, leaving inflation and other nominal variables out of account. This model has been described fully in Meenagh et al (2010); we recap it briefly below.

A further background to this paper is that Davidson et al (2010) set out in full the testing methodology we follow here, using the method of indirect inference, as applied to non-stationary data. Thus they describe the resulting empirical tests of our proposed models, something that these previous contributions have not done but would in our view need to do if they are to be contenders to explain macroeconomic events inclusive of crises. They make use of available theory to calibrate the model; and test its empirical performance; they use the original data and develop tests of the null hypothesis of the model based on this data using a Vector Error Correction Model (VECM) as the ‘auxiliary model’ within indirect inference. This method of testing is still fairly new but the idea behind it is familiar from a large literature testing models by comparing their simulated behaviour with that of the data in respect of particular relationships such as moments and cross-moments. The distinguishing feature of indirect inference is that this comparison is based on classical statistical inference and so normal significance tests can be used to evaluate the model. The idea is to generate the sampling distribution of the data implied by the model and to check whether the actual data lies within it at some chosen confidence level. In order to find this sampling distribution one needs to find the error processes implied by the model, and generate from them the random behaviour of which they are capable in repeated samples. For this the bootstrap is used since generally we are dealing with small samples to which asymptotic tests do not apply accurately. Davidson et al (2010) reported on the results of this testing procedure and found that the model we develop here for the UK was able to fit the key features of UK data — viz the volatility and interactions of GDP, the short-run real interest rate and the real exchange rate.

So the aim of this paper is to set out an empirically-based model of non-stationary economic behaviour in the hope of shedding light on causes of the turbulence that from time to time unpredictably grips the
In what follows we start with a succinct description the model (section 1). In section 2 we briefly discuss the empirical tests we have subjected it to. We then go on to discuss how its behaviour sheds light on booms and crises in a way that is entirely consistent with rational maximising agents with rational expectations (section 3). In section 4 we draw out the policy implications of this model and we conclude in section 5.

1 The Model

We posit a home economy populated by identical infinitely lived agents who produce a single good as output and use it both for consumption and investment; all variables are in per capita terms. It coexists with another, foreign, economy (the rest of the world) in which equivalent choices are made; however this other country is assumed to be large relative to the home economy we treat its income as unaffected by developments in the home economy. We assume that there are no market imperfections. At the beginning of each period $t$, the representative agent chooses (a) the commodity bundle necessary for consumption, (b) the total amount of leisure that it would like to enjoy, and (c) the total amount of factor inputs necessary to carry out production. All of these choices are constrained by the fixed amount of resources necessary to carry out production. All of these choices are constrained by the fixed amount of factor inputs necessary to carry out production.

We posit a home economy populated by identical infinitely lived agents who produce a single good as output and use it both for consumption and investment; all variables are in per capita terms. The consumption, $C_t$, in the utility function below, is composite per capita consumption, made up of agents consumption of domestic goods, $C^d_t$ and their consumption of imported goods, $C^f_t$. We treat the consumption bundle as the numeraire so that all prices are expressed relative to the general price level, $P_t$. The composite consumption utility index can be represented as an Armington (1969) aggregator of the form

$$C_t = \left[ \omega (C^d_t)^{-\varphi} + (1 - \omega) \varsigma_t (C^f_t)^{-\varphi} \right]^{\frac{1}{1-\varphi}}$$

(1)

where $\omega$ is the weight of home goods in the consumption function, $\sigma$, the elasticity of substitution is equal to $\frac{1}{1-\varphi}$ and $\varsigma_t$ is a preference error.

The composite utility index, given that an amount $C_t$ has been chosen for total expenditure, with respect to its components, $C^d_t$ and $C^f_t$ subject to $C_t = p^d_tC^d_t + Q_tC^f_t$ where $p^d_t$ is the domestic price level relative to the general price level and $Q_t$ is the foreign price level in domestic currency relative to the general price level (the real exchange rate). The resulting expression for the home demand for foreign goods is

$$\frac{C^f_t}{C_t} = [(1 - \omega)\varsigma_t]^{\varphi}(Q_t)^{-\sigma}$$

(2)

We also note that:

$$1 = \omega^{\sigma}(p^d_t)^{\sigma\varphi} + [(1 - \omega)\varsigma_t]^{\sigma}Q^\varphi_t$$

(3)

Hence we can obtain the logarithmic approximation:

$$\log p^d_t = -\left(1 - \frac{\omega}{\omega}\right)^{\sigma} \log (Q_t) - \frac{1}{\varphi} \left(1 - \frac{\omega}{\omega}\right)^{\sigma} \log \varsigma_t + \text{constant}$$

(4)

1 we form the Lagrangean $L = \left[ \omega (C^d_t)^{-\varphi} + (1 - \omega) (C^f_t)^{-\varphi} \right]^{\frac{1}{1-\varphi}} + \mu(C_t - p^d_tC^d_t - Q_tC^f_t)$. Thus $\frac{\partial L}{\partial C_t} = \mu$; also at its maximum with the constraint binding $L = C_t$ so that $\frac{\partial L}{\partial C_t} = 1$. Thus $\mu = 1$ - the change in the utility index from a one unit rise in consumption is unity. Substituting this into the first order condition $0 = \frac{\partial L}{\partial C_t}$ yields equation (2). 0 $= \frac{p^d_t}{p^f_t}$ gives the equivalent equation: $\frac{C^f_t}{C_t} = \omega^{\sigma}(p^d_t)^{-\sigma}$ where $p^d_t = \frac{p^d_t}{p^f_t}$. Divide (1) through by $C_t$ to obtain

$$1 = \left[ \omega \left( \frac{C^d_t}{C_t} \right)^{-\varphi} + (1 - \omega) \left( \frac{C^f_t}{C_t} \right)^{-\varphi} \right]^{\frac{1}{1-\varphi}}$$

(5)

substituting into this for $\frac{C^d_t}{C_t}$ and $\frac{C^f_t}{C_t}$ from the previous two equations gives us equation (3).
In a stochastic environment a consumer is expected to maximise expected utility subject to the budget constraint. Each agent’s preferences are given by

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

where $\beta$ is the discount factor, $C_t$ is consumption in period ‘$t$’, $L_t$ is the amount of leisure time consumed in period ‘$t$’ and $E_0$ is the mathematical expectations operator. Specifically, we assume a time-separable utility function of the form

$$U(C_t, 1 - N_t) = \theta_0 (1 - \rho_0)^{-1} \gamma_t C_t^{(1-\rho_0)} + (1 - \theta_0)(1 - \rho_2)^{-1} \xi_t (1 - N_t)^{(1-\rho_2)}$$

where $0 < \theta_0 < 1$, and $\rho_0, \rho_2 > 0$ are the substitution parameters; and $\gamma_t, \xi_t$ are preference errors. This sort of functional form is common in the literature for example McCallum and Nelson (1999a). Total endowment of time is normalised to unity so that

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

Furthermore for convenience in the logarithmic transformations we assume that approximately $L = N$ on average.

The representative agent’s budget constraint is

$$C_t + \frac{b_{t+1}}{1 + r_t} + \frac{Q_t b_{t+1}^f}{1 + r_t^f} + p_t S_t^p = (v_t) N_t - T_t + b_t + Q_t b_t^f + (p_t + d_t) S_t^p$$

where $p_t$ denotes the real present value of shares (in the economy’s firms which they own), $v_t = \frac{W_t}{P_t}$, is the real consumer wage ($w_t$, the producer real wage, is the the wage relative to the domestic goods price level; so $v_t = w_t \frac{p_t^R}{p_t}$). Households are taxed by a lump-sum transfer, $T_t$; marginal tax rates are not included in the model explicitly and appear implicitly in the error term of the labour supply equation, $\zeta_t$. $b_t^f$ denotes foreign bonds, $b_t$ domestic bonds, $S_t^p$ demand for domestic shares and $Q_t = \frac{P_t^f}{P_t}$ is the real exchange rate.

In a stochastic environment the representative agent maximizes the expected discounted stream of utility subject to the budget constraint. The first order conditions with respect to $C_t$, $N_t$, $b_t$, $b_t^f$ and $S_t^p$ are (where $\lambda_t$ is the Lagrangean multiplier on the budget constraint):

$$\theta_0 \gamma_t C_t^{(1-\rho_0)} = \lambda_t$$

(9)

$$(1 - \theta_0) \xi_t (1 - N_t)^{(1-\rho_2)} = \lambda_t (1 - \tau_t) v_t$$

(10)

$$\frac{\lambda_t}{1 + \tau_t} = \beta E_t \lambda_{t+1}$$

(11)

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

(12)

$$\lambda_t p_t = \beta E_t \lambda_{t+1} (p_{t+1} + d_{t+1})$$

(13)

Substituting equation (11) in (9) yields:

$$(1 + r_t) = \left( \frac{1}{\beta} \right) E_t \left( \frac{\gamma_t}{\gamma_{t+1}} \right) \left( \frac{C_t}{C_{t+1}} \right)^{-\rho_0}$$

(14)

Now substituting (9) and (11) in (10) yields

$$(1 - N_t) = \left\{ \frac{\theta_0 C_{t+1}^{(1-\rho_0)} v_t}{(1 - \theta_0) \xi_t} \right\}^{-\frac{1}{\rho_2}}$$

(15)
Substituting out for $v_t = w_t p_t^{i}$ and using (4) equation (15) becomes

$$(1 - N_t) = \left\{ \theta_0 C^{-\rho_t} \left( (1 - \tau_t) \exp \left( \log w_t - \frac{1}{\mu} (\log Q_t + \frac{1}{\rho} \log \xi_t) \right) \right) \right\}^{\frac{1}{\gamma_t}}$$

(16)

Substituting (11) in (13) yields

$$p_t = \left( p_{t+1} + d_{t+1} \right) \left( 1 + r_t \right)$$

(17)

Using the arbitrage condition and by forward substitution the above yields

$$p_t = \sum_{i=1}^{\infty} \frac{d_{t+i}}{(1 + r_t)^i}$$

(18)

i.e. the present value of a share is discounted future dividends.

To derive the uncovered interest parity condition in real terms, equation (11) is substituted into (12)

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

(19)

In logs this yields

$$r_t = r_t^f + \log E_t \frac{Q_{t+1}}{Q_t}$$

(20)

Thus the real interest rate differential is equal to the expected change in the real interest rate. Financial markets are otherwise not integrated and are incomplete, though assuming completeness makes no difference to the model’s solution in this non-stationary world.

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2It turns out that under non-stationary shocks the model solution is the same under complete contingent asset contracts. Consider contingent assets paying 1 consumption unit in specified states of the world (for example when $y_{t+T} = \bar{y}$)? Here we write the price of this asset, $P$, as

$$P_t = \beta^T u_t^{T+T}(y_{t+T} = \bar{y}) p(y_{t+T} = \bar{y})$$

(1)

One, the first, problem here is to define this probability. Since GDP has an infinite variance at T as T tends to infinity, we define the probability for a finite T. Such an asset will not be valued anyway for an ‘infinite’ T since as T tends to infinity $\beta^T$ tends to zero. In practice therefore an asset paying off in ‘infinite’ time is not interesting to a household. For earlier finite periods however $\beta^T$ is non-zero and the probabilities can be defined so that the asset is valued.

Now introduce a foreign country and allow trading of these contingent assets. We now let $y$ stand for the vector of states in both countries. The foreign country’s equivalent asset paying one unit of foreign consumption at T would be

$$P_{Ft} = \beta^T u_{Ft+T}(y_{t+T} = \bar{y}) p(y_{t+T} = \bar{y})$$

(2)

Now the price a home resident would pay for this foreign asset would be

$$P_{Ft} = \beta^T u_{Ft+T}(y_{t+T} = \bar{y}) p(y_{t+T} = \bar{y})$$

(3)

while the price a foreigner would pay for this home asset would be

$$P_t = \beta^T u_{Ft+T}(y_{t+T} = \bar{y}) p(y_{t+T} = \bar{y})$$

(4)

By equating these two values paid for each asset by home and foreign residents we obtain the Uncovered Parity contingent asset condition:

$$1 = \frac{u_{Ft+T} u_{Ft+T}(y_{t+T} = \bar{y})}{u_{Ft} u_{Ft+T}(y_{t+T} = \bar{y})}$$

(5) or

$$\ln u_{Ft+T} - \ln u_{Ft} = (\ln u_{Ft+T} - \ln u_{Ft}) + \ln Q_{t+T} - \ln Q_t$$

for any state of the world at T (6)

This ties together movements in consumption over time in the two countries with the movement in the real exchange rate. Notice that under stationary shocks the probability of the future state at $t + T$ could be defined independently of what $t$ is, provided T is large enough so that the effects of any shocks originating at $t$ have died away. This allowed Chari et al (2001) to fix $t$ at some arbitrary initial date 0 and rewrite the condition

$$\ln u_t = \ln u_{t+T} - \ln Q_T + \ln u_0 - \ln Q_0$$

(7)

We may then normalise the initial values at zero for convenience to obtain

$$\ln u_t = \ln u_{t+T} - \ln Q_T$$

(8)

However under non-stationary shocks such detachment of the condition from $t$ is impossible because the state at $t + T$ depends crucially on the state at $t$: the shocks at $t$ are permanent and therefore alter the state at $t + T$.

We may now note that taking rational expectations at $t$ of the condition we obtain:

$$E_t(\ln u_{t+T} - \ln u_t) = E_t(\ln u_{Ft+T} - \ln u_{Ft}) + E_t(\ln Q_{t+T} - \ln Q_t)$$

(9)

The lhs (by our non-contingent asset first order condition in the text — eqs 9 and 11 there) is simply $T \ln R$, the first term on the rhs is from the foreign equivalent $T \ln R_F$; if $r$ is the net real interest rate then $\ln R \approx r$ so that we obtain UIP:

$$r_t = r_F + T^{-1}(E_t \ln Q_{t+T} - \ln Q_t)$$

(10)

What we discover is that under non-stationary shocks contingent assets do not change the rational expectations equilibrium of the model from that with merely non-contingent assets. The reason is that contingent asset values depend critically on the shocks at $t$ and so do not as with stationary shocks produce a condition binding on the expected levels of variables independent of the date at which the expectation is formed.
1.1 The Government

The government finances its expenditure, $G_t$, by collecting taxes on labour income, $\tau_t$. Also, it issues debt, bonds ($b_t$) each period which pays a return next period.

The government budget constraint is:

$$G_t + b_t = T_t + \frac{b_{t+1}}{1+r_t}$$

where $b_t$ is real bonds.

1.2 The Representative Firm

Firms rent labour and buy capital inputs, transforming them into output according to a production technology. They sell consumption goods to households and government and capital goods to other firms. The technology available to the economy is described by a constant-returns-to-scale production function:

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

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.

It is assumed that $f(N,K)$ is smooth and concave and it satisfies Inada-type conditions i.e. the marginal product of capital (or labour) approaches infinity as capital (or labour) goes to 0 and approaches 0 as capital (or labour) goes to infinity.

$$\lim_{K \to 0} (F_K) = \lim_{N \to 0} (F_N) = \infty$$

$$\lim_{K \to \infty} (F_K) = \lim_{N \to \infty} (F_N) = 0$$

The capital stock evolves according to:

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

1.3 The Foreign Sector

From equation (2) we can derive the import equation for our economy

$$\log C_t^f = \log IM_t = \sigma \log (1 - \omega) + \log C_t - \sigma \log Q_t + \sigma \log \varsigma_t$$

Now there exists a corresponding equation for the foreign country which is the export equation for the home economy

$$\log EX_t = \sigma^F \log (1 - \omega^F) + \log C_t^F + \sigma^F \log Q_t + \sigma^F \log \varsigma_t^F$$
Foreign bonds evolve over time to the balance payments according to the following equation:

\[
\frac{Q_{t+1}^f b_t^f}{(1 + r_t^f)} = Q_t b_t^f + p_t^f E X_t - Q_t I M_t
\]  

Finally there is good market clearing:

\[
Y_t = C_t + I_t + G_t + E X_t - I M_t
\]

### 1.4 Calibration & Deterministic Simulation

The model is calibrated, in loglinearised form (see Model Appendix), with the values familiar from earlier work and used in Meenagh et al (2010) — see Kydland and Prescott, (1982), Obstfeld and Rogoff (1996), Orphanides (1998), Dittmar, Gavin and Kydland (1999), McCallum and Nelson (1999a, 1999b), McCallum (2001), Rudebusch and Svensson (1999), Ball (1999) and Batini and Haldane (1999); the Appendix gives a full listing. Thus in particular the coefficient of relative risk aversion \( \rho_0 \) is set at 1.2 and the substitution elasticity between consumption and leisure \( \rho_2 \) at unity. Home bias \( \omega, \omega^F \) is set high at 0.7. The substitution elasticity between home and foreign goods \( \sigma, \sigma^F \) is set at 1 both for exports and for imports, thus assuming that the UK’s products compete but not sensitively with foreign alternatives; this is in line with studies of the UK (see for example Minford et al., 1984).

Before testing the model stochastically against macro behaviour, we examine its implications in the face of a sustained one-off rise in productivity. Figure 1 shows the model simulation of a rise of the productivity level by 12% spread over 12 quarters and occurring at 1% per quarter (the increase in the whole new path is unanticipated in the first period and from then on fully anticipated) — in other words a three-year productivity ‘spurt’.

![Figure 1: Plots of a 1% Productivity increase each quarter for twelve quarters](image)

The logic behind the behaviour of the real exchange rate, \( Q \), can be explained as follows. The productivity increase 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 while real wages rise to induce extra labour and output supply. The rising real interest rate violates Uncovered Real Interest Parity (URIP) which must be restored by a real appreciation \( (Q) \) relative to the expected future value of the real exchange rate. This appreciation is made possible by the expectation that the real exchange rate will depreciate \( (Q) \) 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, \( Q \) also moves back to equilibrium. This equilibrium however
represents a real depreciation on the previous steady state (a higher Q) since output is now higher and must be sold on world markets by lowering its price.

### 1.5 Stochastic processes

The model contains 8 stochastic processes: 7 shocks and 1 exogenous variable (world consumption). Of all these only one, the productivity shock, is treated as non-stationary and modelled as an ARIMA(1,1,0) with a constant (the drift term, hence the deterministic trend). Since it is produced as an identity from the production function it can be directly measured. This is also true of all but two of the other shocks, which can be directly ‘backed out’ of their equations since they contain no expectations terms. For the two error terms in equations containing expectations, viz consumption and the capital stock, the errors are estimated by using a robust instrumental variables estimator for the expectations due to McCallum (1976) and Wickens (1982).

Other than the productivity shock the other processes are all modelled as stationary or trend-stationary ARMA (1,0) processes plus a deterministic trend. These choices cannot be rejected by the data, when they are treated as the null; however, it turns out that at the single equation level it is not easy to distinguish the two treatments, in the sense that making the alternative the null also leads to non-rejection. Hence we have used the results from the model-testing to help determine which choices to make. The choices reported here — see Table 1 — were influenced by finding that the simulated variances of key variables explode as more processes are treated as non-stationary. (Later we report the result of even treating productivity as trend-stationary; it turns out to worsen the results substantially.)

An important implication of the deterministic components of the stochastic processes is that they generate the balanced growth path (BGP) of the model. This is integrated into our simulations so that the shock elements, be they stationary or non-stationary, are added onto this basic path. In the version of the model here these deterministic components are fixed and so is therefore the BGP; of course if we were investigating policies (such as tax) that affected growth, the BGP would respond to these, however we do not do that in this paper.

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<thead>
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<th>Shock Process</th>
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<th>trend</th>
<th>AR(1)</th>
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<tbody>
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<td>Consumer Preference</td>
<td>Stationary</td>
<td>-0.039181**</td>
<td></td>
<td>0.470434**</td>
</tr>
<tr>
<td>Productivity</td>
<td>Non-Stationary</td>
<td>0.003587**</td>
<td></td>
<td>0.02902</td>
</tr>
<tr>
<td>Labour Demand</td>
<td>Trend Stationary</td>
<td>0.263503**</td>
<td>-0.002141**</td>
<td>0.854444**</td>
</tr>
<tr>
<td>Capital</td>
<td>Stationary</td>
<td>0.086334**</td>
<td></td>
<td>0.870438**</td>
</tr>
<tr>
<td>Labour Supply</td>
<td>Trend Stationary</td>
<td>0.717576**</td>
<td>-0.002946**</td>
<td>0.962092**</td>
</tr>
<tr>
<td>Exports</td>
<td>Trend Stationary</td>
<td>-1.265935**</td>
<td>0.004288**</td>
<td>0.925119**</td>
</tr>
<tr>
<td>Imports</td>
<td>Trend Stationary</td>
<td>0.007662</td>
<td>0.002505**</td>
<td>0.836784**</td>
</tr>
<tr>
<td>Foreign Consumption</td>
<td>Trend Stationary</td>
<td>-0.685495**</td>
<td>0.016268**</td>
<td>0.964308**</td>
</tr>
<tr>
<td>Foreign Interest Rate</td>
<td>Stationary</td>
<td>0.002844</td>
<td></td>
<td>0.917345**</td>
</tr>
</tbody>
</table>

**Note:** ** is significant at 1%, * is significant at 5%  

Table 1: Error Processes

### 2 Testing the model

In this section we discuss the model’s empirical closeness to the data; a full account of methods and results is given by Davidson et al (2010); this involves comparing the simulated behaviour of the model with the actual data behaviour, as summarised by a Vector Error Correction Model (VECM) estimated on both the actual and the simulated data — all the data is in natural logs or in the case of real interest rates fractions per quarter. Here we review the main findings, which are expressed as a value for the model’s Wald statistic when compared to particular features of the data (this is expressed as the percentile of the model distribution where the data lies) and also equivalently as a t-statistic derived from the square root (normalised, also called the Mahalanobis Distance) of the Wald.

We note, to start with, that as usual in such studies when a wide set of variables are entered, the model is totally rejected. For example including Y, Q, C, K and r leads to a normalised Mahalanobis Distance (a t-statistic) of 16.0, massively beyond the 95% critical value of 1.645. We therefore looked for Wald statistics comparing smaller subsets of key variables; we wish to know if the model can replicate the behaviour of some such group, and thus define its contribution. It turns out that the model can
match the behaviour of a few small subsets from among the full set. Here we show the results for the subset Y, Q and r and a summary of the subsets that get closest to the data.

The Table below shows the results for Y, Q and r. The Wald percentile is 94.1 and the normalised distance 1.47, just inside the 95% confidence bound. As part of the test we included the variances of the VECM residuals; these were well outside the model’s 95% bounds individually but inside the joint bounds with other aspects of the data. The relationships include those with the lagged productivity trend (YT) and with the lagged level of net foreign assets (BF) (these being the non-stationary exogenous variables) as well as the dynamic relationships with the lagged endogenous variables, the vector of coefficients on t and the residual variances just noted. Apart from the residual variances only one individual relationship (the partial coefficient of r on the linear time trend) lies outside its 95% bound individually; good or bad individual performances do not necessarily imply that all the relationships will lie jointly within or outside the 95% bound as this depends crucially on the covariances between the coefficients. As we see here very poor individual residual variance fits do not prevent the model overall fitting the data-estimated VECM.

<table>
<thead>
<tr>
<th>ACTUAL</th>
<th>LOWER</th>
<th>UPPER</th>
<th>IN/OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>0.923297</td>
<td>0.504512</td>
<td>0.91564</td>
</tr>
<tr>
<td>YQ</td>
<td>0.007508</td>
<td>-0.147472</td>
<td>0.187975</td>
</tr>
<tr>
<td>Yr</td>
<td>-0.123186</td>
<td>-2.004178</td>
<td>1.457887</td>
</tr>
<tr>
<td>YeYT</td>
<td>0.075655</td>
<td>-0.103227</td>
<td>0.869278</td>
</tr>
<tr>
<td>Ytrend</td>
<td>0.000163</td>
<td>-0.000628</td>
<td>0.001862</td>
</tr>
<tr>
<td>YBF</td>
<td>-0.000001</td>
<td>-0.008759</td>
<td>0.000825</td>
</tr>
<tr>
<td>Q</td>
<td>0.016965</td>
<td>-0.276842</td>
<td>0.173605</td>
</tr>
<tr>
<td>Qr</td>
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<td>0.668766</td>
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</tr>
<tr>
<td>Qtrend</td>
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<td>1.257813</td>
</tr>
<tr>
<td>QBF</td>
<td>0.040013</td>
<td>-0.281961</td>
<td>0.790734</td>
</tr>
<tr>
<td>r</td>
<td>0.000361</td>
<td>-0.000204</td>
<td>0.000549</td>
</tr>
<tr>
<td>rQ</td>
<td>0.000001</td>
<td>-0.009654</td>
<td>0.002967</td>
</tr>
<tr>
<td>rY</td>
<td>-0.006923</td>
<td>-0.016501</td>
<td>0.030427</td>
</tr>
<tr>
<td>rQ</td>
<td>-0.006611</td>
<td>-0.032523</td>
<td>-0.00601</td>
</tr>
<tr>
<td>rY</td>
<td>0.676981</td>
<td>0.571356</td>
<td>0.857914</td>
</tr>
<tr>
<td>rQ</td>
<td>0.006402</td>
<td>-0.038497</td>
<td>0.052605</td>
</tr>
<tr>
<td>rBF</td>
<td>0.000047</td>
<td>-0.000223</td>
<td>0.000026</td>
</tr>
<tr>
<td>rQ</td>
<td>0.000002</td>
<td>-0.000781</td>
<td>0.000038</td>
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<tr>
<td>var(Y)</td>
<td>0.000039</td>
<td>0.000358</td>
<td>0.004198</td>
</tr>
<tr>
<td>var(Q)</td>
<td>0.000328</td>
<td>0.000440</td>
<td>0.005493</td>
</tr>
<tr>
<td>var(r)</td>
<td>0.000009</td>
<td>0.000012</td>
<td>0.000031</td>
</tr>
<tr>
<td>Wald</td>
<td>94.0686</td>
<td>1.4706</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: VAR results

The table of subset results reveals that GDP and asset prices are well explained as we have seen but that combining these with consumption or employment leads to being rejected at 99%. Also GDP and

<table>
<thead>
<tr>
<th>Subset</th>
<th>Wald percentile</th>
<th>Transformed M-dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP + asset prices (+consumption or employment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>YQr</td>
<td>94.1</td>
<td>1.47</td>
</tr>
<tr>
<td>YQC</td>
<td>86.4</td>
<td>0.72</td>
</tr>
<tr>
<td>YQCr</td>
<td>99.8</td>
<td>5.71</td>
</tr>
<tr>
<td>YQNr</td>
<td>99.9</td>
<td>6.52</td>
</tr>
</tbody>
</table>

| GDP + Labour market bloc | | |
| YQw                     | 100              | 18.15             |
| YQN                     | 80.0             | 0.36              |
| YQNW                    | 100              | 19.70             |

Table 3: Table of summary results for various variable subsets
the real exchange rate match the data when combined with either employment or consumption instead of the real interest rate. Summarising one can say that the model fits the data on GDP and the two main asset prices but cannot also match the detailed behaviour of component real variables.

Thus the model passes well for a small set of key variables. That it fails for a broader set is a problem this model appears to share with much more elaborate structures, such as the Christiano et al. (2005)/Smets-Wouters (2007) model (see Le et al., 2011), with their huge efforts to include real rigidities such as habit persistence and variable capacity utilisation, as well as Calvo nominal rigidities in both wages and prices. When these are tested on stationarised data Le et al. (2011) find that invariably the inclusion of consumption wrecks the fit; however they can find a good fit to US data post-1984 for output, real interest rates and inflation taken alone. On a similar two-country model of the US and the EU, again on stationarised data, Le et al. (2010) find that it can fit output and the real exchange rate on their own but no wider set of variables.

We interpret these tests to mean that this model performs rather well in the context of model performance generally, at least in the present state of the DSGE modelling art.3

3 Simulated behaviour of the model: ‘euphoria’ and ‘crisis’

When non-stationary shocks hit this economy they produce permanent changes in income, consumption, capital stock and the real exchange rate, as well as a path to the new equilibrium. But of course each period brings a fresh set of permanent shocks so that the economy is constantly moving towards a new freshly-set equilibrium. When a combination of shocks occurs that is negative for the output equilibrium and a sequence of shocks of this type occur in the same direction, output can fall sharply in what looks rather like a crisis or ‘disaster’. We illustrate this point with a randomly chosen bootstrap simulation for the UK economy over the 200-plus quarters of the sample (from the late 1940s to the early 2000s); it is taken from a very large number of such simulations, some of which are shown in Figure 2 including the BGP trend. Inspection of these random scenarios reveals that euphoric and nasty episodes are not uncommon. In Figure 3 we show the actual residuals or shocks we found were implied by this model and for the UK post-war data.

We now take the particular randomly chosen simulation referred to above and examine it in some detail. In Figure 4 we show the shocks used in this particular scenario. Figure 5 shows what they give in terms of output alone including its BGP trend — we have put the post-war years along the x axis to show that one can think of this as a ‘rerun’ of the post-war period with shocks selected in a different order. We can focus on three sharp downswings here (the shaded part of the shock charts below), after quarter 18 (around the year 1963), quarter 78 (around the year 1978) and quarter 122 (around the year 1989). In each case the large negative shocks to productivity dominate the situation. For example in the second period after 25 or so quarters of rapid growth, it levels off for the next 15 quarters before then plunging for the following 20 quarters — this is the second period shaded on the shock charts. This precipitates a similar profile in output. Productivity dominates because it is the only non-stationary shock in the model. The other shocks contribute but because they are stationary only temporarily. The result is the collapse of output we see; notice that competitiveness varies directly with output because the more is produced the higher competitiveness has to be to sell the extra output (i.e. UK relative prices have to be lower to sell it). The units here are natural logarithms, so that these are substantial movements in output and competitiveness — maybe a bit too substantial for realism but then this is still a fairly primitive model, and the first we have built of its type. But the presence of the crisis element will, we think, remain valid as we introduce more sophistication into the model.

---

3 One issue we have not so far emphasised but one that is nevertheless of empirical importance concerns our choice of error specification. Many of our error processes are not unambiguously either trend-stationary or non-stationary: that is, when we test the null of trend-stationarity we cannot reject it (at say 95% confidence) but neither can we reject the null of non-stationarity. Essentially this is because the distribution of the autoregressive coefficient is different under the two nulls. Hence in entering these errors into the DSGE model we need to make a choice that cannot be made on purely statistical grounds. The way we treat this is the same way that we treat the rest of the DSGE model specification choice where we have one; we reject one versus the other on the basis of indirect inference. We chose only to make productivity non-stationary because making the other errors non-stationary induced massively excessive variability in our key macro variables. However, this leaves the question whether even productivity should be trend-stationary, rather than non-stationary. Here we test the DSGE model under the assumption of trend-stationary productivity. Our findings are that the fit to the data worsens sharply, so that the subset of key variables that can be matched shrinks to none at all: the nearest is Y,Q,r whose Wald is 98.6 and M distance 3.65, hence rejected at 95% but accepted at 99% only. All others we looked at above are rejected at the 99% level. This gives rather clear evidence that treating productivity as non-stationary was the right choice. Thus we do not pursue this alternative representation of the model further.
Figure 2: Selected Output Simulations

Figure 3: Shocks
Figure 4: Shocks to Chosen Simulation

Figure 5: Output Simulation
4 Policy Implications

The policy conclusion from this analysis is a gloomy one: ‘capitalism’, in which large bets are taken on available information, will generate ‘crises’ periodically for particular sectors where the bets go wrong after the event. Occasionally the sector in question will be or will include the banking sector and we will have a banking crisis. Since it is generally agreed that we cannot let a banking system, or nowadays more broadly a financial system, fail, then because the required bail-out is costly to the taxpayer the taxpayer will insist on regulation to control the cost when the inevitable happens.

Since these crises result from exogenous non-stationary productivity shocks (which then interact with the normal propagating mechanisms of the economy) there is no possibility under the capitalist system of predicting or preventing them; these shocks reflect the innovatory nature of capitalism. Thus only if capitalism was abandoned in favour of planning, so that innovation became state-controlled, would prediction and control be possible; however, we assume in this paper that capitalism is generally accepted as part of the modern economy on the usual grounds that it produces better long-term economic results and preserves political and economic freedom.

The only role that regulation could perform would be that of modifying somehow the propagating mechanisms in the economy, so as to mitigate (or ‘cure’) the worst aspects of the crises that will inevitably occur. To this question we now turn.

4.1 Regulation

What can be meant by ‘cure’ when the crisis is inevitable (even though unpredictable)? Here we focus on regulation of banking; it is possible to think of regulations on other propagating mechanisms, such as investment or consumption, but these have not been much mentioned in the current policy debates, perhaps on the grounds that they are an inherent part of the capitalist economy that it would be dangerous to meddle with.

Banking regulation measures could be proposed that can either reduce the chances of a banking crisis, viewed as a propagating mechanism of the original productivity shocks, or reduce the fall-out from it. The main cure suggested is, following the logic above, regulation of bank risk; we had Basel I and then Basel II (which was not fully operative at the time of the crisis) and some have suggested modifications to Basel II such as pro-cyclical risk capital provision. Basel III contains such modifications.

Taxpayers clearly have the right to demand such safeguards to limit the potential calls on their resources. However, the problem does not stop there. We had regulations before this crisis but in many countries the politicians saw that they were disregarded; thus in the UK the new tripartite system of regulation from 1997 gave the Financial Services Authority power to control the banks, and the FSA has reported in its own defence that it was instructed by the government to do ‘light-touch regulation’—i.e. effectively it let the UK banks load up risk off-balance sheet with impunity. Thus we note that the reappearance in this context of the well-known problem of time-inconsistency, whereby politicians can be persuaded for short-term reasons to override sound previous instructions. Thus ‘quis custodiet ipsos custodes?’—which translated asks: ‘how will we keep control of the regulating government itself?’

In the area of other policies where this time-inconsistency crops up the remedy has been that public opinion should discourage politicians from such interfering overrides. For example we frown on politicians interfering with sentencing in law courts, or nowadays with the setting of interest rates. For public opinion to impose this discipline on politicians it needs to be both well educated in the issues at stake and well informed about the facts. In the case of the banking and financial system neither is the case. The system is poorly understood (even upmarket newspapers can describe financial market participants as ‘greedy’ and short-selling as ‘evil’) and as for information it is by law restricted to the regulators themselves. As Beenstock (2009) has argued, it is important that regulators release this information to the public so that restraint on participants from public opinion can be operative. This restraint will work directly on the share prices of those taking excessive risks and indirectly through the political process.

So while there can be no ‘cure’ in the sense of preventing bank crises, there can be some reduction of the social cost when crises occur through regulation of risk-taking and through the release of information about the risk-takers. The actual cost to the taxpayer in taxes and transfers we neglect as taxes can always be raised retrospectively to pay for necessary transfers or bail-outs, in principle from the same sectors or households that received the transfers. While these operations in practice may create second order social costs through distortions, the first order loss is from the loss of output due to the collapse of credit and resulting recession.

So we can see that some regulation to reduce the costs of crises can be justified. These can be compared
to the regulations on motorway speeds and other behaviour, to reduce the costs of motorway accidents when they (inevitably) occur. However, there would be a major cost in over-regulating the financial system, one of the key capitalist mechanisms. A major need in regulation is for disclosure so that risks can be more accurately judged by private agents. For banks with deposit or other guarantees existing regulations already substitute for the discipline of depositor anxiety. Striking a balance between reducing crisis costs and reducing the dynamism of the economy is not easy; but current regulatory pressures, fed by populist resentment of ‘bankers’ excesses’. look like driving the balance towards excessive damage to dynamism.

4.2 Firefighting or pre-emption?

Another obvious implication of this crisis analysis is that governments and central banks (their ‘front office’) must stand ready to ‘firefight’ a financial crisis, with all the means that have become familiar in this crisis, where fortunately they were deployed to good effect. This process is a massive extension to the whole financial sector of Bagehot’s ‘lender of last resort’ support, necessitated by the connectedness of the sector as well as its key role in capitalism.

Against this it is argued that moral hazard will be created making financial risk-taking greater and so increasing the probability of crisis. It is true of course that all insurance schemes, such as the provision of fire engines, create some moral hazard. This needs to be controlled, much as it is controlled in private insurance mainly by co-insurance. In financial crisis this co-insurance takes the form of the larger losses equity and bondholders take when crisis occurs.

As we have seen, since these crises cannot be prevented, there is no alternative to firefighting afterwards. A discussion has existed for some time about whether central banks should pre-empt a crisis by for example targeting asset prices or should ‘clean up after’ (firefighting). Since crises cannot be forecast, it is clear that they cannot take advance action to avoid them — pre-emption is not possible. This applies as much to central bank asset price rules as it does to their forecasting procedures for ‘spotting’ crisis brewing. We can leave on one side whether adding asset prices to the central bank’s interest-rate-setting rule improves its operating characteristics for other reasons. But one thing is clear: their inclusion will not allow the central bank implicitly to ‘forecast’ crisis since the random shocks triggering the crisis cannot be forecast.

4.3 How did this crisis come about?

We have argued that this crisis, for all the failures of regulation and incentives, has to be seen as one of a line of capitalist crises (that look like ‘bubbles’), in which bad news comes hard on the heels of a long period of good news. The resulting crash is worse when it involves the banking and financial system — as often is the case since these are sucked into long periods of expansion into large credit and asset positions. However, this still leaves unclear what bad news it was that precipitated the end of the world expansion fed by the good news since 1992. As we argued above the main factor significant for the economy is productivity; this drives production, consumption and housing demand in particular, all symptoms of the underlying productivity success. It is not hard to see the huge exploitation of the computer as the engine of this long productivity miracle.

What brought this process to a shuddering halt during 2008? We saw during 2007 and 2008 a dramatic upsurge in commodity prices, especially oil. It began to become clear that with emerging market economies like China growing at up to 10 percent a year the demands for commodities would quickly outrun supplies. A similar thing had happened in the 1970s; but this triggered large-scale substitution away from the use of oil and other scarce raw materials so that by the 1990s commodity prices languished at nugatory levels and substitution slowed with them. But by the late 2000s this slowing substitution had been overtaken again by the massive growth in the decade and half from 1992. Productivity growth fuelled by the computer hit a wall of raw material shortage again. For it to restart will require productivity growth in raw material technology — i.e. more substitution. The mechanism by which much higher raw material prices has slowed productivity growth is something that has been inadequately researched; but it seems to be a mixture of a severe terms of trade change directly depressing living standards, a reduction in capital productivity (especially for energy-intensive production), perhaps accompanied by increased capital scrapping, and an increase in policy-making uncertainty (e.g. Ni and Ratti, 2009) in the face of ‘hard times’. The facts in the UK post-crisis are stark: by general agreement among forecasters the UK ‘trend’ in output has taken a 10% drop: ‘excess capacity’ is estimated at between 0 and 3% currently (end 2011) and yet if the previous trend of potential output had prevailed
it would be around 13%.

It is not possible to see a return to the rapid growth rate of the UK or the western world in the mid-2000s until productivity growth has managed to eliminate the new scarcity of raw materials. While the crisis has led to effective firefighting in the post-Lehman phase, and not so effective firefighting in its eurozone sovereign debt phase, the immediate macro prospect — even if the eurozone crisis is resolved — is at best for a return to moderate growth in the West in line with the restraint placed on productivity growth by current raw material shortage.

5 Conclusions

The economy operates under the influence of non-stationary shocks, mainly productivity. These can be considered as a source of ‘Knightian uncertainty’. It is possible for the economy to enjoy a long period of steady strong growth when productivity growth is favourable; and then if that growth turns unfavourable — for example because of shortages of key resources as seems to have happened in the mid-2000s — it can collapse as over-investment (as seen with hindsight) takes a toll on business plans. Such a collapse is a ‘crisis’ and it will usually create a financial crisis among the intermediaries that financed the previous growth and the over-investment.

In this paper we have built a Real Business Cycle model without a banking system to model this crisis tendency which we argue comes from the behaviour of productivity, the fundamental shock driving the economy. We have argued that a banking crisis could occur additionally in consequence of a productivity-created crisis if the banks were heavily involved in lending to the affected sectors. But the crisis is severe with or without the accompanying banking crisis.

We have tested the model’s empirical performance by the method of indirect inference under which we ask whether its simulated behaviour produces relationships in the simulated data like those in the actual data. Though our data here is non-stationary our use of a VECM as the auxiliary equation appears to deal with the non-stationarity satisfactorily, according to Monte Carlo experiment. We found that if we require the model to replicate broad macro behaviour — i.e. here that of output, real interest rates and the real exchange rate — it can meet this indirect inference test rather well.

Thus our first innovation in this paper is to return to the original RBC model with non-stationary productivity and in an open economy as a way of explaining UK macro behaviour inclusive of occasional violent movement. Our second innovation is to test this model statistically against postwar UK data using the method of indirect inference. Perhaps against professional expectation we found that this model does fit key aspects of post-war UK behaviour.

We then showed a typical simulation of the post-war period produced by randomly drawing shocks in a different order. In this simulated post-war scenario crisis periods are clearly visible — just as indeed they occurred in actual fact during the post-war period, though at different times and with differing intensities.

We argue therefore that crises of this sort, as well as the run of ‘good times’ that usually precede them, are endemic in capitalism, that is the free play of decentralised markets. Few policymakers today would wish to trade capitalism for a centralized, planned economy because there is ample evidence that in the long term capitalism delivers higher growth. But this carries some broad policy implications for them; they cannot forecast or pre-empt crises, and therefore the best they can do is to regulate to prevent the worst spill-overs of crisis and also ‘firefight’ them once they have occurred.

In future research we hope to model the mechanisms that can trigger a banking crisis on top of the originating productivity crisis. But we hope at least in this paper to have shown how crises can be triggered by the normal operations of the economy, even when agents are acting with complete rationality.
References


Appendix: Listing of the RBC Model

6.1 Behavioural Equations

1. Consumption \( C_t \); solves for \( r_t \):

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

\[
\log(1 + r_t) = -\rho_0(\log C_t - E_t \log C_{t+1}) + \log \gamma_t - E_t \log \gamma_{t+1} + c_0
\]

Here we use the property that for a lognormal variable \( x_t \), \( E_t \log x_{t+1} = \log E_t x_t + 0.5\sigma^2_{\log x} \). Thus the constant \( c_0 \) contains the covariance of \( -\rho_0 \log C_{t+1} \) with \( (\log \gamma_{t+1}) \).

2. UIP condition:

\[
r_t = r_t^F + E_t \log Q_{t+1} - \log Q_t + c_1
\]

where \( r^F \) is the foreign real interest rate.

Note that equations (1) and (2) are combined.

3. Production function \( Y_t \):

\[
Y_t = Z_t N_t \alpha K_t^{1-\alpha} \quad \text{or} \quad \log Y_t = \alpha \log N_t + (1 - \alpha) \log K_t + \log Z_t
\]

4. Demand for labour:

\[
N_t = \left( \frac{\alpha Y_t}{w_t(1 + \chi_t)} \right) \quad \text{or} \quad \log N_t = c_2 + \log Y_t - \log w_t + \chi_t
\]

5. Capital:

\[
\xi(1 + d_{tt}) K_t = \xi K_{t-1} + \xi d_{tt} E_t K_{t+1} + \frac{(1 - \alpha) Y_t}{K_t} - (r_t + \delta + \kappa_t) \quad \text{or} \quad \log K_t = c_3 + \zeta_1 \log K_{t-1} + \zeta_2 E_t \log K_{t+1} + (1 - \zeta_1 - \zeta_2) \log Y_t - \zeta_3 r_t - \zeta_3 \kappa_t
\]

6. The producer wage is derived by equating demand for labour, \( N_t \), to the supply of labour given by the consumer’s first order conditions:

\[
(1 - N_t) = \frac{\theta_0 C_t^{-\rho_0} \left[ \exp \left( \log w_t - \frac{1 - \omega}{\omega} \sigma (\log Q_t + \frac{\delta}{\omega} \log \xi_t) \right) \right]}{(1 - \theta_0) \xi_t}
\]

\[
\log(1 - N_t) = -\log N_t = c_4 + \frac{\rho_0}{\rho_2} \log C_t - \frac{1}{\rho_2} \log w_t + \frac{1}{\rho_2} \left( \frac{1 - \omega}{\omega} \right)^{\sigma} \log Q_t
\]

\[
+ \frac{1}{\rho_2} \left( \frac{1 - \omega}{\omega} \right)^{\sigma} \log \xi_t + \frac{1}{\rho_2} \log \xi_t
\]

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

7. Imports \( IM_t \):

\[
\log IM_t = \sigma \log (1 - \omega) + \log C_t - \sigma \log Q_t - \sigma \log \xi_t
\]

8. Exports \( EX_t \):

\[
\log EX_t = \sigma^F \log (1 - \omega^F) + \log C_t^F + \sigma^F \log Q_t - \sigma^F \log \xi_t^F
\]

6.2 Budget constraints, market-clearing and transversality conditions:

9. Market-clearing condition for goods:

\[
Y_t = C_t + I_t + G_t + EX_t - IM_t
\]
where investment is :

\[ I_t = K_t - (1 - \delta)K_{t-1} \]

and we assume the government expenditure share is an exogenous process. Loglinearised using mean GDP shares, this becomes

\[ \log Y_t = 0.77 \log C_t + 6.15(\log K_t - \log K_{t-1}) + 0.3 \log G_t + 0.28 \log EX_t - 0.3 \log IM_t \]

(10) Evolution of \( b_t \); government budget constraint:

\[ b_{t+1} = (1 + r_t)b_t + PD_t \]

(11) Dividends are surplus corporate cash flow:

\[ d_t S_t = Y_t - N_t w_t - K_t(r_t + \delta) \]

(12) Market-clearing for shares, \( S_{t+1}^p \):

\[ S_{t+1}^p = S_t \]

(13) Present value of share:

\[ p_t = E_t \sum_{i=1}^{\infty} \frac{d_{t+i}}{(1 + r_t)^i} \]

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

(14) Primary deficit \( PD_t \):

\[ PD_t = G_t - T_t \]

(15) Tax process \( T_t \) designed to ensure convergence of government debt to transversality condition:

\[ T_t = T_{t-1} + \gamma^G \frac{(PD_{t-1} + b_t r_t)}{Y_{t-1}} \]

(16) Evolution of foreign bonds \( b_t^f \):

\[ \frac{Q_t b_{t+1}^f}{(1 + r_t^f)} = Q_t b_t^f + EX_t - Q_t IM_t \]

(17) Evolution of household net assets \( A_{t+1} \):

\[ A_{t+1} = (1 + r_{At})A_t + Y_t - C_t - T_t - I_t \]

where \( r_{At} \) is a weighted average of the returns on the different assets.

(18) Household transversality condition as \( T \to \infty \):

\[ \Delta(\frac{A_T}{Y_T}) = 0 \]

(19) Government transversality condition \( T \to \infty \):

\[ \Delta(\frac{b_T}{Y_T}) = 0 \]
6.3 Values of coefficients

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value — Single equation</th>
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<tr>
<td>$\beta$</td>
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<td>$\delta$</td>
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6.4 Model solution methods

The model is solved in the loglinearised form above using a projection method set out in Minford et al. (1984, 1986); it is of the same type as Fair and Taylor (1983) and has been used constantly in forecasting work, with programme developments designed to ensure that the model solution is not aborted but re-initialised in the face of common traps (such as taking logs of negative numbers); the model is solved by a variety of standard algorithms, and the number of passes or iterations is increased until full convergence is achieved, including expectations equated with forecast values (note that as this model is loglinearised, certainty equivalence holds). Terminal conditions ensure that the transversality conditions on government and households are met — equivalent to setting the current account to zero). The method of solution involves first creating a base run which for convenience is set exactly equal to the actual data over the sample. The structural residuals of each equation are either backed out from the data and the model when no expectations enter as the values necessary for this exact replication of the data; or, in equations where expectations enter, they are estimated using a robust estimator of the entering expectations as proposed by McCallum (1976) and Wickens (1982), using instrumental variables; here we use as instruments the lagged variables in univariate time-series processes for each expectational variable. The resulting structural residuals are treated as the error processes in the model and together with exogenous variable processes, produce the shocks perturbing the model. For each we estimate a low-order ARIMA process to account for its autoregressive behaviour. The resulting innovations are then bootstrapped by time vector to preserve any correlations between them. Two residuals only are treated as non-stochastic and not bootstrapped: the residual in the goods market-clearing equation (the GDP identity) and that in the uncovered interest parity (UIP) condition. In the GDP identity there must be mis-measurement of the component series: we treat these measurement errors as fixed across shocks to the true variables. In the UIP condition the residual is the risk-premium which under the assumed homoscedasticity of the shocks perturbing the model should be fixed; thus the residuals represent risk-premium variations due to perceived but according to the model non-existent movements in the shock variances. We assume that these misperceptions or mismeasurements of variances by agents are fixed across shocks perturbing the model — since, although these shocks are being generated by the true variances, agents nevertheless ignore this, therefore making these misperceptions orthogonally.

To obtain the bootstraps, shocks are drawn in an overlapping manner by time vector and input into the model base run (including the ARIMA processes for errors and exogenous variables). Thus for period 1, a vector of shocks is drawn and added into the model base run, given its initial lagged values; the model is solved for period 1 (as well as the complete future beyond) and this becomes the lagged variable vector for period 2. Then another vector of shocks is drawn after replacement for period 2 and added into this solution; the model is then solved for period 2 (and beyond) and this in turn becomes the lagged variable vector for period 3. Then the process is repeated for period 3 and following until a bootstrap simulation is created for a full sample size. Finally to find the bootstrap effect of the shocks the base run is deducted from this simulation. The result is the bootstrap sample created by the model’s shocks.
We generate some 1500 of such bootstraps. We add these bootstraps to the Balanced Growth Path implied by the model and the deterministic trend terms in the exogenous variables and error processes. We find this BGP by solving for the effect of a permanent change in each error/exogenous variable at the terminal horizon $T$; we then multiply this steady-state effect by the deterministic rate of change of this variable. When this BGP is incorporated in every bootstrap we have 1500 full alternative scenarios for the economy over the sample period; these bootstrap samples are then used in estimation of the VECM auxiliary equation.

To generate the model-implied joint and individual distributions of the parameters of the VECM estimated on the data, we carry out exactly the same estimation on each bootstrap sample. This gives us 1500 sample estimates which provide the sampling distribution under the null of the model. The sampling distribution for the Wald test statistic, $[a_T - \alpha_S]'W[a_T - \alpha_S]$, is of principal interest. We represent this as the percentile of the distribution where the actual data-generated parameters jointly lie. We also compute the value of the square root of this, the Mahalanobis distance, which is a one-sided normal variate; we reset this so that it has the 95% value of the variate at the same point as the 95th percentile of the bootstrap distribution (which is not necessarily normal). This ‘normalised Mahalanobis Distance’ we use as a measure of the distance of the model from the data under the bootstrap distribution. Its advantage is that it is a continuous variable representation of the theoretical distribution underlying the bootstrap distribution — which is made finite by the number of bootstraps.