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WHAT CAUSES BANKING CRISES? AN EMPIRICAL INVESTIGATION FOR THE WORLD ECONOMY

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ABSTRACT

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Keywords: banking, DSGE and indirect inference

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What causes banking crises? An empirical investigation for the world economy*

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November 2012

Abstract

We add the Bernanke-Gertler-Gilchrist model to a world model consisting of the US, the Eurozone and the Rest of the World in order to explore the causes of the banking crisis. We test the model against linear-detrended data and reestimate it by indirect inference; the resulting model passes the Wald test only on outputs in the two countries. We then extract the model's implied residuals on unfiltered data to replicate how the model predicts the crisis. Banking shocks worsen the crisis but 'traditional' shocks explain the bulk of the crisis; the non-stationarity of the productivity shocks plays a key role. Crises occur when there is a 'run' of bad shocks; based on this sample Great Recessions occur on average once every quarter century. Financial shocks on their own, even when extreme, do not cause crises — provided the government acts swiftly to counteract such a shock as happened in this sample.

1 Introduction

Since the banking crisis controversy has surrounded available macroeconomic models. They have been criticised for failing to predict the crisis. While clearly the models imply that it is impossible to predict crises, one might consider this to be a strength rather than a weakness since if it were possible to predict such a crisis, then it would surely have been widely predicted (and no doubt thus avoided). Thus models seem in this respect to mirror the actual situation. Nevertheless they did fail — much more seriously — to predict the possibility of crisis because they contained no mechanisms that could produce it. Thus they had no banking sector, so that *a fortiori* no banking crisis could occur. Furthermore they embodied only stationary shocks so that permanent shocks to the level of trend output, such as appear to characterise crisis episodes, were not examined; true, in the background there was possibly a non-stationary trend in productivity (typically removed by filtering from the model data) but there was not much focus on this in practice. A further issue concerns their ability to fit the facts; economists such as Heckman [1] have attacked the lack of empirical content in macro models, implying that it is hardly surprising they could give little guidance to policy in the crisis.

Le, Meenagh and Minford (2012) addressed these issues within a model of the US. Here we address them, using essentially the same procedures, within a 'world' economy model, in which we link a model of the US with a model of the euro-area (EA) and add a trade bloc for the Rest of the World. This wider effort seems worthwhile since the crisis was international in scope. We build on recent work in various ways. The model incorporates monetary linkages that can be thought of as a form of informal policy coordination; these have been found by Hong and Minford (2012) to greatly improve the fit of the model to the data and incidentally reduce the improbable 'orthogonality' found by Le, Meenagh, Minford and Wickens (Le et al, 2010) between the US and the EA under monetary independence. We also integrate the familiar Bernanke et al (1999) banking sector model into the widely-used Smets-Wouters-style DSGE model (as adapted by Le et al, 2011) for each economy. We test the model unconditionally against the data and re-estimate it to enable it to fit as closely as possible; this is important as it ensures that the

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[1] '. . . Macroeconomics is not a science, it's a patchwork of theorems and bad data. There is little serious work on the subject, which seems dominated by beliefs' (Heckman, 2010, interview in The Observer)

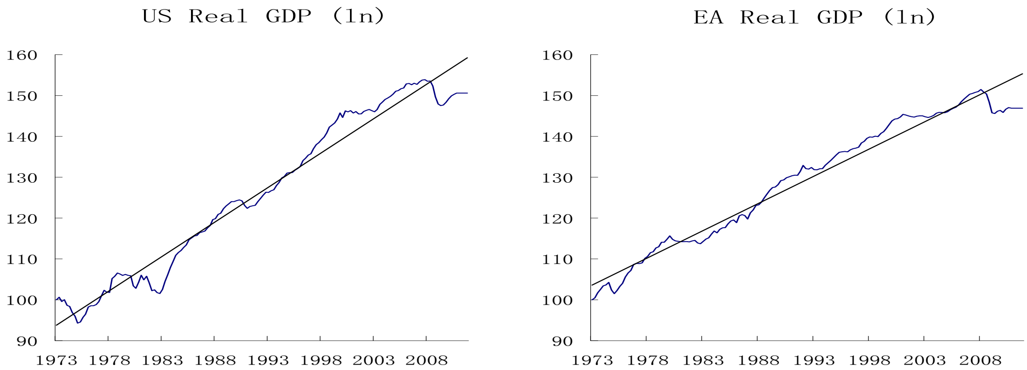

Figure 1: US/EA output: trend and volume

origins of the shocks are accurately measured and their effects not exaggerated. Finally, we then apply it to unfiltered data to extract the potentially non-stationary shocks the model implies, and use these to give an account of what produced this banking crisis, relating this finding to the current policy debate.

Since the crisis, much work has been done to incorporate a banking sector into DSGE models. The banking models involve a friction in the intermediation process based on Townsend's (1979) costly state verification set-up so that the interest margin required reflects the risk of loan default. This risk varies with the state of the economy because the willingness of the private sector to invest and therefore borrow varies directly with the expected return on capital. The exact transmission between the state and the risk-premium differs across the various banking models that have been proposed but that of Bernanke, Gertler and Gilchrist (1999) has been designed to capture many of the common features of these models; it is their set-up that we therefore use here as a representative one. In it, the IS curve now includes a variable risk-premium which is related to the economic state. We examine the empirical performance of this model and establish how far the banking element contributes to the overall explanation of crisis episodes.

We use the method of indirect inference in preference to Bayesian or Maximum Likelihood methods of testing and estimation because we have found in recent work (Le et al., 2012) that the Wald test in indirect inference has considerably greater power than the equivalent tests available with these other methods in testing the whole model against the data. Thus we use the Wald test to allow the data to reject potential models as a whole and we then use a powerful Simulated Annealing algorithm to search over the model's permissible parameter range for the set that gets closest to the data behaviour.

An important element in 'crisis' episodes is the permanence of crisis shocks. The graphs of US and EA show rather clearly how output has collapsed below the old trend line and shows little sign of reverting to it. This also seems to have occurred after the Great Depression in the US and after the oil crisis of the mid-1970s in most western economies. Thus the trend level seems to take a permanent hit in these crisis episodes. Furthermore the same appears to be true in reverse for periods of strong growth, such as the US in the late 90s and early 2000s; the output trend in these periods gets shifted upwards permanently. This suggests that the productivity and perhaps other shocks hitting the economy are non-stationary. Hence here our aim is to model the economy under potentially nonstationary shocks.

While the banking crisis originated in the US, it spread to the rest of the world rapidly; thus our model here is for a 'world' that consists of two main economies, the US and the EA, with a third Rest of the World sector which picks up trade flows of the two main continents with other countries, so that the model spans world trade. For each continental economy our strategy is to take the well-known and empirically relatively successful models built by Smets and Wouters (2007, 2003, SW), and add to each the banking model due to Bernanke, Gertler and Gilchrist (1999, BGG). Variants of the combination of SW and BGG have been used in recent papers by Christiano, Motto & Rostagno (2010) for the US and Eurozone separately; Gilchrist et al. (2009) for the US alone and Fahr et al (2011) for the Eurozone alone. They find that shocks that come from the financial sector have an important role in explaining macroeconomic fluctuations. All these authors use the Bayesian approach to estimating the model parameters. We modify the Smets-Wouters set-up along the lines set out in Le et al (2011) by allowing for a competitive sector in both the labour and the product markets; this modification allows the models to fit the data behaviour better, reflecting the great variability across sectors in price and wage flexibility as noted by Dixon and coauthors (eg Dixon and Kara, 2012). We also follow the recent work of Hong and Minford (2012) in which evidence is found of monetary reactions by both the US Fed and EA's central bank(s) to each other's policies- this is modelled as a reaction by each to the US/EA real exchange rate.

What distinguishes our work from other recent papers modelling the crisis is three main things. First, we use a world model, whereas previous work uses models of individual countries; we hope in this way to pick up the global reach of the crisis. Second, we make the models pass an empirical hurdle of fitting the data behaviour overall on the indirect inference test. If, as we find, the original (calibrated or more often Bayesian) parameters do not pass the test, we search for parameters that get closest to the data according to this test; and we only finally use a parameter set that passes the test for the variables we want to explain. We think this empirical hurdle is necessary in this particular area because while it is possible to construct models that generate large financial accelerator effects by suitable choice of priors, the parameter sets that get closest to an overall fit to the data do not give anywhere near such large effects; it seems they cannot be found in the data. Third, we use this estimated model to extract the true residuals from the original unfiltered data. While we are forced by currently available technology to estimate the model on data that has been linear-detrended to make it stationary, we find it is crucial in accounting for the crisis to include all the data and hence also the full residuals, with their non-stationary elements.

The paper is organised as follows. We begin in section 2 by giving a brief account of the model. In section 3 we examine the results of empirical tests of the model with its original calibrated or Bayesian coefficients; we then re-estimate it to obtain the version that gets closest to the data; this is done on stationary data, for which testing and estimation methods are fully developed. In section 4, we apply the model as re-estimated to the original unfiltered data and consider what light it sheds on the causes of this banking crisis as well as of crises and banking crises in general. Section 5 concludes and draws out some implications for policy.

2 The SW and BGG models

2.1 The SW model of the US and EA economy

The SW models of the US and EA (2003, 2007) follow the specification of Christiano et al (2005) which itself marked a major development in macroeconometric modelling based on DSGE models. Their main aim is to construct and estimate a DSGE model in which prices and wages, and hence real wages, are sticky due to nominal and real frictions arising from Calvo pricing in both the goods and labour markets, and to examine the consequent effects of monetary policy which is set through a Taylor rule. It may be said, therefore, to be a New Keynesian model. In deciding the model coefficients SW combine both calibration and Bayesian estimation methods on post-war quarterly data.

Smets and Wouters made various tests of their models. Subsequently Del Negro, Schorfheide, Smets and Wouters (2007, DSSW) further examined the US model by considering the extent to which its restrictions help to explain the data. Estimating the SW model using Bayesian methods, they approximate it by a VAR in vector error-correction form and compare this with an unrestricted VAR fitted to actual data that ignores cross-equation restrictions. They introduce a hyperparameter λ to measure the relative weights of the two VARs. $\widehat{\lambda}$ is chosen to maximise the marginal likelihood of the combined models given the priors. DSSW find that this estimate of λ is a reasonable distance away from $\lambda = 0$, its value when the restrictions are ignored, but is also far away from $\lambda = \infty$, its value when the SW restrictions are correct. Even though this is not a test, it is consistent with what we find with our formal Wald test, that the US model is rejected strongly by the data behaviour.

A key respect in which the model can be modified to fit the data better is to allow for variations in the degree of price and wage rigidity across sectors. In further work on the US, Le et al (2011) proposed a hybrid model that merged the NK and NC models by assuming that wage and price setters find themselves supplying labour and intermediate output partly in a competitive market with price/wage flexibility, and partly in a market with imperfect competition. The price and wage setting equations in the hybrid model are assumed to be a weighted average of the corresponding NK and NC equations; this is similar to including many 'Calvo sectors' of different degrees of rigidity as in Dixon and Kara (2012). Essentially, the NK model tends to generate too little nominal variation while the NC model delivers too much. However the hybrid model was able to reproduce the variances of the data; and it is this key feature that enables it to match the data overall more closely. It is this 'hybrid' version of the SW model that we adopt here for both the US and EA models. To the two-country set-up we add trade spillovers to and from the Rest of the World, to ensure that world trade flows carefully accounted for. Finally, we follow the recent work of Hong and Minford (2012) in which evidence is found of monetary reactions by both the US Fed and EA's central bank(s) to each other's policies- this is modelled as a reaction by each to the US/EA real exchange rate.

2.2 The BGG model of the banking sector together with the SW model

The BGG financial sector produces certain changes in the model of Smets and Wouters (2007) in the form used here as modified by Le et al. (2011) but much remains unchanged. The key difference in BGG lies in the nature of entrepreneurs. They still produce intermediate goods, but now they do not rent capital from households (who do not buy capital but only buy bonds or deposits) but must buy it from capital producers and in order to buy this capital they have to borrow from a bank which converts household savings into lending; the terms of this borrowing are set by a contract governed by the costly state verification set-up of Townsend (1979). On their production side, entrepreneurs face the same situation as in Le et al. (2011). They hire labour from households for wages that are partly set in monopolistic, partly in competitive labour markets; and they buy capital from capital producers at prices of goods similarly set in a mixture of monopolistic and competitive goods markets. Thus the production function, the labour demand and real marginal cost equations are unchanged. It is on their financing side that there are major changes. Entrepreneurs buy capital using their own net worth, pledged against loans from the bank, which thus intermediates household savings deposited with it at the risk-free rate of return. The net worth of entrepreneurs is kept below the demand for capital by a fixed death rate of these firms $(1-\theta)$; the stock of firms is kept constant by an equal birth rate of new firms. Entrepreneurial net worth therefore is given by the past net worth of surviving firms plus their total return on capital minus the expected return (which is paid out in borrowing costs to the bank) on the externally financed part of their capital stock — equivalent to

$$nw_t = \theta nw_{t-1} + \frac{K}{N}\left(r_t^{ex} - E_{t-1}r_t^{ex}\right) + E_{t-1}r_t^{ex} + enw_t \tag{1}$$

where $\frac{K}{N}$ is the steady state ratio of capital expenditures to entrepreneurial net worth and θ is the survival rate of entrepreneurs. Those who die will consume their net worth, so that entrepreneurial consumption is equal to $(1-\theta)$ times net worth. In logs this implies that this consumption varies in proportion to net worth so that:

$$c_t^e = nw_t \tag{2}$$

In order to borrow, entrepreneurs have to sign a debt contract prior to the realisation of idiosyncratic shocks on the return to capital: they choose their total capital and the associated borrowing before the shock realisation. The optimal debt contract takes a state-contingent form to ensure that the expected gross return on the bank's lending is equal to the bank opportunity cost of lending. When the idiosyncratic shock hits, there is a critical threshold for it such that for shock values above the threshold, the entrepreneur repays the loan and keeps the surplus, while for values below it, he would default, with the bank keeping whatever is available. From the first order conditions of the optimal contract, the external finance premium is equated with the expected marginal product of capital which under constant returns to scale is exogenous to the individual firm (and given by the exogenous technology parameter); hence the capital stock of each entrepreneur is proportional to his net worth, with this proportion increasing as the expected marginal product rises, driving up the external finance premium. Thus the external finance premium increases with the amount of the firm's capital investment that is financed by borrowing:

$$E_t r_{t+1}^{ex} - (R_t - E_t\pi_{t+1}) = \chi(Q_t + k_t - nw_t) + epr_t \tag{3}$$

where the coefficient $\chi > 0$ measures the elasticity of the premium with respect to leverage. Entrepreneurs leverage up to the point where the expected return on capital equals the cost of borrowing from financial intermediaries. The external finance premium also depends on an exogenous premium shock, epr_t. This can be thought of as a shock to the supply of credit: that is, a change in the efficiency of the financial intermediation process, or a shock to the financial sector that alters the premium beyond what is dictated by the current economic and policy conditions.

Entrepreneurs buy capital at price Q_t in period t and uses it in $(t+1)$ production. At $(t+1)$ entrepreneurs receive the marginal product of capital r^k_{t+1} and the ex-post aggregate return to capital is r^{ex}_{t+1}. The capital arbitrage equation (Tobin's Q equation) becomes:

$$Q_t = \frac{1-\delta}{1-\delta^{us}+R^k_*}E_tQ_{t+1} + \frac{R^k_*}{1-\delta^{us}+R^k_*}E_tr^k_{t+1} - E_tr^{ex}_{t+1} \tag{4}$$

The resulting investment by entrepreneurs is therefore reacting to a Q-ratio that includes the effect of the risk-premium. There are as before investment adjustment costs. Thus, the investment Euler equation and capital accumulation equations are unchanged from Le et al. (2011). The output market-clearing condition now includes the consumption of entrepreneurs.

This completes our brief account of the model we are using here. A full listing is given in the Appendix.

3 Testing the model

3.1 The method of indirect inference

We evaluate the models' capacity in fitting the data using the method of Indirect Inference originally proposed in Minford, Theodoridis and Meenagh (2009) and subsequently with a number of refinements by Le et al. (2011) who evaluate the method using Monte Carlo experiments. The approach employs an auxiliary model that is completely independent of the theoretical one to produce a description of the data against which the performance of the theory is evaluated indirectly. Such a description can be summarised either by the estimated parameters of the auxiliary model or by functions of these; we will call these the descriptors of the data. While these are treated as the 'reality', the theoretical model being evaluated is simulated to find its implied values for them.

Indirect inference has been widely used in the estimation of structural models (e.g., Smith, 1993, Gregory and Smith, 1991, 1993, Gourieroux et al., 1993, Gourieroux and Monfort, 1995 and Canova, 2005). Here we make a further use of indirect inference, to evaluate an already estimated or calibrated structural model. The common element is the use of an auxiliary time series model. In estimation the parameters of the structural model are chosen such that when this model is simulated it generates estimates of the auxiliary model similar to those obtained from the actual data. The optimal choices of parameters for the structural model are those that minimise the distance between a given function of the two sets of estimated coefficients of the auxiliary model. Common choices of this function are the actual coefficients, the scores or the impulse response functions. In model evaluation the parameters of the structural model are taken as given. The aim is to compare the performance of the auxiliary model estimated on simulated data derived from the given estimates of a structural model—which is taken as a true model of the economy, the null hypothesis — with the performance of the auxiliary model when estimated from the actual data. If the structural model is correct then its predictions about the impulse responses, moments and time series properties of the data should statistically match those based on the actual data. The comparison is based on the distributions of the two sets of parameter estimates of the auxiliary model, or of functions of these estimates.

The testing procedure thus involves first constructing the errors implied by the previously estimated/calibrated structural model and the data. These are called the structural errors and are backed out directly from the equations and the data[2]. These errors are then bootstrapped and used to generate for each bootstrap new data based on the structural model. An auxiliary time series model is then fitted to each set of data and the sampling distribution of the coefficients of the auxiliary time series model is obtained from these estimates of the auxiliary model. A Wald statistic is computed to determine whether functions of the parameters of the time series model estimated on the actual data lie in some confidence interval implied by this sampling distribution.

In the case of the large three-country model here we examine a variety of variable sets, in a VAR(1) inclusive of their variances. to establish the capacity of the model to replicate data behaviour. The fullest set contains output, inflation and interest rates for both the US and the EA, plus the real US/EA exchange rate. We examine a large number of subsets of these also, with the smallest being the real exchange rate on its own. The Wald statistic is computed for each set, in total and separately for the

[2] Some equations may involve calculation of expectations. The method we use here is the robust instrumental variables estimation suggested by McCallum (1976) and Wickens (1982): we set the lagged endogenous data as instruments and calculate the fitted values from a VAR(1)—this also being the auxiliary model chosen in what follows.

VAR coefficients and the data variances[3]. Thus effectively we are testing whether the observed dynamics and volatility of the chosen variables are explained by the simulated joint distribution of these at a given confidence level. The Wald statistic is given by:

$$(\Phi - \overline{\Phi})' \sum\nolimits_{(\Phi\Phi)}^{-1} (\Phi - \overline{\Phi}) \tag{5}$$

where Φ is the vector of VAR estimates of the chosen descriptors yielded in each simulation, with $\overline{\Phi}$ and $\sum_{(\Phi\Phi)}$ representing the corresponding sample means and variance-covariance matrix of these calculated across simulations, respectively.

The joint distribution of the Φ is obtained by bootstrapping the innovations implied by the data and the theoretical model; it is therefore an estimate of the small sample distribution[4]. Such a distribution is generally more accurate for small samples than the asymptotic distribution; it is also shown to be consistent by Le et al. (2011) given that the Wald statistic is 'asymptotically pivotal'; they also showed it had quite good accuracy in small sample Monte Carlo experiments[5].

This testing procedure is applied to a set of (structural) parameters put forward as the true ones (H_0, the null hypothesis); they can be derived from calibration, estimation, or both. However derived, the test then asks: could these coefficients within this model structure be the true (numerical) model generating the data? Of course only one true model with one set of coefficients is possible. Nevertheless we may have chosen coefficients that are not exactly right numerically, so that the same model with other coefficient values could be correct. Only when we have examined the model with all coefficient values that are feasible within the model theory will we have properly tested it. For this reason we later extend our procedure by a further search algorithm, in which we seek other coefficient sets that could do better in the test.

Thus we calculate the minimum-value full Wald statistic for each period using a powerful algorithm based on Simulated Annealing (SA) in which search takes place over a wide range around the initial values, with optimising search accompanied by random jumps around the space[6]. In effect this is Indirect Estimation of the model; however here this estimation is being done to find whether the model can be rejected *in itself* and not for the sake of finding the most satisfactory estimates of the model parameters. Nevertheless of course the method does this latter task as a by-product so that we can use the resulting unrejected model as representing the best available estimated version. The merit of this extended procedure is that we are comparing the best possible versions of each model type when finally doing our comparison of model compatibility with the data.

3.2 Tests of the model

What we find from our testing procedure is fairly encouraging for the model, considering that it is an ambitious undertaking to replicate the joint behaviour of two large continents. As we will see, it is possible to do so only to a limited extent with the current specifications embedded in the model. Plainly, this opens up a challenging research agenda for open economy macroeconomics. But it is at least useful to know just in what features particularly the model fails.

We begin by testing the model with the original Bayesian estimates of SW for the US and EA models on their own, plus banking parameters for both continents taken from the US version of the model with banking. The model is strongly rejected with this parameter set. Just how bad the failures are is shown in the first column of table 1.

[3] Note that the VAR impulse response functions, the co-variances, as well as the auto/cross correlations of the left-hand-side variables will all be implicitly examined when the VAR coefficient matrix is considered, since the former are functions of the latter.

[4] The bootstraps in our tests are all drawn as time vectors so contemporaneous correlations between the innovations are preserved.

[5] Specifically, they found that the bias due to bootstrapping was just over 2% at the 95% confidence level and 0.6% at the 99% level. They suggested possible further refinements in the bootstrapping procedure which could increase the accuracy further; however, we do not feel it necessary to pursue these here.

[6] We use a Simulated Annealing algorithm due to Ingber (1996). This mimics the behaviour of the steel cooling process in which steel is cooled, with a degree of reheating at randomly chosen moments in the cooling process—this ensuring that the defects are minimised globally. Similarly the algorithm searches in the chosen range and as points that improve the objective are found it also accepts points that do not improve the objective. This helps to stop the algorithm being caught in local minima. We find this algorithm improves substantially here on a standard optimisation algorithm. Our method used our standard testing method: we take a set of model parameters (excluding error processes), extract the resulting residuals from the data using the LIML method, find their implied autoregressive coefficients ($AR(1)$ here) and then bootstrap the implied innovations with this full set of parameters to find the implied Wald value. This is then minimised by the SA algorithm.

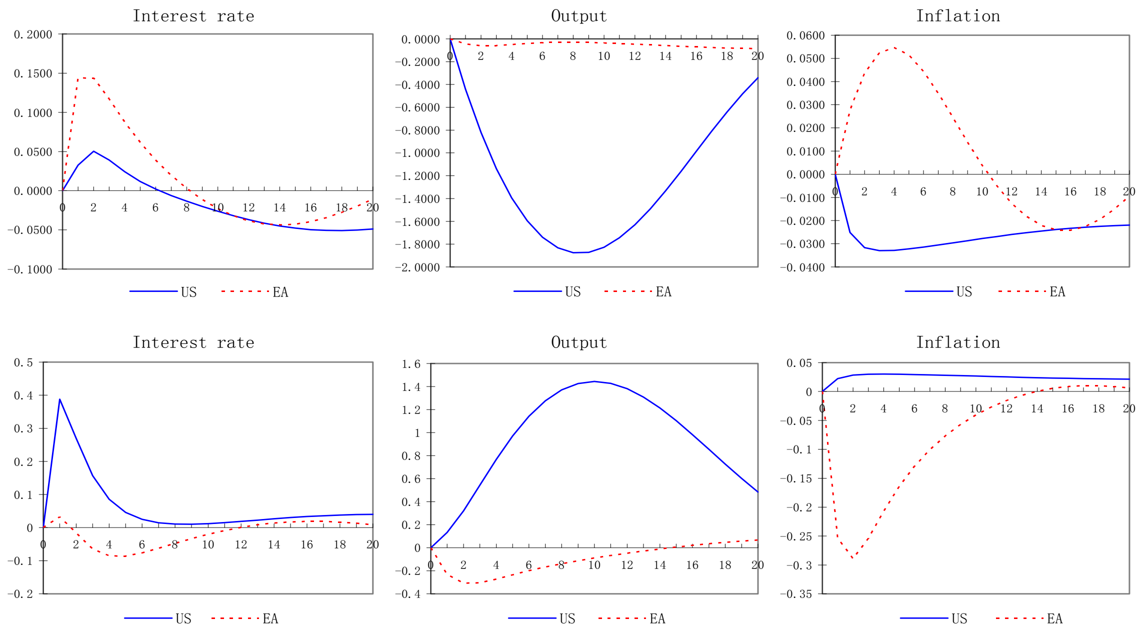

Figure 2: Model IRFs to a Monetary Shock (row1: US shock; row2 EA shock)

Using the Simulated Annealing algorithm, we are able to find a parameter set that gets a lot closer to the data, even though it is still rejected overall by a set of 7 key macro variables output, inflation, interest rates and the euro/dollar real exchange rate. While it can jointly match the volatility in this set and all subsets of these except the interest rates pair, it cannot at all match its dynamics and hence its overall behaviour. We can only find a much narrower subset for which the model achieves an overall match to behaviour- viz. output in the US and the EA. The model cannot match the behaviour of the two inflation rates or the two interest rates, though it does get quite a lot closer than for the full 7. We show these results in full in table 1 while the Simulated Annealing estimates in tables 2 and 3 (other fixed parameters are shown in table 4); these are the estimates we use in what follows. Of course for an even wider set of variables including consumption or investment, not shown here, the model is very severely rejected, as generally found with such models- for an example of such results see Le et al (2010) and also Le, Minford and Wickens (2010) in which the results for a US-EA model similar that of Chari et al (2002) are reviewed. While individual features of the data can be matched, they cannot be matched jointly. It seems that the failure of the world model to match the data may well lie essentially in its failure to match EA data- thus Meenagh et al (2009) found that they could not match the behaviour of the EA at all well when features are considered jointly. This is in contrast to Le et al (2011) who found that with reestimation by simulated annealing they could match the behaviour of key US variables jointly.

The conclusion of this reestimation process is that we can match the two continents' output behaviour with this model and therefore it is worthy of further interrogation, to discover what it implies about the sources and nature of the crisis for output- for other variables we should not take the implications too seriously. We show in a spirit of illustration the impulse response functions for US and EA monetary shocks- figure 2. As we have seen these are not reliable empirically except for outputs, but it is of some interest to see what the best-fitting model of this type that we can find implies for the other responses. In particular we see that there are substantial spill-overs in the model from the US onto the EA though little in the opposite direction.

[7] Note for shocks to government spending we have followed Smet and Wouters (2007) to assume $\varepsilon_{g,t}= \rho_i \varepsilon_{g,t-1}+v_{g,t}+\theta_a v_{a,t}$ so productivity is both a supply and a demand shock.

VAR(1) auxiliary equation	Full Wald: Bayesian estimates	Full Wald: SA estimates	Directed Wald (SA estimates): dynamics	Directed Wald (SA estimates): volatility
	(Normalized t-stat values in parenthesis)			
y_t^{US},π_t^{US},R_t^{US} y_t^{EA},π_t^{EA},R_t^{EA},s	100 (209.2)	100 (34.0)	100 (35.2)	65.0 (-0.15)
y_t^{US},π_t^{US},R_t^{US} y_t^{EA},π_t^{EA},R_t^{EA}	100 (20.3)	100 (33.2)	100 (35.8)	69.9 (-0.04)
y_t^{US},π_t^{US} y_t^{EA},π_t^{EA},s	100 (120.7)	100 (12.6)	100 (13.7)	60.9 (-0.32)
y_t^{US},R_t^{US} y_t^{EA},R_t^{EA}, s_t	100 (170.4)	100 (24.1)	100 (25.8)	64.1 (-0.25)
π_t^{US},R_t^{US} π_t^{EA},R_t^{EA},s	100 (244.6)	100 (27.8)	100 (30.4)	68.5 (-0.11)
y_t^{US},π_t^{US},y_t^{EA},π_t^{EA}	100 (17.0)	100 (11.1)	100 (11.0)	67.7 (-0.19)
y_t^{US},R_t^{US},y_t^{EA},R_t^{EA}	100 (16.1)	100 (10.2)	100 (10.6)	72.5 (-0.07)
π_t^{US},R_t^{US},π_t^{EA},R_t^{EA}	100 (14.1)	100 (34.1)	100 (36.6)	77.0 (0.11)
y_t^{US},y_t^{EA},s_t	100 (138.7)	100 (11.0)	100 (10.3)	77.8 (0.06)
π_t^{US},π^{EA},s_t	100 (138.9)	100 (10.8)	100 (10.5)	75.2 (-0.07)
R_t^{US},R^{EA},s_t	100 (133.8)	100 (10.6)	100 (10.8)	56.2 (-0.49)
y_t^{US},y_t^{EA}	95.5 (0.71)	84.2 (0.69)	60.1 (-0.20)	85.6 (0.36)
π_t^{US},π^{EA}	100 (12.8)	100 (11.6)	100 (11.8)	83.4 (0.28)
R_t^{US},R^{EA}	100 (25.8)	100 (24.2)	100 (13.9)	100 (25.3)
s_t	94.1 (1.49)	99.9 (5.39)	100 (8.28)	87.2 (0.08)

Table 1: Comparing the Models' Fit to the Data (1973Q1-2010Q4)

	US model			EA model	
Main equ. parameters	Start values	SA estimates	Main equ. parameters	Start values	SA estimates
h^{us}	0.71	0.68	h^{EA}	0.55	0.64
σ_c^{us}	1.40	1.12	σ_c^{EA}	1.61	1.80
φ^{US}	5.74	5.29	φ^{EA}	7	6.49
$\mu_{r^k}^{US}$	n.a	0.86	$\mu_{r^k}^{EA}$	n.a	0.73
ι_p^{US}	0.24	0.28	ι_p^{EA}	0.43	0.31
ξ_p^{US}	0.66	0.96	ξ_p^{EA}	0.91	0.72
ϕ_p^{US}	1.6	1.61	ϕ_p^{EA}	1.49	1.92
α^{US}	0.19	0.15	α^{EA}	0.3	0.23
μ_w^{US}	n.a	0.68	μ_w^{EA}	n.a	0.23
ι_w^{US}	0.58	0.64	ι_w^{EA}	0.66	0.87
ξ_w^{US}	0.7	0.61	ξ_w^{EA}	0.76	0.57
σ_l^{US}	1.83	1.94	σ_l^{EA}	1.19	1.35
ψ^{US}	0.54	0.75	ψ^{EA}	0.85	0.21
ρ^{US}	0.81	0.51	ρ^{EA}	0.93	0.76
θ_π^{US}	2.03	1.27	θ_π^{EA}	1.66	2.94
θ_y^{US}	0.08	0.07	θ_y^{EA}	0.14	0.14
$\theta_{\triangle y}^{US}$	0.22	0.22	$\theta_{\triangle y}^{EA}$	-0.17	-0.19
χ^{US}	0.05	0.06	χ^{EA}	0.05	0.02
κ_1^{US}	n.a	3.11	κ_1^{EA}	n.a	0.28
κ_2^{US}	n.a	3.40	κ_2^{EA}	n.a	0.40
δ^{US}	fixed	0.025	$\theta_{\triangle\pi}^{EA}$	0.22	0.16
γ^{US}	fixed	1.0043	γ^{EA}	fixed	1
ε_p	fixed	10	σ	fixed	0.8
ε_w	fixed	10	δ^{EA}	fixed	0.025
ϕ_w^{US}	fixed	1.5	λ_w	fixed	0.596
θ_{nw}^{US}	fixed	0.9	θ_{nw}^{EA}	fixed	0.9

Table 2: Simulated Annealing Estimates of the US-EA-World Model (1973Q1-2010Q4)

US model		EA model	
$\varepsilon_{i,t}=\rho_i\varepsilon_{i,t-1}+v_{i,t}+\theta_i v_{i,t-1}$			
ρ_b^{US}	0.28	ρ_b^{EA}	0.38
ρ_i^{US}	0.51	ρ_i^{EA}	0.21
ρ_{pi}^{US}	0.67	ρ_{pi}^{EA}	0.96
(θ_{pi}^{US})	(-0.57)	(θ_{pi}^{EA})	(-0.55)
ρ_a^{US}	0.96	ρ_a^{EA}	0.99
ρ_w^{US}	0.90	ρ_w^{EA}	0.99
(θ_w^{US})	(-0.68)	(θ_w^{EA})	(-0.80)
ρ_{wNC}^{US}	0.98	ρ_{wNC}^{EA}	0.99
(θ_{wNC}^{US})	(-0.03)	(θ_{wNC}^{EA})	(-0.02)
ρ_g^{US}	0.81	ρ_g^{EA}	0.99
(θ_a^{US})[7]	(0.22)	(θ_a^{EA})	(1.04)
ρ_R^{US}	0.55	ρ_R^{EA}	0.57
ρ_{pr}^{US}	0.83	ρ_{pr}^{EA}	0.95
ρ_{nw}^{US}	-0.05	ρ_{nw}^{EA}	0.42

Table 3: Estimated Evolution Process of Shocks (1973Q1-2010Q4)

$R_*^{k,us}$	0.0326	$R_*^{k,ea}$	0.04
$\frac{C^{us}}{Y^{us}}$	0.54	$\frac{C^{ea}}{Y^{ea}}$	0.57
$\frac{I^{us}}{Y^{us}}$	0.12	$\frac{I^{ea}}{Y^{ea}}$	0.21
$\frac{IM^{ea}}{Y^{us}}$	0.0032	$\frac{IM^{us}}{Y^{ea}}$	0.0212
$\frac{IM^{us}}{Y^{us}}$	0.0042	$\frac{IM^{ea}}{Y^{ea}}$	0.0172
$\frac{EX_w^{us}}{Y^{us}}$	0.0115	$\frac{EX_w^{ea}}{Y^{ea}}$	0.205
$\frac{IM_w^{us}}{Y^{us}}$	0.0183	$\frac{IM_w^{ea}}{Y^{ea}}$	0.207
$\frac{C^{e,us}}{Y^{us}}$	0.11	$\frac{C^{e,ea}}{Y^{ea}}$	0.012
$\frac{K^{us}}{Y^{us}}$	0.12		
$\frac{K^{us}}{N^{us}}$	1.1214	$\frac{K^{ea}}{N^{ea}}$	1.27
$\frac{IM_w^{us}}{Y^w}$	0.31	$\frac{IM_w^{ea}}{Y^w}$	0.69
β	0.99		

Table 4: Other fixed parameters of the US-EA-World Model (1973Q1-2010Q4)

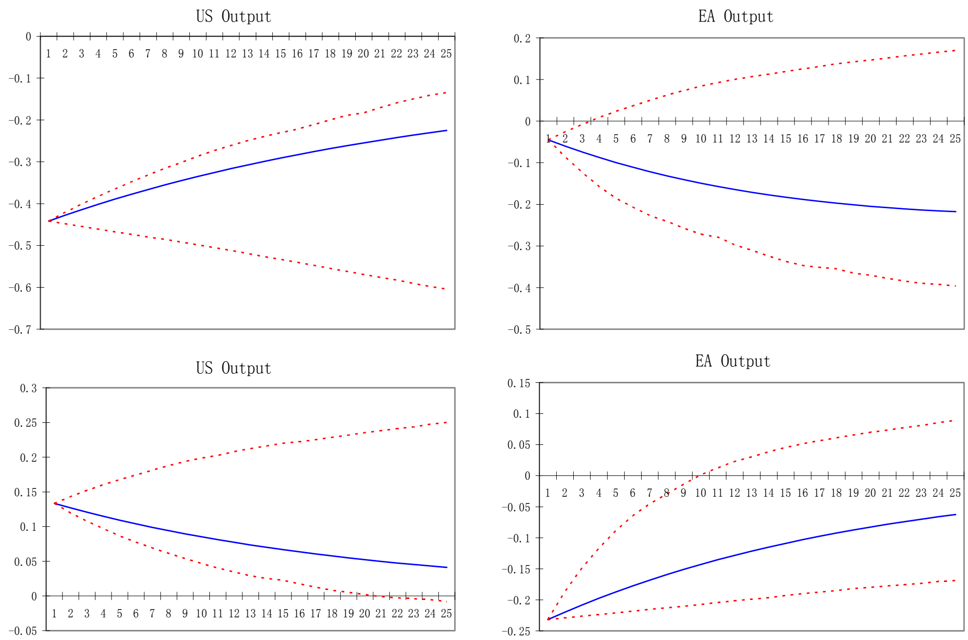

Figure 3: VAR(1) IRFs to a Monetary Shock (row1: US shock; row2: EA shock)

Given that it passes the Wald test for the two outputs VAR(1), it generates 95% confidence limits for implied VAR responses that easily encompass the data-based VAR responses to key shocks for these two variables; in figure 3 we show the monetary shock VAR IRFs and the model 95% bounds as an example. Some authors have wanted to assess a model solely on whether it could fit the VAR IRFs (eg Christiano et al, 2005, assessed their model of the US solely on the fit to the monetary shock IRFs). One can thus think of our Wald test on the VAR coefficients for the two outputs as assessing the model on the basis of all the shock IRFs for the two outputs.

4 What does the model say about the origins of the banking crisis?

Having established a model that integrates the banking sector and fits the data at least to a limited extent, we now go on to apply it to the recent crisis episode in the US, the EA and the ROW. To do this we extract the model shocks from the unfiltered data and fit to each an ARMA time-series process over the sample period. Figures 4 and 5 show these shock series.

Table 5 shows the order of integration of each shock according to two widely-used tests and also the ARMA parameters. Several of the shocks show evidence of a one-off structural break. In the US the wage mark-up and competitive wage ('labour supply') move downwards sharply in the 1990s; this could be related to the labour supply reforms of US administrations in the 1980s and the rise of globalisation which together led to large falls in labour union power. In the EA the Taylor Rule setting of interest rates rose sharply in the early 1980s; we associate this with the toughening of monetary policy at this time across the EA, in parallel with similar toughening in the US and the UK. In the EA this was achieved by linkage of other countries to the Deutschemark through the European Exchange Rate Mechanism. There are also downward movements in the external finance premium and the price mark-up during much the same period, which may well be associated with increasing product market competition as the Single Market began to be introduced. We allow for these shifts by a single dummy variable in each case and test the adjusted error in the table below. The steady upward movements of the wage mark-up and the competitive wage ('labour supply') may be associated with intensifying Social Market intervention in the labour market, more trendlike behaviour than a one-off shift.

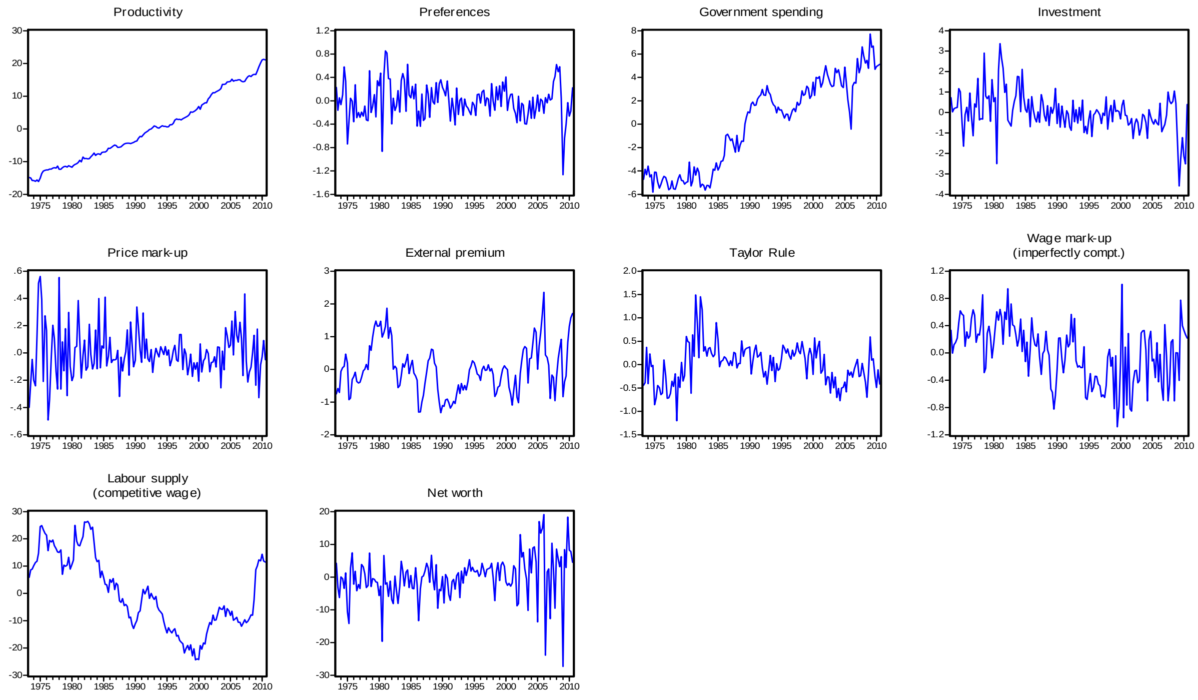

Figure 4: US Structural Errors (1973Q2-2010Q3)

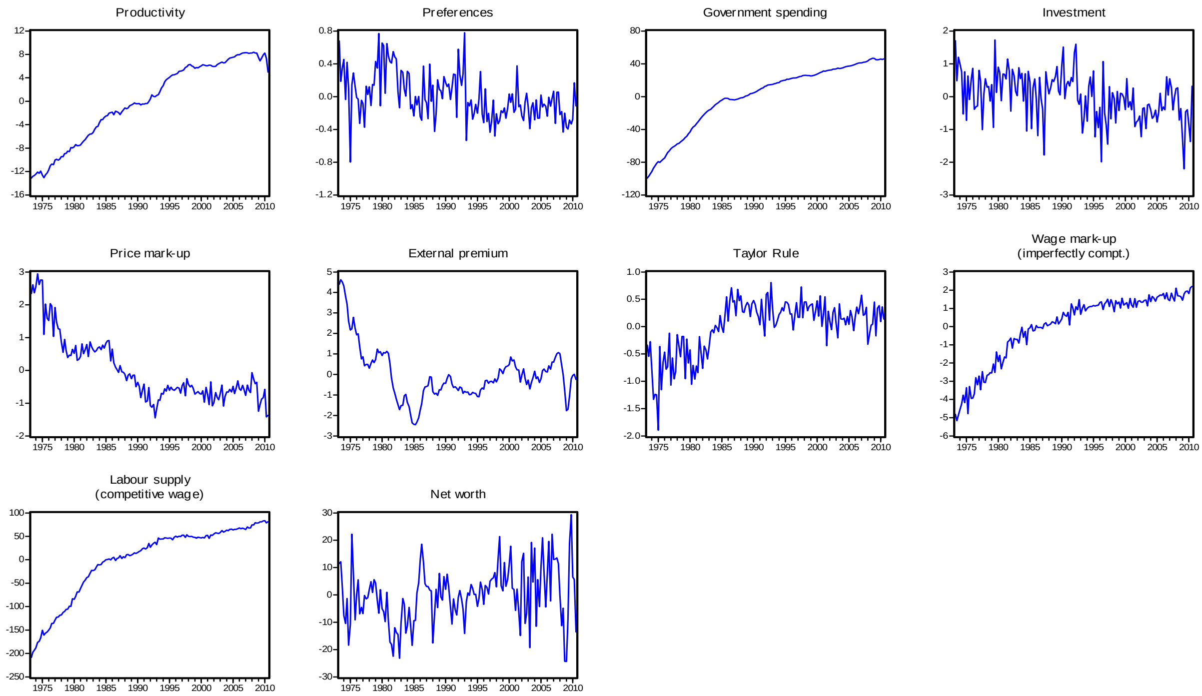

Figure 5: EA Structural Errors (1973Q2-2010Q3)

The tests conflict in several cases. A significant KPSS indicates rejection of stationarity whereas a low ADF p-value rejects non-stationarity. For US productivity the tests both suggest nonstationarity. For EA productivity the same is true. US investment and net worth are ambivalent but their ADFs very strongly reject the unit root and their AR roots are well inside the unit circle. All other US errors are clearly stationary on both tests. The other EA errors are ambiguous in four cases; government spending, labour supply, the wage mark-up and net worth. In all of them however the ADFs strongly reject the unit root and the AR roots are below unity so we treat them all as stationary, with or without a trend. Ultimately, with more work on testing and estimation we could determine the optimal status of the more ambiguous errors based on the overall model match to the data; in other work we have found that with borderline errors, making them non-stationary worsens the overall match. Here we have limited the assumption of non-stationarity to productivity in both US and EA. However as can be seen from the table above of estimated parameters the stationary EA errors are mostly very close to the unit root.

	ADF p-value^{+}	KPSS statistic	AR(1) coeff.	MA(1) coeff.	Conclusion
		US (1973Q2-2010Q3)			
Government spending	0.0121	0.1181	0.88	-0.23	Trend stationary
Preferences	0.0000	0.1369	0.46	-0.25	Stationary
Investment	0.0000	0.8185***	0.62	-0.28	Stationary
Taylor Rule	0.0022	0.2123	0.92	-0.57	Stationary
Productivity	0.9997	1.4363***	1.01	0.09	Nonstationary
Price mark-up	0.0000	0.0583	0.50	-0.48	Stationary
Wage mark-up (imperfectly compet.)	0.0000	0.3656	0.96	-0.78	Stationary¶
Labour supply (competitive wage)	0.1831	0.3991	0.99	-0.04	Stationary¶
External premium	0.0102	0.1751	0.82	0.06	Stationary
Net worth	0.0000	1.0783***	-0.20	0.23	Stationary
		EA (1973Q2-2010Q3)			
Government spending	0.0010	1.3451***	0.98	0.32	Stationary
Preferences	0.0027	0.0585	0.86	-0.61	Stationary¶¶
Investment	0.0000	0.0431	0.55	-0.53	Stationary¶¶
Taylor Rule	0.0000	0.0887	0.72	-0.42	Stationary¶¶¶
Productivity	0.1063	1.4209***	0.99	0.26	Nonstationary
Price mark-up	0.0007	0.2128	0.94	-0.73	Stationary¶¶¶
Wage mark-up (imperfectly compet.)	0.0004	1.2808***	0.98	-0.89	Stationary
Labour supply (competitive wage)	0.0020	1.2702***	0.98	-0.38	Stationary
External premium	0.0004	0.1592	0.90	0.18	Stationary¶¶¶
Net worth	0.0000	0.2417***	0.74	-0.37	Trend stationary

$^{+}$: p-value of 0.05 is the 5% confidence limit for rejecting the unit root.
***: rejection of stationarity at 1%.
¶(¶¶)(¶¶¶): break dummy at 1996 (1993) (1984)- all in Q1.

Table 5: Stationarity of Structural Errors (1970Q2-2010Q3)

4.1 The errors driving the episode

We begin by showing the behaviour of the main model errors (i.e. the total cumulated innovations) during the crisis episode, which we treat as 2006Q1 to 2009Q2. We have not included the 'recovery period' at this stage, though this would be interesting; our focus is on the period when the world economy first went into recession and then bottomed out. Of course for the EA the government solvency crisis that followed the world banking crisis began in 2010 and is not yet over. However, we may consider this to be

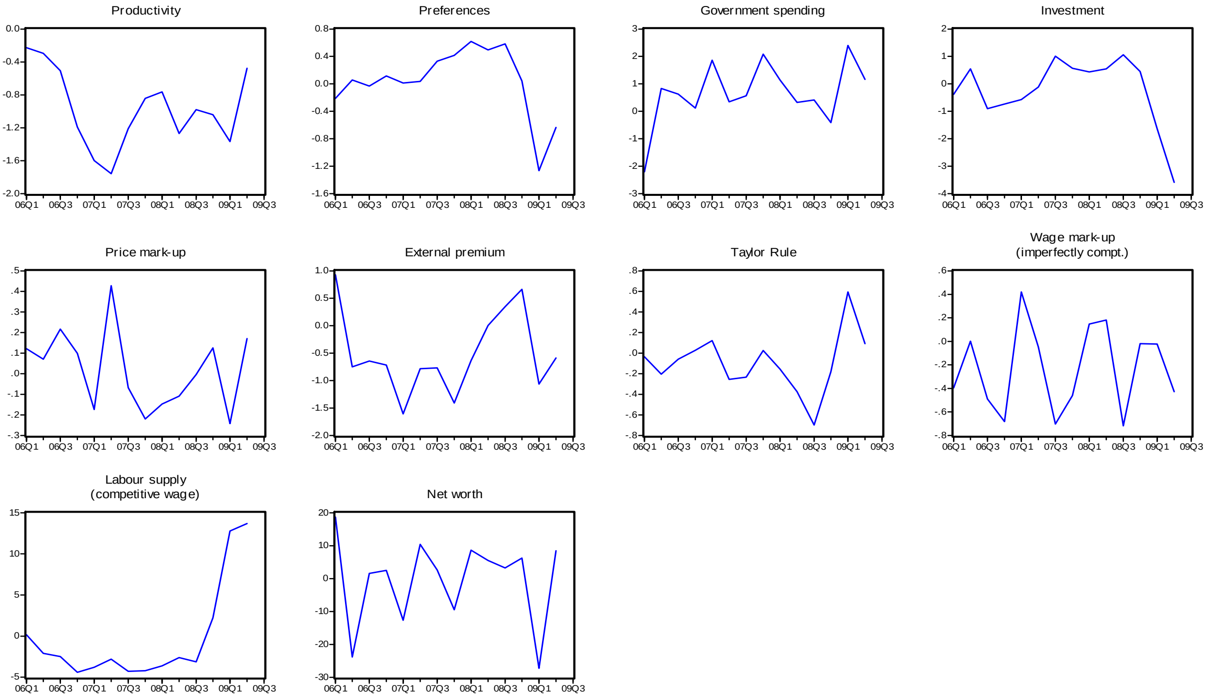

Figure 6: US Accumulated Innovations (2006Q1-2009Q2)

a separate crisis of the euro-zone itself, even if it was triggered by the banking crisis. We do not consider it here.

What is striking about the two sets of shocks for the crisis period is how different they are in most cases between the two continents (tables 6 and 7). In the US the external finance premium shock peaks in the Lehman collapse in 2008 Q4, whereas in the EA it peaks early in 2008 reflecting the general banking problems connected with sub-prime mortgage products. The other banking shock, to net worth, fluctuates in the US, dropping sharply after the Lehman collapse, while in the EA it drops steadily from the start of the crisis; both recover in 2009.

In the US productivity rises from early 2007 whereas in the EA it declines steadily throughout the crisis. In the US government spending rises at the start of the episode and then flattens off until Lehman, whereas in the EA it rises strongly but falls from late 2008. In both continents the price mark-up fluctuates, reflecting commodity price movements. The Taylor Rule error rises in 2008 in both the US and the EA, because of the zero lower bound we assume. For three errors however the reactions are the same: in both the US and the EA there was a large rise in the competitive wage error, reflecting the failure of real wages to fall as much as the model equation suggests, and in both continents there was a fall in the consumer and investment errors ('confidence' effects).

We first use these errors to establish a general variance decomposition. This analysis treats the episode stochastically — that is, we take the shocks in the episode and replay them by redrawing them randomly and repeatedly with replacement to see what a typical crisis episode would be like. Our variance decomposition is therefore for such a typical episode- table 6.

We are particularly interested in whether 'banking shocks' (which we define as the external finance premium and the net worth shocks) were mainly responsible for the output effects. Here we find that for the US banking shocks (of US origin) are responsible for about a third of the output variance; and for the EA it is a similar 40% (all of it EA in origin). The model also implies that the EA was greatly affected by the general recession during the crisis, with virtually no spill-over from the US. As for US output, non-banking shocks contributed two thirds of its variance, with roughly half of that contribution coming from the EA. Thus while banking is important for the world as a whole, the dominant contributor to the crisis period is non-banking shocks. This, as we noted at the start, is similar to the finding of Stock and Watson (2012), using dynamic factor VAR methods, that there was nothing particularly different about this crisis from previous US macro behaviour, other than the size of the shock draws.

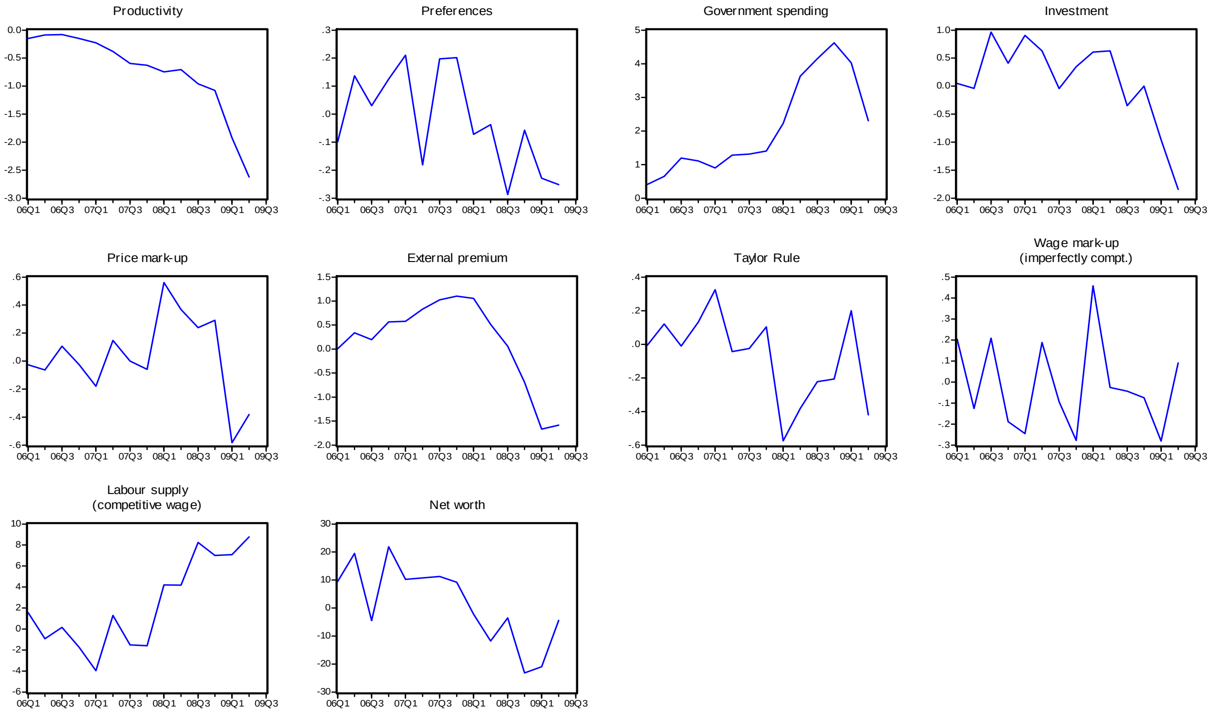

Figure 7: EA Accumulated Innovations (2006Q1-2009Q2)

If we turn to interest rate and inflation variances we find that there are large spillovers from the EA to the US but much less from the US to the EA. Banking shocks are the dominant contributor to the variance of both variables in both continents. The model is not accurate on these variables so these results need to be regarded cautiously. However, it is plausible that these two continents were strongly linked in monetary reactions during the crisis.

4.2 Accounting for this particular banking crisis episode

We can also decompose what actually happened in the precise episode that occurred according to the model as a result of these shocks. We do this in the charts that follow for US and EA output.

We see (figure 8) how the model suggests the crisis period shocks drove US output down nearly 7% between 2008Q3 and 2009Q2. The main sources of this were large swings in net worth (dark blue), investment (light blue) and consumer (red) shocks. The first, banking shock, contributed 2% of the total, just under a third; the other two contributed about 4%. In addition there was a miscellany of shocks from the EA, contributing the remaining 1%.

For the EA (figure 9) the crisis period shocks drove output down by just under 5% over the same period. EA labour supply and productivity shocks each contributed 2%; worsening investment shock another 2% and declining government spending another 1%. However this total decline of some 7% was offset by a quick improvement in the external finance premium, net of a worsening net worth shock; thus the banking shocks by mid 2009 had pushed EA output up by 2% compared with mid-2008. Thus the EA suffered from the crisis of late 2008 almost as severely as the US, but the causes of this were not directly from its own banking problems (the euro-zone banking and sovereign crisis was to come later), rather they were from general non-banking sources.

The overall interpretation coming from this analysis is of a crisis triggered by severe exogenous shocks, and exacerbated by a large financial shock in the US. Plainly from the timing of the output collapse these shocks were associated with the collapse of Lehman; thus it might be that, had Lehman not been allowed to collapse, these shocks would not have occurred. However, since the shocks all came from different sources, even if their timing was coordinated, this would not imply that the Lehman collapse caused these shocks and so the overall crisis; they could just as well have all happened in an uncoordinated way

Unit (%)		Int. rate	Inflation (US)	Output	Int. rate	Inflation (EA)	Output
(US)							
Government spending		0.9	2.9	22.4	1.9	1.9	0.0
Preferences		0.1	0.2	3.1	0.2	0.2	0.0
Investment		0.0	0.1	2.5	0.3	0.3	0.0
Taylor Rule		0.8	1.6	3.2	5.0	5.6	0.0
Productivity		4.5	10.5	1.4	0.1	0.2	0.0
Price mark-up		0.3	6.1	1.6	0.4	0.4	0.0
Wage mark-up (Imperfectly compet.)		0.0	0.0	0.0	0.0	0.0	0.0
Labour supply (Competitive wage)		0.3	0.7	0.0	0.0	0.0	0.0
External premium		0.0	0.0	0.2	0.0	0.0	0.0
Net worth		4.3	10.6	34.8	4.8	4.9	0.0
(EA)							
Government spending		0.5	0.6	0.5	4.9	4.0	14.9
Preferences		1.9	0.8	1.1	2.3	5.7	0.1
Investment		0.1	0.1	0.0	0.2	0.2	0.6
Taylor Rule		9.3	3.3	6.0	6.5	19.5	0.1
Productivity		33.9	21.7	12.8	23.2	26.7	29.5
Price mark-up		20.0	14.8	5.6	24.2	19.7	4.7
Wage mark-up (Imperfectly compet.)		0.0	0.0	0.0	0.0	0.0	0.0
Labour supply (Competitive wage)		21.2	23.2	1.7	16.8	6.0	10.5
External premium		1.1	1.9	2.6	7.1	3.4	28.8
Total		100	100	100	100	100	100
Banking shocks	(US)	4.4	10.6	34.9	4.8	5.0	0.0
	(EA)	2.0	2.8	3.1	9.2	4.7	39.5
Non-banking shocks	(US)	6.8	22.1	34.2	7.9	8.5	0.1
	(EA)	86.9	64.4	27.7	78.0	81.8	60.4

Table 6: Variance Decomposition of the Crisis Episode

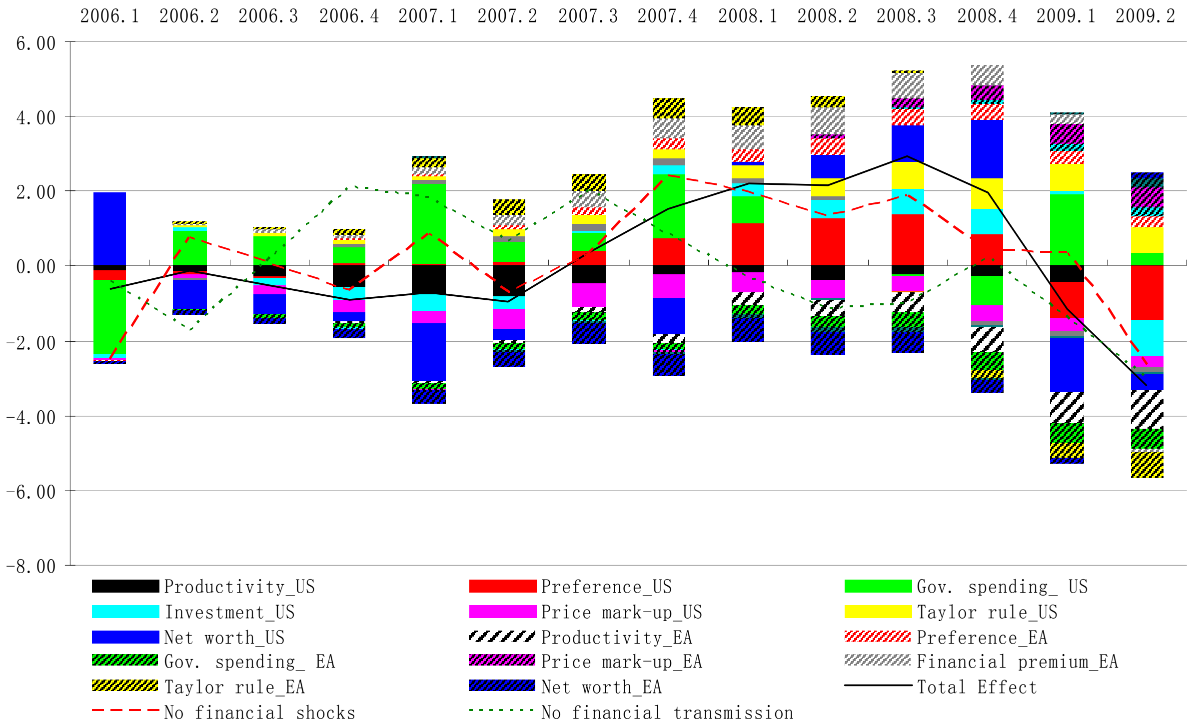

Figure 8: Shocks Decomposition of US Output (crisis episode)

at different times. Consider the parallel with the Asian Crisis of 1997-8; this was triggered by events in Thailand in July 1997 but no one could say that 'Thailand caused the Asian Crisis' since plainly that crisis was already brewing across South East Asia for a variety of reasons internal to all the countries involved. Thus while the Lehman collapse was in this episode clearly a trigger event, this cannot be used to identify it as the cause of the crisis. Thus our analysis of the various sources of the downturn suggest that this was not a crisis 'created by the financial system'.

Plainly in this conclusion we differ from other studies of the US and the EA's crisis experience, as noted in our introduction above. These all find that banking shocks were the main cause of the crisis. However, these studies differ from ours in two crucial respects: first, they do not use parameters and specifications that pass any sort of overall empirical test of fit to the data behaviour and second, they do not include shocks drawn from the raw non-stationary data. They also differ in not embedding the models in a world economy which given the spillovers we find between the two continents may be a further factor. Le, Meenagh and Minford (2012) found that for the US model the first two differences explained the far lower share they, like we, find for banking shocks. On stationary data and with the original parameters of SW and BGG banking shocks, they found with essentially the same model as here for the US that as much as 80% of US output variance for the crisis period is due to banking shocks but they also found that this drops to only 13% when the empirically-based parameters are used and the errors are drawn from the raw data. Thus non-stationarity and empirical fit are essential to evaluating the role of banking shocks in the crisis.

4.3 What is and causes a (financial) crisis?

We now ask: what is a crisis and what causes it, according to our analysis of this sample of US and EA data? Let us define a 'crisis' as a severe and highly persistent downturn in output; and a financial crisis as a crisis in which financial indicators show severe distress. We examine this question by inspecting the bootstrap experience (potential scenarios over the period) from the model. Numerically, we define two types of crisis: a) a 'Great Depression' in which there is a fall in GDP of 10% or more, lasting for 5 years or more, b) a 'Great Recession' in which there is a GDP fall of 5% or more lasting 10 quarters or more. We create 80 such scenarios for the discussion that follows, each 25 years long; thus a total experience of 2000 years.

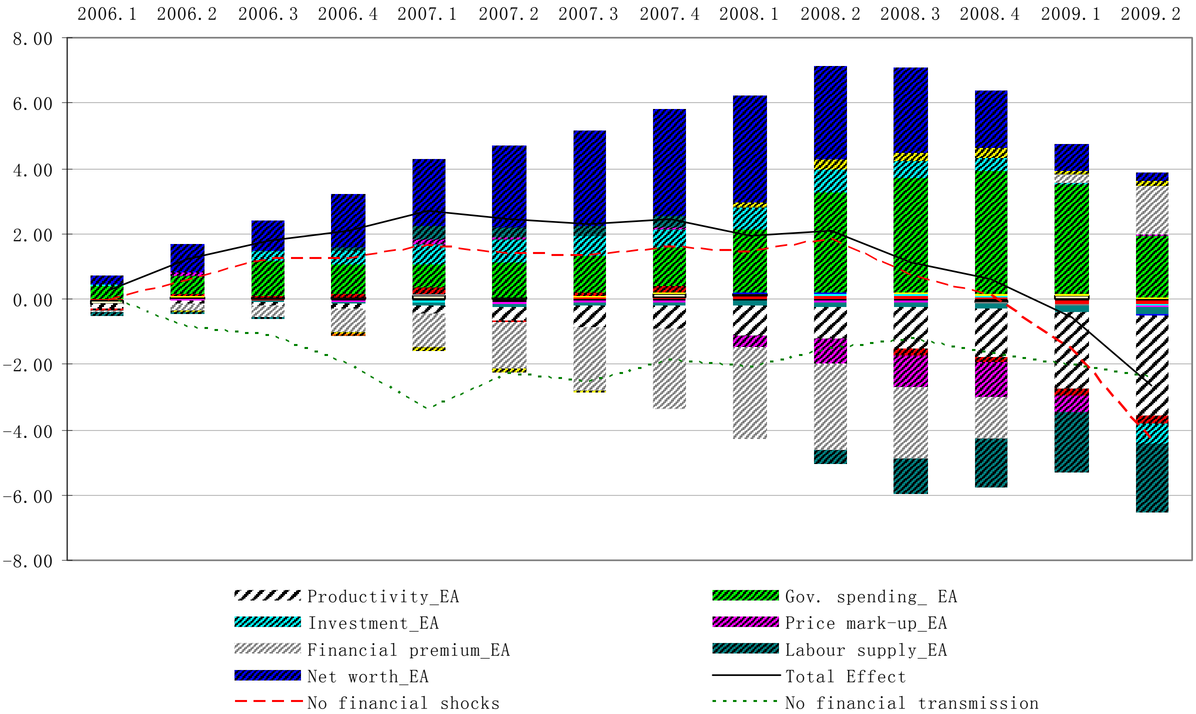

Figure 9: Shocks Decomposition of EA Output (crisis episode)

We find that:

a) Crises are a normal part of capitalism: this economy will generate crises regularly from 'standard' shock sequences. We illustrate this- see following graphs- from some of the bootstrap simulations/scenarios produced from the shocks of the period up to 2006 (i.e. sans crisis). In almost all of them there were quite serious interruptions of activity, which satisfy the definition of crisis. A Great Recession on average occurred on average every 33 years in the US and every 26 years in the EA.

We also ran the scenarios with the full set of shocks including the crisis period up to 2009; this not surprisingly produced a somewhat greater average frequency; a Great Recession occurs every 26 years in the US and every 23 years in the EA. This more or less coincides with post-war experience, in that there was the severe oil crisis of the 1970s and the recent crisis of the late 2000s.

A Great Depression is a rare event, requiring largescale shocks much as occurred in this crisis episode. Without such shocks it is exceedingly rare- only happening every 250 years in the US and every 110 years in the EA. If we include such shocks, it will occur every 156 years in the US, every 68 years in the EA. Apparently the EA is more crisis-prone.

As for financial crisis, in some of these crises there were signs of severe financial distress and so financial crisis also occurred; in others financial problems were muted- we show a selection of each below.

b) We can gauge the importance of financial crises, ie crises caused by financial shocks, by examining scenarios when only financial shocks occur. We redid these scenarios with just the financial shocks including the crisis period values; thus this shock series includes both normal and extreme financial shocks. We show three such scenarios in the graphs following (figure 12). For the US we find that a Great Recession occurs only once every 543 years, and in the EA every 177 years; one never gets Great Depressions in either continent. Thus financial shocks alone cannot cause any sort of crisis in this model except extremly rarely.

This is broadly in line with what we found in the crisis episode itself: that banking shocks worsen output fluctuations materially but are not their major source.

Here we should emphasise that the extreme financial shocks in the sample included the effects of massive government intervention, which occurred largely because of the experience of the Great Depression when there was no such intervention; thus this particular finding relies crucially on the assumption that financial shocks are accompanied by vigorous lender-of-last-resort activity by governments. It is quite

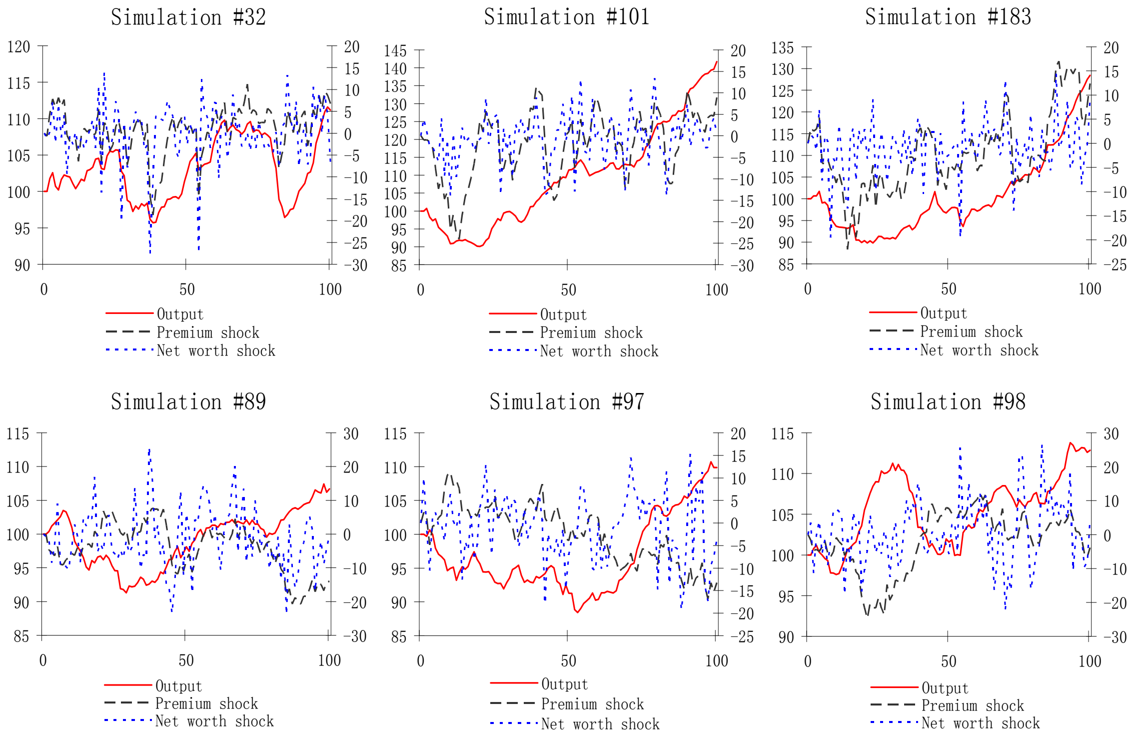

Figure 10: Crises not Accompanied by Financial Crisis (row1: US; row2: EA)

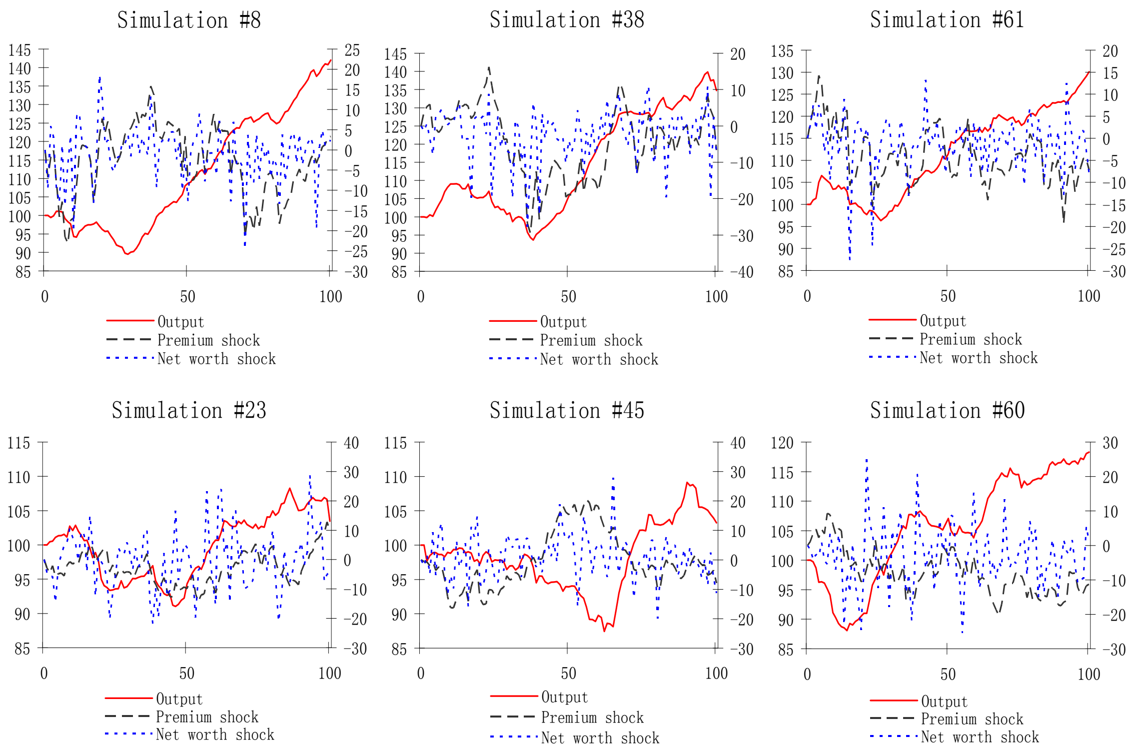

Figure 11: Crises Accompanied by Financial Crisis (row1: US; row2: EA)

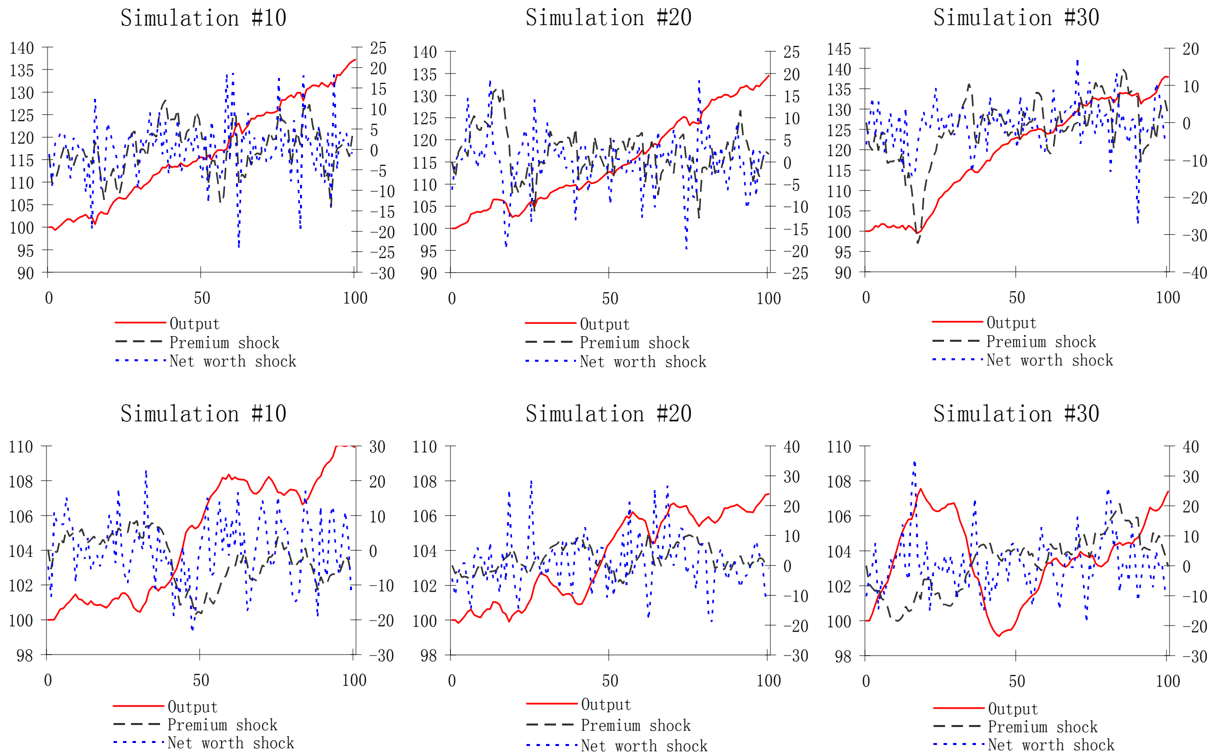

Figure 12: Simulations with only Financial Shocks (row1: US; row2 EA)

possible that had we had the inter-war sample of financial shocks in our data we would have generated substantially more crises and Great Depressions. So our conclusion here assumes that government is ready to respond vigorously to large financial collapses.

5 Conclusions

In this exercise we have examined the origins of the crisis across the US and the EA treated as a world economy, the first time this has been done. To do this, we have taken the Smets-Wouters model of the US and the EA, derived from Christiano et al. (2005), but here in the form as modified by Le et al.(2011) to allow for more heterogeneity in price/wage behaviour, and we have integrated into it the banking/financial accelerator model of Bernanke et al. (1999) in order to discover how far the banking crisis might have been caused by non-banking and by banking shocks. We began by testing the model on an original set of parameters largely estimated by SW by Bayesian methods for the two continental models separately. These were strongly rejected by the data. However, we then re-estimated each model by Indirect Estimation, thus effectively getting it as close as possible to the data on the indirect inference test we are using. This version still failed the Wald test badly on a set of seven key macro variables but it passed comfortably for the two continents' outputs and did match all these seven variables' variances. We would claim that by carefully fitting the data behaviour, we have given our results empirical credibility for the output effects of the crisis, on which we focus our main analysis. Furthermore by using the original data without filtering, we have been able to extract the total shocks during the crisis period; by focusing on the total shocks we are able to give full weight to nonstationary shocks, here productivity, in both continents.

We then used this version to carry out an accounting exercise in the shocks causing the crisis episode. We did a variance decomposition to establish what a typical crisis generated by these shocks if redrawn randomly would be caused by. We then looked at the decomposition for this particular episode. Finally we ran a variety of simulations bootstrapped from different sets of the shocks in our sample (over the last three decades, on the grounds that this is of most relevance today) to shed light on the causes of crisis and banking crisis.

Our main conclusion is that the banking crisis was largely the result of non-banking shocks impacting through the usual non-financial channels on the world economy. The main non-bank shocks to output were from productivity, labour supply, consumer preferences, and investment shocks. On top of these banking shocks made a further contribution, for about a third; thus they were material but not dominant. Our conclusion mirrors qualitatively Stock and Watson's (2012) finding from dynamic factor VAR analysis that the US crisis period was essentially the result of the same set of shocks (of which some were financial) as in previous post-war experience, but with bigger values.

We recognise that this differs from the findings of the others who have done similar exercises; they all find that banking shocks were the main cause of the crisis. However, these studies differ from ours in two crucial respects: first, they do not use parameters and specifications that pass empirical tests of overall fit to the data behaviour and second, they do not include shocks drawn from the raw non-stationary data. These two differences seem to explain our quite different findings.

Our second conclusion was that crises are endemic in the world economy largely because of non-banking shocks; banking shocks contribute to crises but cannot cause crises on their own exept with extreme rarety. We found that on average a centenarian will live through four Great Recessions and one Great Depression. Note however that in this sample public policy was highly interventionist whereas it was not in the Great Depression; thus without such a sharp policy response we would no doubt see more frequent crises and a greater effect of purely financial shocks.

The purpose of this study has been to analyse the sources of banking crises such as we have just experienced. The study comes with caveats: the model cannot match the overall data behaviour of the world as defined here except for outputs, largely it seems because it cannot match EA data. Nevertheless, for the US Le, Meenagh and Minford (2012) find qualitatively similar results, using a shorter sample from 1984 and a model that does match the key US data behaviour.

In these circumstances what we can say about policy is limited. But one policy conclusion is that bank regulation seems unlikely to prevent future crises, though it should mitigate them. Therefore its benefits may be more limited than currently thought and should be carefully weighed against its costs in raising the price of intermediation.

Another conclusion is that if indeed future crises cannot realistically be prevented; thought should be given to future crisis mitigation by taxpayer responses such as bail-outs. The shocks in this study include large responses of this sort. We can probably learn from the contrast between crises including these and crises without them such as in the Great Depression. Costs from moral hazard can be compared with what may be quite large gains from reduced crisis dimensions.

6 Appendix FULL US/EA/ROW Model Listing

6.1 US

Consumption Euler equation:

$$c_t^{US} = \frac{\frac{h^{us}}{\gamma^{us}}}{1+\frac{h^{us}}{\gamma^{us}}} c_{t-1}^{US} + \frac{1}{1+\frac{h^{us}}{\gamma^{us}}} E_t c_{t+1}^{US} + \frac{(\sigma_c^{us}-1)\frac{W_*^{us}L_*^{us}}{C_*^{us}}}{\left(1+\frac{h^{us}}{\gamma^{us}}\right)\sigma_c^{us}} (l_t^{US} - E_t l_{t+1}^{US}) - \left(\frac{1-\frac{h^{us}}{\gamma^{us}}}{\left(1+\frac{h^{us}}{\gamma^{us}}\right)\sigma_c^{us}}\right)(R_t^{US} - E_t \pi_{t+1}^{US}) + eb_t^{US} \tag{6}$$

Investment Euler equation:

$$i_t^{US} = \frac{1}{1+\beta(\gamma^{us})} i_{t-1}^{US} + \frac{\beta(\gamma^{us})}{1+\beta(\gamma^{us})} E_t i_{t+1}^{US} + \frac{1}{[1+\beta(\gamma^{us})](\gamma^{us})^2 \varphi^{US}} Q_t^{US} + ei_t^{US} \tag{7}$$

Tobin's Q equation:

$$Q_t^{US} = \frac{1-\delta^{us}}{1-\delta^{us}+R_*^{k,us}} E_t Q_{t+1}^{US} + \frac{R_*^{k,us}}{1-\delta^{us}+R_*^{k,us}} E_t r_{t+1}^{k,US} - E_t r_{t+1}^{ex,US} \tag{8}$$

Capital accumulation equation:

$$k_t^{US} = \left(\frac{1-\delta^{us}}{\gamma^{us}}\right) k_{t-1}^{US} + \left(1-\frac{1-\delta^{us}}{\gamma^{us}}\right) i_t^{US} + \left(1-\frac{1-\delta^{us}}{\gamma^{us}}\right)[1+\beta(\gamma^{us})](\gamma^{us})^2 \varphi^{US} ei_t^{US} \tag{9}$$

Price setting equation:

$$
\begin{aligned}
r_t^{k,US} \quad = \quad & \mu_{r^k}^{US} \left\{ \frac{1}{\alpha^{us}} \left[\begin{array}{c} \left(\pi_t^{US} - \frac{\iota_p^{us}}{1+\beta(\gamma^{us})\iota_p^{us}} \pi_{t-1}^{US} - \frac{\beta(\gamma^{us})}{1+\beta(\gamma^{us})\iota_p^{us}} E_t \pi_{t+1}^{US} - ep_t^{US} \right) \left(\frac{(1+\beta(\gamma^{us})\iota_p^{us})(\xi_p^{us}[(\phi_p^{us}-1)\varepsilon_p+1])}{\left(1-\beta(\gamma^{us})\xi_p^{us}\right)\left(1-\xi_p^{us}\right)} \right) \\ +[ea_t^{US} - (1-\alpha^{us})\, w_t^{US}] \end{array} \right] \right\} \\
& + \left(1 - \mu_{r^k}^{US}\right) \left\{ \frac{1}{\alpha^{us}} \left[ea_t^{US} - (1-\alpha^{us})\, w_t^{US}\right] \right\} \qquad (10)
\end{aligned}
$$

Labour supply:

$$
\begin{aligned}
w_t^{US} \quad = \quad & \mu_w^{US} \left\{ \left[\begin{array}{c} \frac{\beta(\gamma^{us})}{1+\beta(\gamma^{us})} E_t w_{t+1}^{US} + \frac{1}{1+\beta(\gamma^{us})} w_{t-1}^{US} + \frac{\beta(\gamma^{us})}{1+\beta(\gamma^{us})} E_t \pi_{t+1}^{US} - \frac{1+\beta(\gamma^{us})\iota_w^{us}}{1+\beta(\gamma^{us})} \pi_t^{US} \\ + \frac{\iota_w^{us}}{1+\beta(\gamma^{us})} \pi_{t-1}^{US} - \frac{1}{1+\beta(\gamma^{us})} \left(\frac{(1-\beta(\gamma^{us})\xi_w^{us})(1-\xi_w^{us})}{(1+\varepsilon_w(\phi_w^{us}-1))\xi_w^{us}} \right) \\ \left(w_t^{US} - \sigma_l^{us} l_t^{US} - \left(\frac{1}{1-\frac{h^{us}}{\gamma^{us}}} \right) \left(c_t^{US} - \frac{h^{us}}{\gamma^{us}} c_{t-1}^{US} \right) \right) \end{array} \right] + ew_t^{US} \right\} \\
& + \left(1 - \mu_w^{US}\right) \left\{ \sigma_l^{us} l_t^{US} + \left(\frac{1}{1-\frac{h^{us}}{\gamma^{us}}} \right) \left(c_t^{US} - \frac{h^{us}}{\gamma^{us}} c_{t-1}^{US} \right) - (\pi_t^{US} - E_{t-1}\pi_t^{US}) + ew_t^{USNC} \right\} (11)
\end{aligned}
$$

Labour demand:

$$
l_t^{US} = -w_t^{US} + \left(1 + \frac{1-\psi^{us}}{\psi^{us}}\right) r_t^{k,US} + k_{t-1}^{US} \qquad (12)
$$

Market clearing condition:

$$
\begin{aligned}
y_t^{US} \quad = \quad & \frac{C^{us}}{Y^{us}} c_t^{US} + \frac{I^{us}}{Y^{us}} i_t^{US} + R_*^{k,us} \frac{K^{us}}{Y^{us}} (\frac{1-\psi^{us}}{\psi^{us}}) r_t^{k,US} + \frac{IM^{ea}}{Y^{us}} im_t^{EA} - \frac{IM^{us}}{Y^{us}} im_t^{US} \qquad (13) \\
& + \frac{EX_w^{us}}{Y^{us}} ex_{W,t}^{US} - \frac{IM_w^{us}}{Y^{us}} im_{W,t}^{US} + \frac{C^{e,us}}{Y^{us}} c_t^{e,US} + eg_t^{US}
\end{aligned}
$$

Production function:

$$
y_t^{US} = \phi_p^{us} [\alpha^{us} (\frac{1-\psi^{us}}{\psi^{us}}) r_t^{k,US} + \alpha^{us} k_{t-1}^{US} + (1-\alpha^{us})\, l_t^{US} + ea_t^{US}] \qquad (14)
$$

Taylor Rule:

$$
R_t^{US} = \rho^{us} R_{t-1}^{US} + (1-\rho^{us}) \left[\theta_\pi^{us} \pi_t^{US} + \theta_y^{us} (y_t^{US} - y_t^{f,US})\right] + \theta_{\triangle y}^{us} [y_t^{US} - y_t^{f,US} - (y_{t-1}^{US} - y_{t-1}^{f,US})] - \kappa_1^{US} s_t + \kappa_2^{US} s_{t-1} + eR_t^{US} \qquad (15)
$$

Import:

$$
im_t^{US} = c_t^{US} + \sigma s_t \qquad (16)
$$

Exchange rate (s≡Euros/dolar):

$$
s_t = R_t^{US} - E_t \pi_{t+1}^{US} - \left(R_t^{EA} - E_t \pi_{t+1}^{EA}\right) + E_t s_{t+1} \qquad (17)
$$

Consumption decomposition:

$$
c_t^{US} = 0.7 c_t^{USd} + 0.15 im_t^{US} + 0.15 im_{W,t}^{US} \qquad (18)
$$

External premium:

$$
E_t r_{t+1}^{ex,US} - \left(R_t^{US} - E_t \pi_{t+1}^{US}\right) = \chi^{us} (Q_t^{US} + k_t^{US} - nw_t^{US}) + epr_t^{US} \qquad (19)
$$

Net worth:

$$
nw_t^{US} = \frac{K^{us}}{N^{us}} (r_t^{ex,US} - E_{t-1} r_t^{ex,US}) + E_{t-1} r_t^{ex,US} + \theta_{nw}^{us} nw_{t-1}^{US} + enw_t^{US} \qquad (20)
$$

Entrepreneurial consumption:

$$
c_t^{e,US} = nw_t^{US} \qquad (21)
$$

6.2 EA

Consumption Euler equation:

$$c_t^{EA} = \frac{\frac{h^{ea}}{\gamma^{ea}}}{1+\frac{h^{ea}}{\gamma^{ea}}} c_{t-1}^{EA} + \frac{1}{1+\frac{h^{ea}}{\gamma^{ea}}} E_t c_{t+1}^{EA} - \left(\frac{1-\frac{h^{ea}}{\gamma^{ea}}}{\left(1+\frac{h^{ea}}{\gamma^{ea}}\right)\sigma_c^{ea}} \right) \left(R_t^{EA} - E_t \pi_{t+1}^{EA}\right) + eb_t^{EA} \tag{22}$$

Investment Euler equation:

$$i_t^{EA} = \frac{1}{1+\beta(\gamma^{ea})} i_{t-1}^{EA} + \frac{\beta(\gamma^{ea})}{1+\beta(\gamma^{ea})} E_t i_{t+1}^{EA} + \frac{1}{[1+\beta(\gamma^{ea})](\gamma^{ea})^2 \varphi^{EA}} Q_t^{EA} + ei_t^{EA} \tag{23}$$

Tobin's Q equation:

$$Q_t^{EA} = \frac{1-\delta^{ea}}{1-\delta^{ea}+R_*^{k,ea}} E_t Q_{t+1}^{EA} + \frac{R_*^{k,ea}}{1-\delta^{ea}+R_*^{k,ea}} E_t r_{t+1}^{k,EA} - E_t r_{t+1}^{ex,EA} \tag{24}$$

Capital accumulation equation:

$$k_t^{EA} = (1-\delta^{ea})\, k_{t-1}^{EA} + \delta^{ea} i_t^{EA} \tag{25}$$

Price setting equation:

$$\begin{aligned} r_t^{k,EA} \quad = \quad & \mu_{r^k}^{EA} \left\{ \frac{1}{\alpha^{ea}} \left[\begin{array}{c} \left(\pi_t^{EA} - \frac{\iota_p^{ea}}{1+\beta(\gamma^{ea})\iota_p^{ea}} \pi_{t-1}^{EA} - \frac{\beta(\gamma^{ea})}{1+\beta(\gamma^{ea})\iota_p^{ea}} E_t \pi_{t+1}^{EA} - ep_t^{EA}\right) \left(\frac{(1+\beta(\gamma^{ea})\iota_p^{ea})\xi_p^{ea}}{\left(1-\beta(\gamma^{ea})\xi_p^{ea}\right)\left(1-\xi_p^{ea}\right)} \right) \\ +[ea_t^{EA} - (1-\alpha^{ea})\, w_t^{EA}] \end{array} \right] \right\} \\ & + \left(1-\mu_{r^k}^{EA}\right) \left\{ \frac{1}{\alpha^{ea}} \left[ea_t^{ea} - (1-\alpha^{ea})\, w_t^{EA}\right] \right\} \end{aligned} \tag{26}$$

Labour supply:

$$\begin{aligned} w_t^{EA} \quad = \quad & \mu_w^{EA} \left\{ \left[\begin{array}{c} \frac{\beta(\gamma^{ea})}{1+\beta(\gamma^{ea})} E_t w_{t+1}^{EA} + \frac{1}{1+\beta(\gamma^{ea})} w_{t-1}^{EA} + \frac{\beta(\gamma^{ea})}{1+\beta(\gamma^{ea})} E_t \pi_{t+1}^{EA} - \frac{1+\beta(\gamma^{ea})\iota_w^{ea}}{1+\beta(\gamma^{ea})} \pi_t^{EA} + \frac{\iota_w^{ea}}{1+\beta(\gamma^{ea})} \pi_{t-1}^{EA} \\ -\frac{1}{1+\beta(\gamma^{ea})} \left(\frac{(1-\beta(\gamma^{ea})\xi_w^{ea})(1-\xi_w^{ea})}{\left(1+\frac{(1+\lambda_w)\sigma_l^{ea}}{\lambda_w}\right)\xi_w^{ea}} \right) \left(w_t^{EA} - \sigma_l^{ea} l_t^{EA} - \left(\frac{\sigma_c^{ea}}{1-\frac{h^{ea}}{\gamma^{ea}}}\right) \left(c_t^{EA} - \frac{h^{ea}}{\gamma^{ea}} c_{t-1}^{EA}\right) \right) \end{array} \right] + ew_t^{EA} \right\} \\ & + \left(1-\mu_w^{EA}\right) \left\{ \sigma_l^{ea} l_t^{EA} + \left(\frac{\sigma_c^{ea}}{1-\frac{h^{ea}}{\gamma^{ea}}} \right) \left(c_t^{EA} - \frac{h^{ea}}{\gamma^{ea}} c_{t-1}^{EA} \right) - (\pi_t^{EA} - E_{t-1}\pi_t^{EA}) + ew_t^{EUNC} \right\} \end{aligned} \tag{27}$$

Labour demand:

$$l_t^{EA} = -w_t^{EA} + \left(1 + \frac{1-\psi^{ea}}{\psi^{ea}}\right) r_t^{k,EA} + k_{t-1}^{EA} \tag{28}$$

Market clearing condition:

$$\begin{aligned} y_t^{EA} \quad = \quad & \frac{C^{ea}}{Y^{ea}} c_t^{EA} + \frac{I^{ea}}{Y^{ea}} i_t^{EA} + \frac{IM^{us}}{Y^{ea}} im_t^{US} - \frac{IM^{ea}}{Y^{ea}} im_t^{EA} \\ & + \frac{EX_w^{ea}}{Y^{ea}} ex_{W,t}^{EA} - \frac{IM_w^{ea}}{Y^{ea}} im_{W,t}^{EA} + \frac{C^{e,ea}}{Y^{ea}} c_t^{e,EA} + eg_t^{EA} \end{aligned} \tag{29}$$

Production function:

$$y_t^{EA} = \phi_p^{ea}[\alpha^{ea}(\frac{1-\psi^{ea}}{\psi^{ea}}) r_t^{k,EA} + \alpha^{ea} k_{t-1}^{EA} + (1-\alpha^{ea})\, l_t^{EA} + ea_t^{EA}] \tag{30}$$

Taylor Rule:

$$R_t^{EA} = \rho^{ea} R_{t-1}^{EA} + (1-\rho^{ea}) \left[\theta_\pi^{ea} \pi_{t-1}^{EA} + \theta_y^{ea}(y_t^{EA} - y_t^{f,EA})\right] + \theta_{\triangle\pi}^{ea}(\pi_t^{EA} - \pi_{t-1}^{EA}) + \theta_{\triangle y}^{ea}[y_t^{EA} - y_t^{f,EA} - (y_{t-1}^{EA} - y_{t-1}^{f,EA})] + \kappa_1^{EA} s_t - \kappa_2^{EA} s \tag{31}$$

Import:

$$im_t^{EA} = c_t^{EA} - \sigma s_t \tag{32}$$

Consumption decomposition:

$$c_t^{EA} = 0.7c_t^{EUd} + 0.15im_t^{EA} + 0.15im_{W,t}^{EA} \tag{33}$$

External premium:

$$E_t r_{t+1}^{ex,EA} - \left(R_t^{EA} - E_t \pi_{t+1}^{EA}\right) = \chi^{ea}(Q_t^{EA} + k_t^{EA} - nw_t^{EA}) + epr_t^{EA} \tag{34}$$

Net worth:

$$nw_t^{EA} = \frac{K^{ea}}{N^{ea}}(r_t^{ex,EA} - E_{t-1} r_t^{ex,EA}) + E_{t-1} r_t^{ex,EA} + \theta_{nw}^{ea} nw_{t-1}^{EA} \tag{35}$$

Entrepreneurial consumption:

$$c_t^{e,EA} = nw_t^{EA} \tag{36}$$

6.3 Rest of the World

World production:

$$y_t^W = \frac{IM_{W,t}^{US}}{Y^W} im_{W,t}^{US} + \frac{IM_{W,t}^{EA}}{Y^W} im_{W,t}^{EA} \tag{37}$$

World market clearing:

$$c_t^W = y_t^W \tag{38}$$

World consumption:

$$c_t^W = 0.4083 ex_{W,t}^{US} + 0.5917 ex_{W,t}^{EA}$$

Export to the US (from the Leontief production function's ratio):

$$im_{W,t}^{US} = \phi_p^{us} \alpha^{us} k_{t-1}^{US} + \phi_p^{us} \left(1-\alpha^{us}\right) l_t^{US} + \phi_p^{us} \alpha^{us} (\frac{1-\psi^{us}}{\psi^{us}}) r_t^{k,US} + \phi_p^{us} ea_t^{US} \tag{39}$$

Export to the EA (from the Leontief production function's ratio):

$$im_{W,t}^{EA} = \phi_p^{ea} \alpha^{ea} k_{t-1}^{EA} + \phi_p^{ea} \left(1-\alpha^{ea}\right) l_t^{EA} + \phi_p^{ea} \alpha^{ea} (\frac{1-\psi^{ea}}{\psi^{ea}}) r_t^{k,EA} + \phi_p^{ea} ea_t^{EA} \tag{40}$$

World's relative demand for US and EA exports:

$$ex_{W,t}^{US} = ex_{W,t}^{EA} - \sigma s_t \tag{41}$$

6.4 Glossary of Model Variables

c_t :	Consumption	s_t	Real exchange rate
i_t :	Investment	im_t^{US} :	US imports from EA
y_t :	Output	im_t^{EA} :	EA imports from US
Q_t :	Tobin's Q	$im_{W,t}^{US}$:	US imports from World
k_t :	Capital	$im_{W,t}^{EA}$:	EA imports from World
l_t :	Labour	$ex_{W,t}^{US}$:	US exports to World
w_t :	Nomianl wage	$ex_{W,t}^{EA}$:	EA exports to World
$\pi_{t:}$:	Inflation	y_t^W :	World production
R_t :	Nominal interest rate	c_t^W :	World consumption
r_t^{ex} :	External premium		
r_t^k :	Captial return		
c_t^d :	Demestic consumption		
c_t^e :	Entrepreneurial consumption		
nw_t :	Net worth		

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