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Working Paper

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Working Paper, No. 845

Provided in Cooperation with:
School of Economics and Finance, Queen Mary University of London

Suggested Citation: Mumtaz, Haroon; Theodoridis, Konstantinos (2018) : US financial shocks and the distribution of income and consumption in the UK, Working Paper, No. 845, Queen Mary University of London, School of Economics and Finance, London

This Version is available at:
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School of Economics and Finance

Queen Mary University of London

US financial shocks and the distribution of income and consumption in the UK.

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December 2017

Abstract

We show that US financial shocks have an impact on the distribution of UK income and consumption. Households with higher income and higher levels of consumption are affected more by this shock than households located towards the lower end of these distributions. An estimated multiple agent DSGE model suggests that the heterogeneity in the household responses can be explained by the different levels of access to financial markets. We find that this heterogeneity magnifies the effect of this shock on aggregate output.

Key words: FAVAR, DSGE model, Financial Shock.

JEL codes: D31, E32, E44

1 Introduction

The UK economy is known to be fairly open and integrated with world economic developments. In an early contribution, Mumtaz and Surico (2009) show that international monetary and supply shocks can have important implications for real and financial variables in the UK.[1] A more recent investigation by Chowla *et al.* (2014) suggests that world shocks were responsible for the bulk of the decline experienced by UK GDP in 2008/2009. Chowla *et al.* (2014) explicitly consider the role of world financial shocks, a class of economic disturbances that has gained prominence since the global financial crisis of 2007. The importance of these shocks is further highlighted by Abbate *et al.* (2016) who show that US financial shocks explained about 20 percent of the forecast error variance of UK GDP growth over the late 2000s. This supports the analysis in Eickmeier and Ng (2015) who report that an unexpected deterioration in US credit supply has a statistically significant negative effect on UK GDP, credit and equity prices.

It is, therefore, clear from this literature that international financial shocks have important economic effects on the UK, *on aggregate*. However, this analysis largely ignores the possible re-distribution effects of these fluctuations for UK households. This omission is surprising for two reasons. First, the post-1985 period not only coincided with financial liberalisation in the UK and financial globalisation across the industrial world (see Terrones *et al.* (2007)), it also saw one of the largest increases in consumption and income inequality in the UK as documented in Mumtaz and Theophilopoulou (2017) and Blundell and Etheridge (2010). If the UK became more sensitive to global financial developments over this period, this then raises the possibility that these shocks

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[1] In this paper, 'international' shocks and 'world' shocks are used interchangeably.

may have contributed to the disparity in income and consumption across households. Second, if the effect of these shocks differs in magnitude for households at different points of the income distribution, then this phenomenon may have aggregate consequences if the marginal propensity to consume is heterogenous.

The aim of this paper is to fill this gap in the literature. We investigate the effect of US financial shocks on the distribution UK real income and consumption. Our empirical results suggest that the response of income and consumption growth of households at the top end of the income and consumption distribution to these shocks is systematically larger than those towards the left tail of the distribution. Moreover, the contribution of these disturbances to income and consumption growth and their forecast error variance is larger when considering the top 80th percentile of the respective distribution. Given the existing gap in the level of income and consumption in top and bottom percentiles, these estimates suggest that adverse international financial shocks reduce inequality by disproportionally reducing the growth rate of these variables at the right tail of the distributions.

In order to explain the transmission of the shock, we build and estimate a multiple agent DSGE model that tries to incorporate the features of households found at different points of the consumption and income distribution. The households in the model differ in terms of home ownership, employment status and access to financial markets. A one standard deviation adverse foreign financial shock leads to a large reduction in domestic output, with GDP falling by about 1.5 percent at the two year horizon. The shock induces a cut in lending by domestic banks which reduces housing demand from the indebted home-owners. The resulting fall in house prices amplifies the credit constraints faced by these households leading to a fall in their consumption and investment. Falling aggregate demand leads to declining wages which adversely affects households classified as employed and unemployed tenants. The reduction in rates by the monetary authority in response to the shock benefits households that own their homes outright. However, the increase in consumption of this group is not enough to ameliorate the negative impact of the shock. Counterfactual experiments suggest that heterogeneity across households is a key factor driving the large effect of this shock. If households are assumed to be more homogenous, then the negative financial shock has a negligible impact. Intuitively, this occurs because with a more homogenous economy (where agents have access to financial markets), the monetary authority can easily counter the adverse shock via lower interest rates.

Our analysis is related to the growing empirical literature on the disaggregate effects of macroeconomic shocks in the UK. Papers such as Cloyne *et al.* (2016), Mumtaz and Theophilopoulou (2017) and Cloyne and Surico (2017) investigate how the effects of domestic monetary and fiscal policy shocks differ across features of the household distribution. Our paper adds to this literature in two ways: (a) We show that the effects of key non-policy shocks are also heterogenous across households and (b) this heterogeneity has important implications for the aggregate impact of such shocks. This latter result highlights the importance of modelling hetrogeneity within economic models when attempting to measure the transmission of policy and non-policy shocks within a DSGE framework. This insight is clearly in line with papers that employ heterogeneous agent (HA) models (see for e.g. Kaplan and Violante (2014), Werning (2015), Kaplan *et al.* (2017) and Auclert (2017)). While our paper employs a simpler approach than the HA literature, we are able to take our model to the data.

From a policy perspective, our analysis highlights the importance of financial shocks, both for aggregate outcomes and their effect on the distribution of income and consumption. Our results suggest that the persistent impact of the recent financial crisis on the UK economy may be driven by the effect of deleverging on the part of some households in the economy. In such circumstances stimulus measures such as quantitative easing that works via their impact on long term interest

rates may not be particularly effective. Policies designed to ease credit constraints directly may be more effective in these conditions.

The paper is organised as follows: The empirical analysis in the paper is presented in section 2 with the model, data and results described in sections 2.1, 2.2 and 2.3 respectively. Section 3 introduces the theoretical model and considers the role of heterogeneity in driving aggregate fluctuations.

2 Estimating the effects of US financial shocks

2.1 Empirical model

We adopt a simple approach to estimate the effects of US financial shocks on UK aggregate and disaggregate variables. In particular, we employ a following factor augmented vector autoregression model (FAVAR). The observation equation of the model is defined as:

$$\begin{pmatrix} X_t^{US} \\ X_t^{UK} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & \Lambda \end{pmatrix} \begin{pmatrix} X_t^{US} \\ F_t^{UK} \end{pmatrix} + \begin{pmatrix} 0 \\ v_t \end{pmatrix} \tag{1}$$

where X_t^{US} is a matrix of endogenous variables for the US economy chosen for the purpose of identifying a US financial shock. We describe the data and shock identification in detail below. X_t^{UK} is a panel of variables for the UK covering both aggregate macroeconomic and financial data and the distribution of real income growth and real consumption growth. F_t^{UK} denotes a set K factors that summarise the information in X_t^{UK} while v_t captures the idiosyncratic components.

In the benchmark model, X_t^{US} contains GDP growth, CPI inflation, the three month treasury bill rate and a measure of financial conditions for the US economy f_t. In the benchmark case we proxy f_t using the excess bond premium (EBP) proposed in Gilchrist and Zakrajsek (2012). The EBP measures the excess return required by bond investors over and above their compensation for firms' expected defaults. We also show that our results are robust to using alternative measures of financial conditions. These include the Chicago Fed financial condition index (FCI) and the spread between the BAA corporate bond-rate and ten year treasury bill rate. As discussed in Brave and Butters (2011) the FCI is constructed as a factor from a set of 120 series that relate to money, debt and equity markets as well as the leverage of financial intermediaries in the US. The BAA spread provides a simpler non-parametric measure of financial stress. In the benchmark model, we treat the US variables as 'observed factors' and assume a factor structure only for the UK block. However, this assumption (which simplifies the model) is innocuous and a factor structure in the US block does not change the key conclusions of the analysis.

The matrix X_t^{UK} includes 29 aggregate variables for the UK covering real activity, inflation, the yield curve, money and credit growth, exchange rates, stock and home prices and corporate bond spreads. In addition, we include real income and real consumption growth in 5 percentile groups of the household distribution. As described in detail in section 2.2.1 below, this household level data is constructed using the Family Expenditure Survey (FES).

The set of factors $Z_t = \begin{pmatrix} X_t^{US} \\ F_t^{UK} \end{pmatrix}$ follows a $VAR(P)$:

$$Z_t = c + \sum_{p=1}^{P} B_p Z_{t-p} + A_0 e_t \tag{2}$$

where A_0 denotes the contemporaneous impact matrix. We assume an $AR(P)$ structure for the

idiosyncratic components $v_t = [v_{1t}, v_{2t}, .., v_{Nt}]$. Note that the FAVAR model implies that the series in X_t^{UK} are driven by aggregate shocks e_t and idiosyncratic shocks v_t. When the disaggregate income and consumption series in X_t^{UK} are considered, our model captures the impact of aggregate shocks *net* of the effect of idiosyncratic disturbances that might proxy measurement error or differences in characteristics specific to the particular percentile group (see Giorgi and Gambetti (2017)).

2.1.1 Identification of US financial shocks

In the benchmark model, we assume that A_0 has a recursive structure with the ordering: (1) US GDP growth, (2) US CPI inflation, (3) US 3 month treasury bill rate, (4) f_t and (5) F_t^{UK}. This ordering implies that US financial shocks, i.e. shocks to f_t have a lagged impact on US variables while f_t reacts immediately to the remaining US shocks. In contrast, shocks to the UK factors are constrained to affect f_t with a lag. This ordering reflects the simple idea that as f_t represents forward looking variables, it is unlikely that there is a one quarter lag between developments in the US economy and changes in US financial conditions. In contrast, developments in the UK economy might be of less immediate importance for US financial conditions given its small relative size. This type of ordering is typically used in VARs to seperate real and financial shocks with macroeconomic variables ordered before the financial variables for the country of interest (see for example Prieto *et al.* (2016) and Alessandri and Mumtaz (2017)).

We estimate several variations of this benchmark model in order to show that our results are robust (see section 2.3.1). First, as mentioned above, we consider three different proxies for f_t and show that the key results remain relatively unchanged. Second, we consider an alternative ordering by moving f_t before the US treasury bill rate. Third, we assume a factor structure for the US block which is expanded to incorporate a large panel of variables and identify the financial shock using two methods: (a) via a recursive ordering and (b) by treating f_t as an external instrument to estimate the shock of interest. In all cases, we obtain results very similar to the benchmark case.

2.2 Data and model specification

2.2.1 Disaggregate data on income and consumption

As mentioned above, our data set for the UK contains real income and consumption growth at different points on the household distribution. The household level data on these variables is obtained from the Family Expenditure Survey (FES) from 1975 to 2014. The FES is an annual survey which provides detailed information on demographics, income, expenditure and consumption for a representative sample of around 7,000 UK households per year. In 2001 FES merged with the National Food Survey and became the Expenditure and Food Survey (EFS) and with the Living Costs and Food Survey (LCFS) in 2008. The variable for income is defined as weekly household income net of taxes and national insurance contributions for the entire household (reported under code p399 to 1978 and then p389). The measure of total household consumption is based on the Office of National Statistics (ONS) definition of total expenditure. This is the sum of housing, food, alcohol, tobacco, fuel, light and power, clothing and footwear, durable household goods, other goods, transport, vehicles and services. In order to take into account family size, the income data is equivalised by dividing the income of each household by the square root of the number of individuals in the household. We use consumption per-capita by dividing total household expenditure by the number of household members.

For each year in the sample, households are assigned to a quarter based on the date of their survey interview. We then remove any households reporting zero or negative income and trim the

top and bottom one percent of the distribution to remove possible outliers. This leaves us a sample of about 2000 households per quarter. These households are then sorted into 5 percentile groups by the level of income and consumption, respectively. The percentile groups are defined as: $P_1 = \left[\leq 20^{th}\right], P_2 = \left[> 20^{th} \& \leq 40^{th}\right], P_3 = [> 40^{th} \& \leq 60^{th}], P_4 = [> 60^{th} \& \leq 80^{th}], P_5 = [> 80^{th}]$. We calculate average income and consumption within these five groups. Repeating this procedure from 1975 to 2014 provides us a time series for income and consumption in these 5 groups which is deflated by CPI and seasonally adjusted.

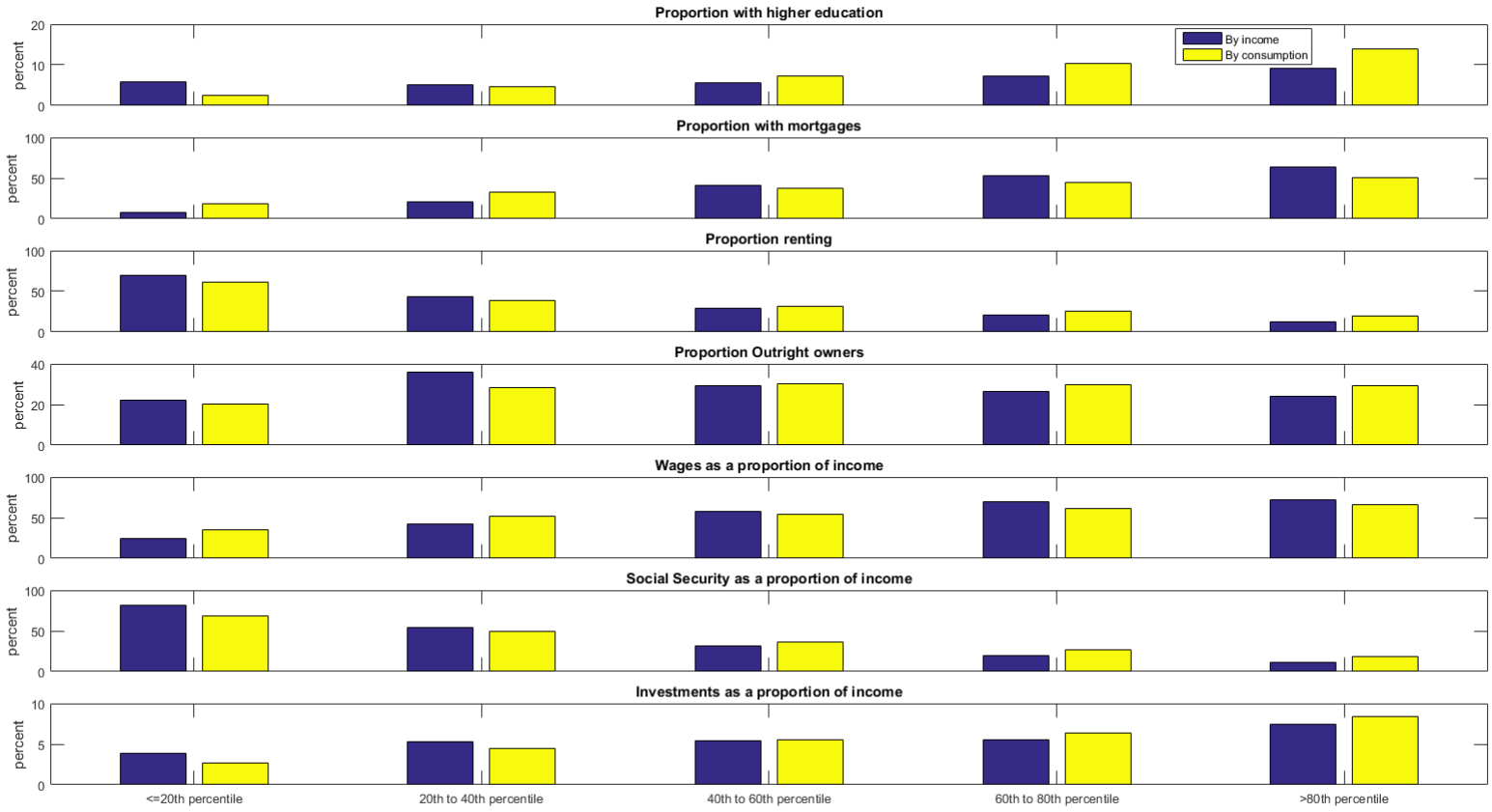

Figure 1: Household characteristics within each percentile group. The top row presents the proportion of households where the head is educated to university level. The last three rows present wages, social security and investments as a proportion of Gross income. The estimates reported in the figure are averages over the years 1975, 1980, 1985, 1990, 1995, 2000, 2005 and 2010.

Figure 1 presents some basic characteristics of households that fall within these percentile groups. The bottom tail of both the income and consumption distribution is characterised by a lower level of education, with households more likely to be renters rather than mortgagors, deriving a large proportion of their income from social security benefits. In contrast, richer households and those with a higher level of consumption are more likely to be home owners, better educated and derive a larger part of their income from wages and investments.

Figure 2 provides information about the level of income and consumption in these groups. The figure shows that inequality rose substantially during the mid-1980s, with the disparity in income and consumption rising throughout the distribution. While the post-1990 period saw some declines in the difference between the median and tenth percentile, the 90/50 measure remained broadly stable suggesting a persistent difference between high income/consumption households and the remaining population. Inequality in income is more acute than equality in consumption below the median, while consumption inequality is higher towards the top of the distribution.

2.2.2 Aggregate data

The aggregate data series used in the FAVAR are fairly standard and listed in Table 3 in Appendix A along with their source. For the benchmark model, data for EBP is obtained from the website of Simon Gilchrist (http://people.bu.edu/sgilchri/Data/data.htm). All non-stationary series are log differenced. The estimation sample runs from 1975Q1 to 2014Q1.

2.2.3 Model specification and estimation

One of the key choices with regards to specification of the model is the number of factors. We follow the general approach used in Bernanke *et al.* (2005): i.e. the benchmark model is estimated using $K = 5$. We then show that the main results do not change substantially if either a more parsimonious model is used or the number of factors is increased to 7. The lag length P is set to 4.

The FAVAR is estimated using a Gibbs sampling algorithm. The priors and the conditional posterior distributions are fairly standard and described in the technical appendix. The Gibbs algorithm simply exploits the fact that given F_t^{UK}, the FAVAR collapses to a series of linear regressions and a VAR model where the conditional posteriors are well known. Given the factor loadings and the parameters of the transition equations, the moments of the conditional posterior for F_t^{UK} can be obtained via the Kalman filter. We employ 200,000 iterations of the algorithm setting a burn-in period of 100,000 iterations. Of the remaining draws, every 10th is retained for inference. The technical appendix presents evidence in favour of convergence of the algorithm.

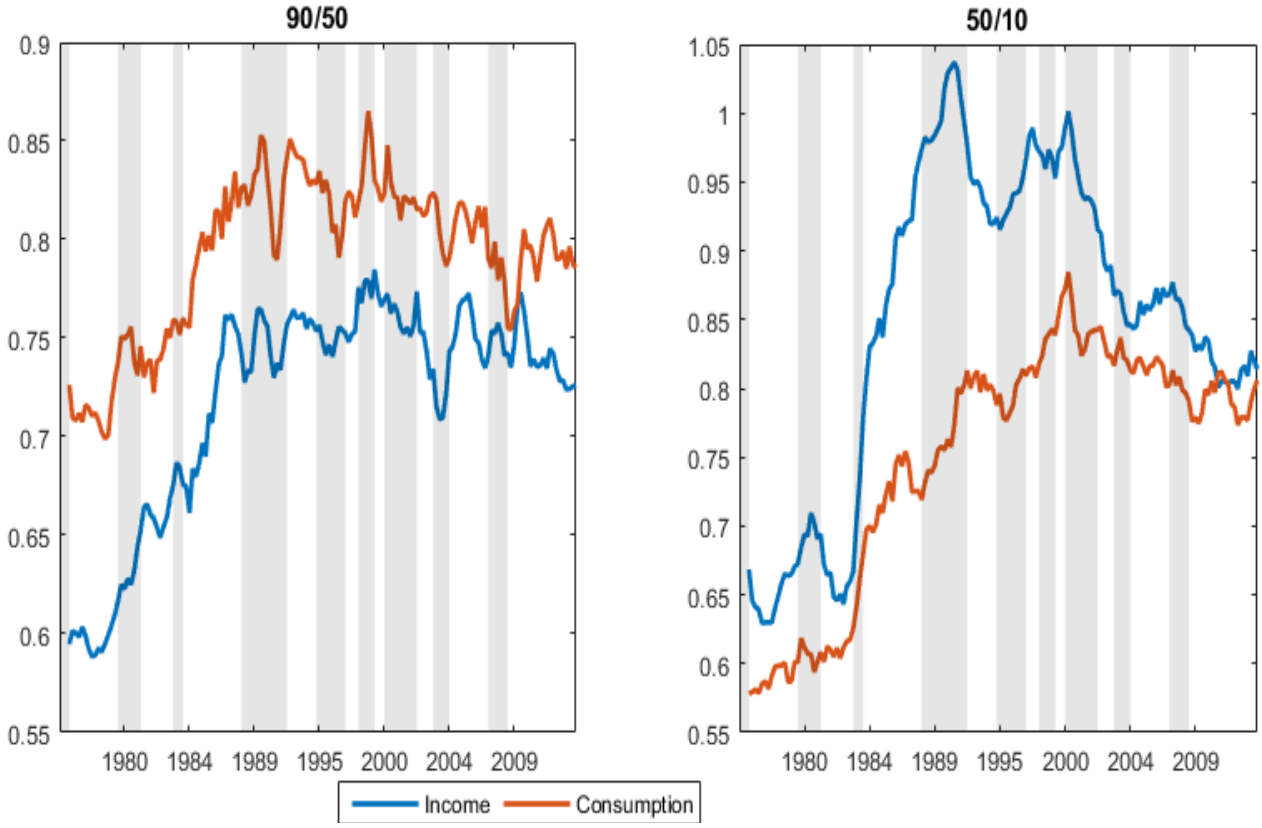

Figure 2: The difference between the 90th and 50th percentile of log income and consumption. (left panel). The difference between the 50th and 10th percentile of log income and consumption. (right panel). The figures report 4 quarter moving averages.

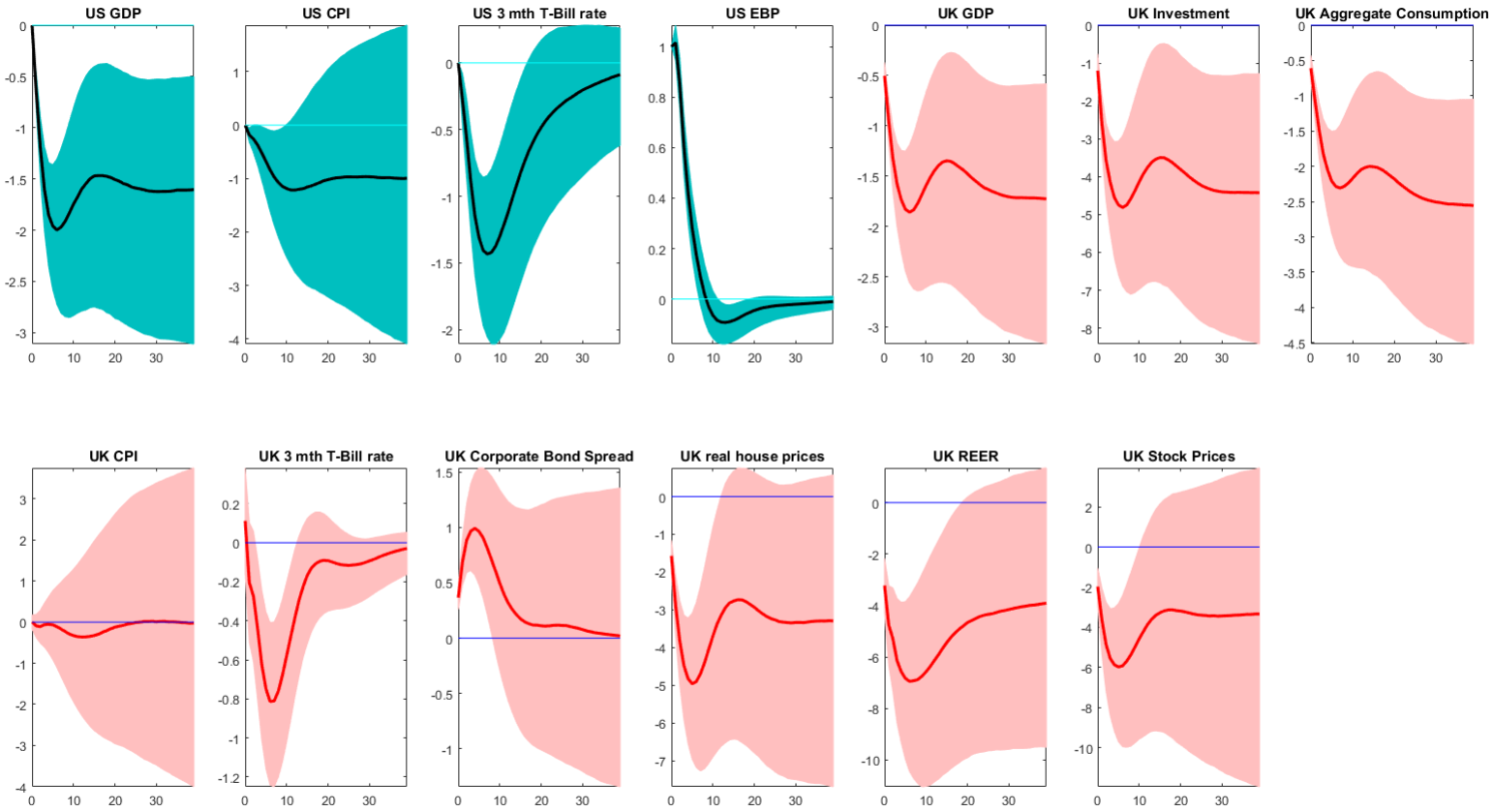

Figure 3: Cumulated response of key aggregate variables to a US financial shock

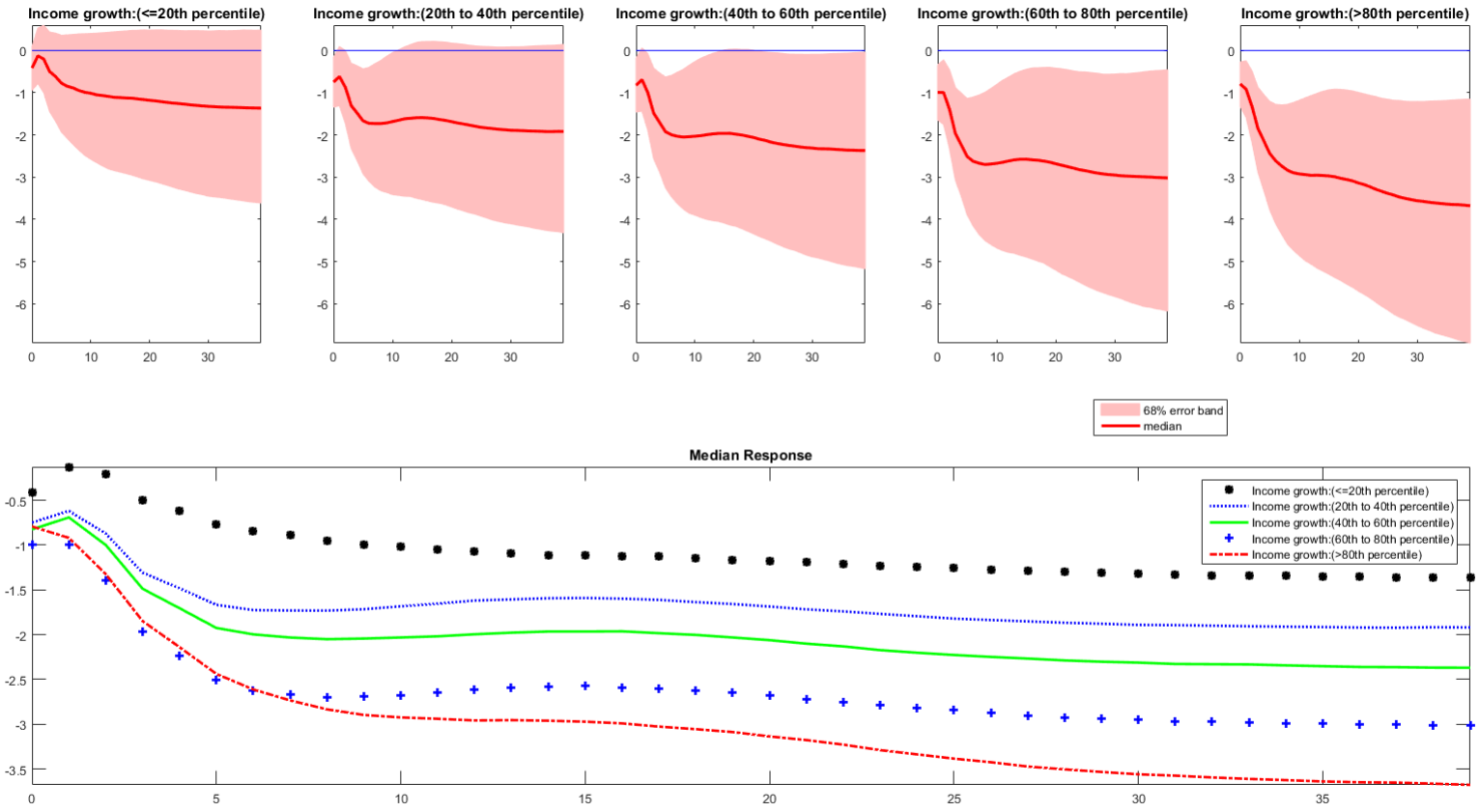

Figure 4: Cumulated response of the distribution of income growth to a US financial shock.

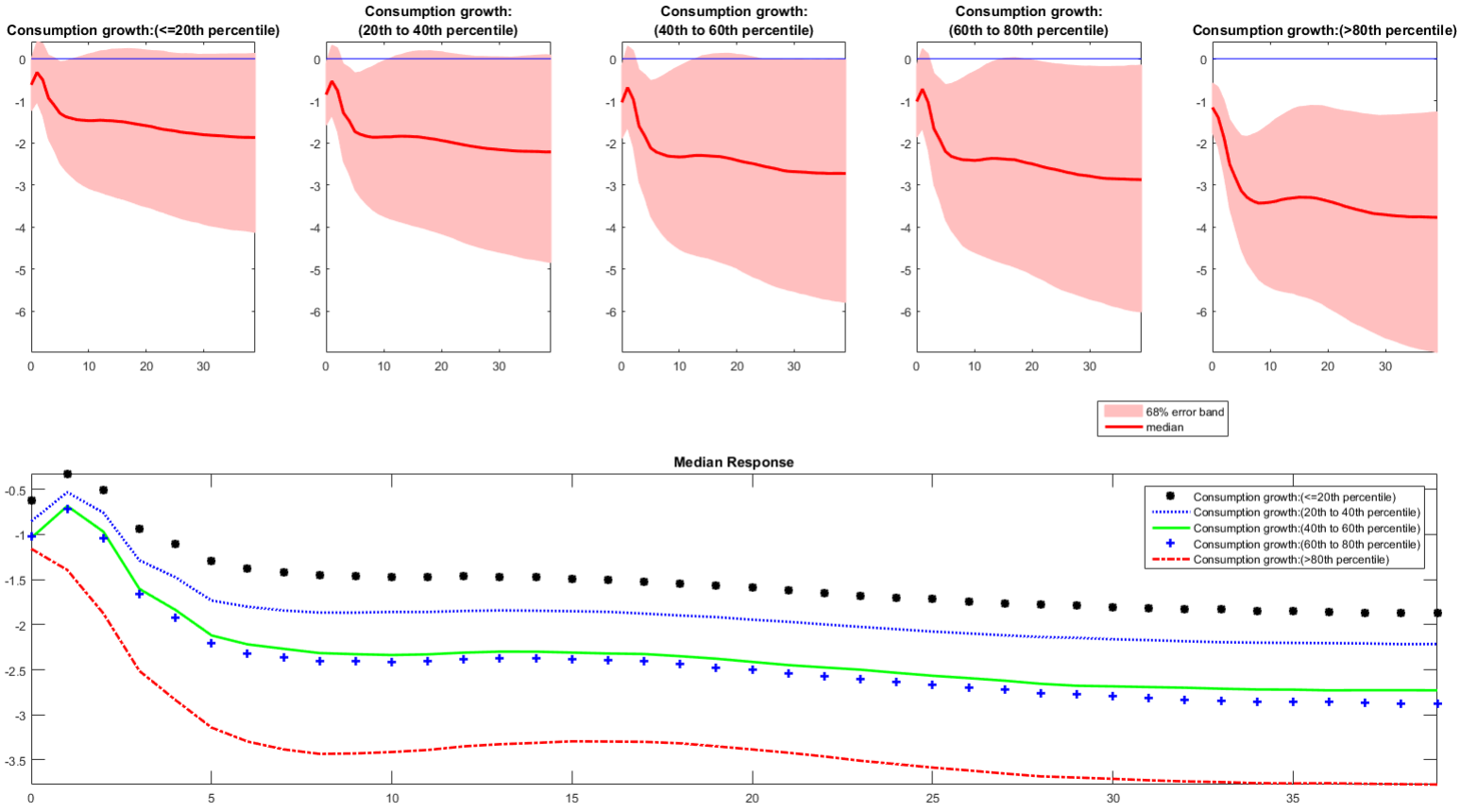

Figure 5: Cumulated response of the distribution of consumption growth to a US financial shock.

2.3 Empirical results

2.3.1 Impulse response to US financial shocks

Figure 3 shows the response of key aggregate series to an adverse financial shock in the US normalised to increase the EBP by one unit. The results are similar to those reported by Gilchrist and Zakrajsek (2012) in their VAR analysis for the US economy. US GDP declines by about two percent at the two year horizon with CPI falling more gradually by one percent. The short-term interest rate declines, possible indicating the response of monetary policy. As far as the UK economy is concerned, this shock leads to a sharp deterioration in the financial outlook with large falls in asset prices and a rise in the corporate bond spread. This is accompanied by a sharp-downturn in real activity with consumption investment and GDP showing large declines. There is a fall in the short-term interest rate accompanied by a depreciation of the real effective exchange rate.

Figure 4 presents the cumulated response of real income growth in the five percentile groups, P_1 to P_5. The top panel shows that real income declines across groups in response to the US financial shock. It is clear from the comparison of the median responses in the bottom panel that this decline is not uniform. The percentile group P_1 displays the smallest decline with real income falling by about -0.5 percent at the two year horizon. Groups P_2 and P_3 experience a much larger fall of income of around 1.7 to 2 percent at the 8 quarter horizon. It is the top two groups, however, that display the largest negative response to the shock with income falling by about 2.6 percent. When the error bands are taken into account, the key systematic difference lies between the response of groups P_1 and the rest – as shown in Appendix B, over at least some of the horizon, we can reject the hypothesis that zero lies within the 68 percent highest posterior density interval of the difference of the response of P_1 and the remaining groups.

Figure 5 shows that a similar pattern can be seen in the response of consumption growth to this shock. The response of P_1 is the smallest while consumption in P_5 falls by about three times as much as P_1. When we consider the posterior distribution of the difference in the responses (see Appendix B), there is evidence of a systematic difference between the response of P_1 and P_5 and that of the remaining groups. It is also interesting to note that in terms of magnitude, the consumption responses are as large, if not larger than the income responses.

In terms of inequality, the income responses suggest that the financial shock does not have large implications for the dispersion at the top of the dispersion as captured by measures such as the 90/50 difference shown in figure 2. However, the relatively small response of income in group P_1 suggests that this shock reduces inequality between low and medium/high income groups. The consumption responses also suggest a fall in dispersion between these groups as consumption falls substantially more at the middle and top of the distribution. However, as the decline in consumption of group P_5 is systematically larger than that of groups P_3 and P_4, there is some evidence that suggests that consumption inequality also declines towards the top end of the distribution.

Before turning to a discussion of the implications of these results, we investigate the robustness of these estimates. Figure 12 in Appendix C shows the estimate impulse responses of the income and consumption percentile groups using five alternative methods of identifying the US financial shock. The top two panels of the figure show impulse responses from FAVARs that replace the EBP with the Chicago Fed FCI and the corporate bond spread, respectively. As in the benchmark case, the response of income in group P_1 is smaller than groups that fall towards the right tail of the distribution. Similarly, the response of consumption rises in the top groups. As shown in the third row of the figure, very similar results are obtained when the EBP is ordered before the interest rate in the benchmark model. The fourth and the fifth rows of the figure presents results from FAVAR models where we also assume a factor structure for the US block. In other words, we include a

panel of 91 US series covering the real and financial sector. The factors extracted from these series replace GDP growth, CPI inflation and the short-term interest rate. In the model labelled 'FAVAR 1', the financial shock is identified by ordering the EBP after the US factors but assuming that EBP can contemporaneously affect 'fast-moving' US variables and all the UK variables in the data set.[2] In contrast, 'FAVAR 2' follows the approach of Stock and Watson (2012) and uses the EBP as an external instrument to identify the shock. Under this scheme, no restrictions are placed on the contemporaneous impact of the shock. In both cases, the results support the benchmark results – the income response in group P_1 is the smaller than richer households, while the consumption response increases in magnitude as one moves towards the right tail of the distribution. Note that the technical appendix presents further sensitivity analysis which shows that the key results are robust to the number of factors included in the benchmark model.

[2] The technical appendix provides a list of US data series used in this model.

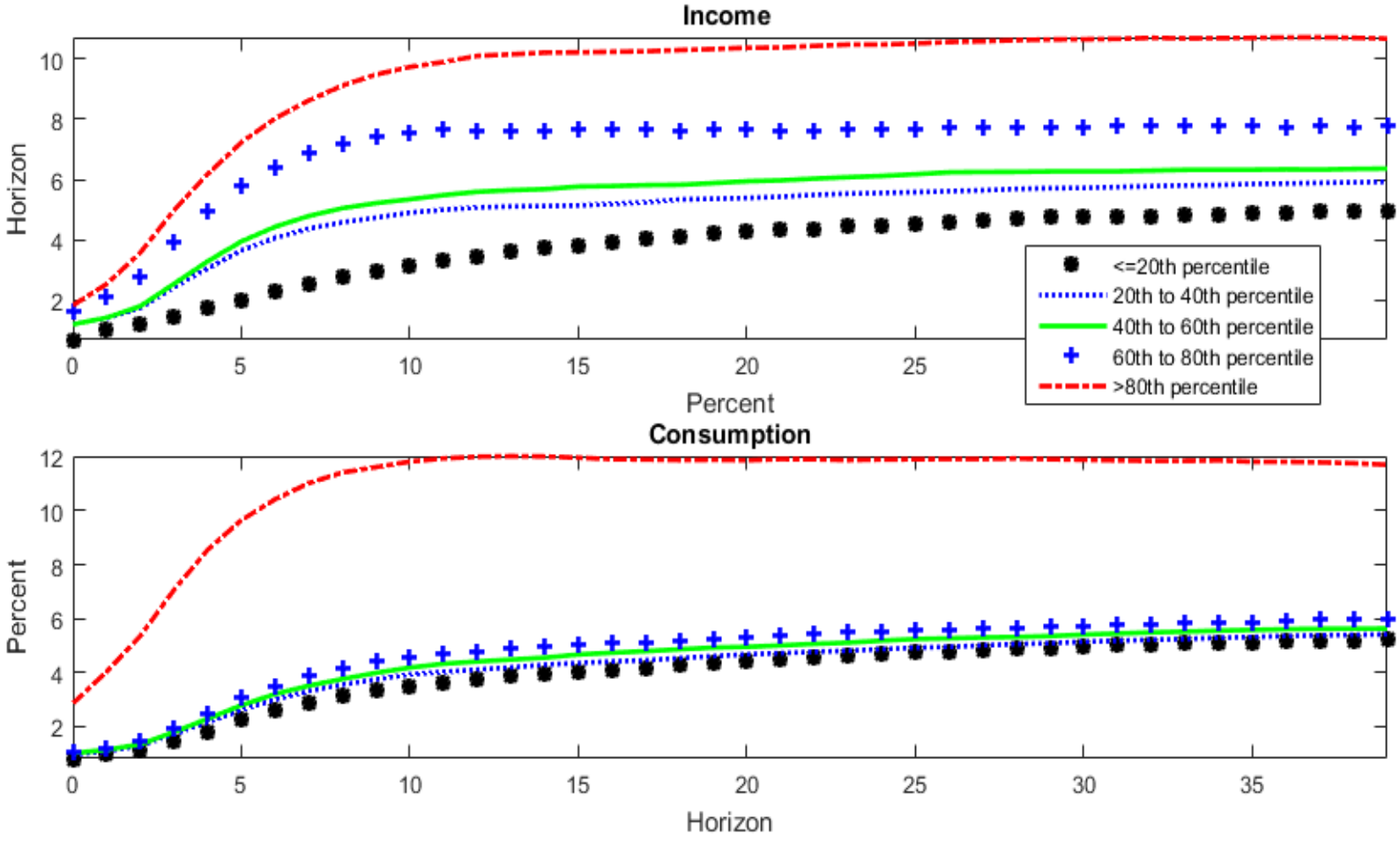

Figure 6: Contribution of the US financial shock to the FEV of income and consumption. The figure shows the posterior median estimate.

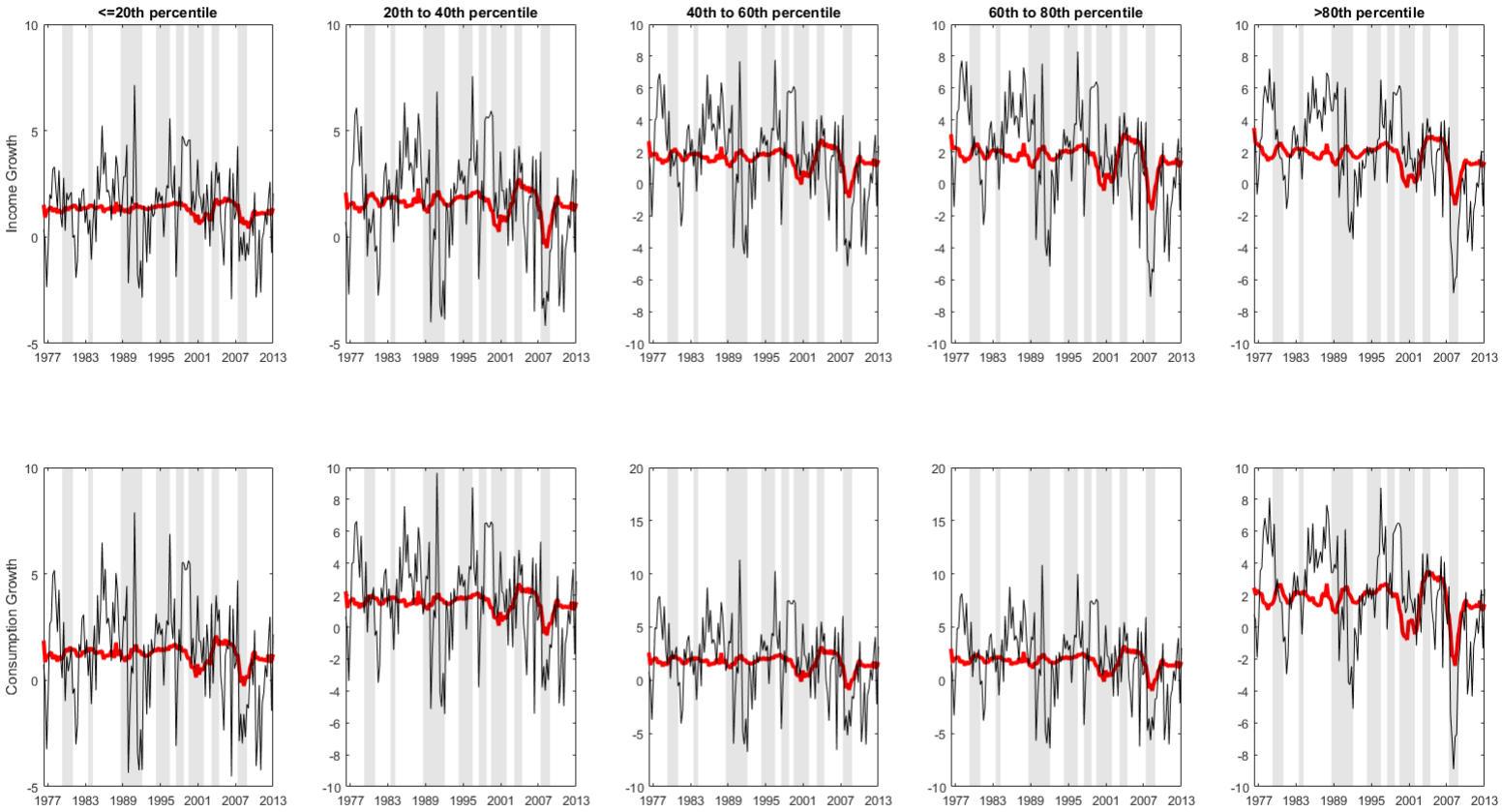

Figure 7: Contribution of the US financial shock to income and consumption growth. The black line denotes income or consumption growth less its idiosyncratic component. The red line shows the (posterior median) counterfactual estimate of this quantity assuming only the US financial shock is active. In both the actual and counterfactual case, a four quarter moving sum (i.e. annual growth rates) are shown. The shaded areas are recessions as indicated by the OECD.

2.3.2 Variance and historical decomposition

Figure 6 presents the percentage contribution of the financial shock to the forecast error variance (FEV) of income and consumption in each of the percentile groups obtained using the benchmark model.[3] The contribution of the shock to the FEV of income below the 60th percentile is fairly small, and estimated to be below six percent at the two year horizon. In contrast, the contribution of the shock to the FEV of income in the top two percentile groups is estimated to be larger, with the estimate for income in P_5 close to ten percent. A similar pattern is observed for contributions to the FEV of consumption – the contribution of the shock to consumption in the top group is non-negligible.

Figure 7 presents the historical contribution of the shock to fluctuations in annual income and consumption growth (net of the idiosyncratic error) in each percentile group. In particular, the black lines in the figure display the four quarter moving average of $X_{it}^{UK} - v_{it}$ where $i = 1, 2, ...10$ denote the ten variables of interest shown in Figure 7. The red lines display a counterfactual estimate of this quantity obtained by generating data from the FAVAR assuming that only the entry corresponding to the US financial shock is non-zero in e_t (see equation 2). Two features of the estimates immediately stand out. First, the contribution of the shock to both income and consumption growth was fairly small before the late 1980s. The US financial shock appears to be important in post-2000 period, driving down income and consumption growth in the early part of the decade, before making a positive contribution. The positive impact of the shock came to an abrupt end in 2007, with the contribution pushing down on both variables. The second key feature of the results is the fact that in terms of magnitude, the contribution of the shock is largest in higher percentile groups. Taking the financial crisis period as an example, both income and consumption growth in group P_1 would have suffered only a modest decline (relative to the actual data) if only the US financial shock was active. In contrast, income and consumption growth in group P_5 fall by a substantial amount under this counter-factual scenario.

In summary, results based on impulse responses and decompositions suggest strongly that US financial shocks have an asymmetric effect on the distribution of income and consumption in the UK. The impact of the shock on these variables is larger when considering the right tail of the distribution. We now turn to a consideration of the causes and consequences of this asymmetry.

3 Theoretical considerations

Why is the effect of the US financial shock larger at the right tail of the distribution? Possible reasons for this heterogeniety can be discerned from the statistics presented in Figure 1 and the responses of income and consumption discussed above. As discussed in section 2.2.1 above, the right tail of the distribution is dominated by households that are mortgagors rather than renters or outright owners. In an influential contribution, Cloyne *et al.* (2016) show that households with mortgage debt are likely to be 'wealthy hand to mouth' households that are liquidity contrained. In particular, using the British household panel survey, 40 percent to 50 percent of mortgagors are classified in this category.[4] This conclusion is supported by the fact that the consumption response of the percentile groups above the median to the adverse financial shock is relatively large indicating the possibility of a higher marginal propensity to consume. Figure 1 also suggests that the right tail of the consumption and income distribution derive a larger (albeit, marginally) proportion of

[3] The contribution of the shock at the 2 year horizon to US GDP, EBP, UK GDP and UK stock price growth is 12 percent, 85 percent, 17 percent and 13 percent respectively.

[4] Cloyne *et al.* (2016) define wealthy hand to mouth households as those whose net liquid wealth is less than half of their monthly labour income.

their income in the form of investments and this may imply a larger exposure to the decline of the interest rate in the face of the financial shock (see Figure 3). In contrast, households to the left of the consumption and income distribution obtain a larger proportion of income in the form of benefits and this may cushion the negative impact of the financial shock.

In order to explore the implications of this heterogeneity for aggregate dynamics, we consider a DSGE model that incorporates the household characteristics evident in Figure 1. The model features multiple agents and is therefore a compromise between a representative agent set up and a fully fledged HA model. The main advantage of our simpler approach is that we are able to estimate the model while still retaining a structure that reflects the key cross-sectional features of the survey data considered in our study. Taking the model to the data is important in our context as our interest centers on quantitative effects of the foreign financial shock.

3.1 DSGE model

The model developed in this section builds upon the work of Iacoviello (2005), Iacoviello and Minetti (2006), Liu *et al.* (2013), Iacoviello (2015) and Liu *et al.* (2016). We extend these studies along many dimensions: First, we include the financial frictions considered in these papers into one model. We add two additional types of households (unemployed and employed tenants) that do not own homes but rent housing services. The employed tenants have access to financial markets but they use it to buy unemployment insurance. Domestic intermediate good value added producers and importers are assumed to be price setters and this gives a role to monetary policy. All agents operate in a small open economy setting and bankers (who also face a borrowing constraint) can invest in both domestic and foreign assets.

The complete model equations are provided in the technical appendix. We describe the key agents in the model below:

3.1.1 Unemployed Tenants

The model includes unemployed tenants who receive an unemployment benefit ξ (transfers from outright home-owners) and work a small number of hours l_t^{ut} (the labour income consists only 20% of their consumption expenditure – $\frac{wl^{ut}}{c^{ut}} = 0.20$).

$$c_t^{ut} + r_t^h h_{t-1}^{ut} = \xi + w_t l_t^{ut} \tag{3}$$

Both the unemployment benefit and labour income $w_t l_t^{ut}$ are used to finance consumption c_t^{ut} and housing $r_t^h h_{t-1}^{ut}$. As in Gali *et al.* (2007) these households are "hand-to-mouth" consumers. This class of agents in the model is a proxy for the households that fall in the left tails of the income and consumption distributions estimated using the survey data.

3.1.2 Employed Tenants

Employed tenants receive utility from consumption $\left(c_t^{et}\right)$, housing services $\left(h_t^{et}\right)$ and dis-utility from working $\left(l_t^{et}\right)$

$$u_t^{et} = E_t \sum_{i=0}^{\infty} \left(\beta^{et}\right)^i \left\{ \log\left(c_{t+i}^{et} - \eta_c^{et} c_{t+i-1}^{et}\right) + j^{et} \log\left(h_{t+i}^{et} - \eta_h^{et} h_{t+i-1}^{et}\right) - \psi^{et} \frac{\left(l_{t+i}^{et}\right)^{1+\sigma_l}}{1+\sigma_l} \right\} \tag{4}$$

where η_c^{et} and η_h^{et} are the smoothing parameters for consumption and housing, respectively, j^{et} and ψ^{et} are normalising constants and σ_l denotes the (inverse) Frisch elasticity. Employed tenants

decide about c_t^{et}, h_t^{et}, d_t^{et} and l_t^{et} subject to their budget constraint:

$$c_t^{et} + r_t^h h_{t-1}^{et} + d_t^{et}\left(1 + \frac{\kappa}{2}\left(\frac{d_t^{et}}{\tilde{c}_t^{et}} - \frac{d^{et}}{\tilde{c}^{et}}\right)^2\right) = w_t l_t^{et} + \frac{r_{t-1}}{\pi_t} d_{t-1}^{et} \tag{5}$$

These agents receive labour income $w_t l_t^{et}$ and real interest rate $\frac{r_{t-1}}{\pi_t}$ on deposits d_{t-1}^{et} where π_t denotes inflation. Both unemployed and employed tenants do not own part of the housing stock and rent housing services from capital producers. Employed tenants have access to financial markets but they face an adjustment cost when they use assets to smooth consumption across time. The logic behind the adjustment cost is agents' fear of becoming unemployed. They have no access to "unemployment insurance" and their private savings are the only instrument they have for consumption smoothing. The steady state value of the deposits to consumption ratio $\left(\frac{d^{et}}{\tilde{c}^{et}}\right)$ captures the desired level of deposits (relative to consumption) that are used for precautionary reasons, while the quadratic terms $\left(\frac{\kappa}{2}\left(\frac{d_t^{et}}{\tilde{c}_t^{et}} - \frac{d^{et}}{\tilde{c}^{et}}\right)^2\right)$ indicates their reluctance to move away from this ratio.[5] The adjustment cost makes employed tenants' consumption decisions less responsive to interest rate variations.

3.1.3 Indebted Home Owners

We model two types of agents to proxy home-owners observed in the survey data. The first type are labelled "indebted home owners". This group is a proxy for mortgagors found in the survey data towards the right tail of the income and consumption distributions. These agents are the impatient households whose preference are given by:

$$u_t^{iho} = E_t \sum_{i=0}^{\infty} \left(\beta^{iho}\right)^i \left\{ \log\left(c_{t+i}^{iho} - \eta_c^{iho} c_{t+i-1}^{iho}\right) + j^{iho} \log\left(h_{t+i}^{iho} - \eta_h^{iho} h_{t+i-1}^{iho}\right) - \psi^{iho} \frac{\left(l_{t+i}^{iho}\right)^{1+\sigma_l}}{1+\sigma_l} \right\} \tag{6}$$

Similar to employed tenants, they obtain utility from consumption $\left(c_t^{iho}\right)$ and housing services $\left(h_{t+i}^{iho}\right)$, while dislike working $\left(l_t^{iho}\right)$. The parameter η_c^{iho} and η_h^{iho} captures the degree of consumption and housing smoothing respectively, j^{iho} and ψ^{iho} are normalising constants. Employed tenants own part of the housing stock $q_t^h h_t^{iho}$ where q_t^h denotes the real house price. The purchase of the housing stock is achieved via borrowing b_t^{iho} and $\frac{r_t^b}{\pi_t}$ is the real rate obtained on last period's loan.

$$c_t^{iho} + q_t^h\left(h_t^{iho} - h_{t-1}^{iho}\right) + \frac{r_t^b}{\pi_t} b_{t-1}^{iho} = w_t l_t^{iho} + b_t^{iho} \tag{7}$$

Finally, borrowing is constrained and it cannot exceed a fraction $\left(m_t^{iho}\right)$ of the value of the expected value of the collateral

$$E_t r_{t+1}^b b_t^{iho} \leq \rho_b^{iho} r_t^b b_{t-1}^{iho} + E_t\left\{\left(1 - \rho_b^{iho}\right) m_t^{iho} q_{t+1}^h h_t^{iho} \pi_{t+1}\right\} \tag{8}$$

[5] Alternatively, d_t^{et} could be viewed as savings paid in a pension account and the adjustment cost represents the fact agents' desire not to use pension saving for consumption smoothing over the business cycle.

3.1.4 Outright Home Owners

The second category of home-owners are modelled as "outright home owners". These are the patient households with the following preferences:

$$u_t^{oho} = E_t \sum_{i=0}^{\infty} \left(\beta^{oho}\right)^i \left\{ \log\left(c_{t+i}^{oho} - \eta_c^{oho} c_{t+i-1}^{oho}\right) + j^{oho} \log\left(h_{t+i}^{oho} - \eta_h^{oho} h_{t+i-1}^{oho}\right) - \psi^{oho} \frac{\left(l_{t+i}^{oho}\right)^{1+\sigma_l}}{1+\sigma_l} \right\} \tag{9}$$

They receive utility from consumption $\left(c_t^{oho}\right)$ and housing services $\left(h_t^{oho}\right)$ and dis-utility from working $\left(l_t^{oho}\right)$. The parameters η_c^{oho} and η_h^{oho} control the smoothing of consumption and housing services across time respectively, while j^{oho} and ψ^{oho} are normalising constants. Unlike employed tenants, capital producers and bankers, they do not face a borrowing constraint. Instead, they have savings, own part of the housing stock and all the firms in the economy that pay them dividends (div_t). Their budget constraint is therefore defined as:

$$c_t^{oho} + q_t^h \left(h_t^{oho} - h_{t-1}^{oho}\right) + d_t^{oho} + \xi = w_t l_t^{oho} + \frac{r_{t-1}}{\pi_t} d_{t-1}^{oho} + div_t \tag{10}$$

3.1.5 Capital Producers

Capital producers are another continuum of impatient households, who only draw utility from consuming (c_t^{cp}):

$$u_t^{cp} = E_t \sum_{i=0}^{\infty} \left(\beta^{cp}\right)^i \log\left(c_{t+i}^{cp} - \eta_c^{cp} c_{t+i-1}^{cp}\right) \tag{11}$$

They borrow (b_t^{cp}) from banks to (i) buy investment (i_t) for the production of capital stock (subject to an adjustment cost, $\frac{\psi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2$)

$$k_t = (1-\delta) k_{t-1} + \left(1 - \frac{\psi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2\right) i_t \tag{12}$$

and (ii) to buy part of the housing stock, which they rent to employed tenants, unemployed tenants and intermediate value added good producers. Their budget constraint is thus given as:

$$c_t^{cp} + i_t + \frac{r_t^b}{\pi_t} b_{t-1}^{cp} + q_t^h \left(h_t^{cp} - h_{t-1}^{cp}\right) = r_t^h h_{t-1}^{cp} + r_t^k k_{t-1} + b_t^{cp} \tag{13}$$

where r_t^h and r_t^k are the rental rate of housing and capital respectively. Their borrowing constraint is given by:

$$E_t r_{t+1}^b b_t^{cp} \leq \rho_b^{cp} r_t^b b_{t-1}^{cp} + E_t\left(1 - \rho_b^{cp}\right) \left\{ m_t^{cp} \left(\omega_k q_{t+1} k_t \pi_{t+1} + \omega_h q_{t+1}^h h_t^{cp} \pi_{t+1}\right)\right\} \tag{14}$$

Capital producers can use a fraction (m_t^{cp}) of both capital and land as collateral to obtain loans for the bank, the parameters ω_k and ω_h control the weight of physical capital and land in the collateral value. Similar to Liu *et al.* (2016) we proceed with the assumption that residential and commercial land are perfect substitutes and, therefore, they have the same price. As explained by Liu *et al.* (2016) this seems to be a reasonable assumption as residential and commercial land prices appear to be highly correlated.

3.1.6 Bankers

These agents consume $\left(c_{t+i}^{b}\right)$ and act as an intermediary between lenders and borrowers. Their utility function is given by

$$u_t^b = E_t \sum_{i=0}^{\infty} \left(\beta^b\right)^i \log\left(c_{t+i}^b - \eta_c^b c_{t+i-1}^b\right) \tag{15}$$

which is maximised subject to their budget constraint. Banks receive deposits (d_t) from employed tenants and outright home owners and make loans (b_t) to indebted home owners and capital producers. Their budget constraint is defined as:

$$c_t^b + \frac{r_{t-1}^d}{\pi_t} d_{t-1} + b_t + s_t b_t^* = d_t + \frac{r_t^b}{\pi_t} b_{t-1} + \frac{s_t r_{t-1}^* b_{t-1}^*}{\pi_t^*} \tag{16}$$

Banks are allowed to invest on foreign assets b_t^*, where s_t is the real exchange rate and r_t^* and π_t^* denote foreign interest rates and inflation. Note that:

$$d_t \leq m_t^b b_t + \frac{s_t b_t^*}{\varepsilon_t^*}$$

Bankers face a borrowing constraint, the amount of deposits can issue cannot exceed the sum of a fraction $\left(m_t^b\right)$ of domestic plus foreign assets. The term ε_t^* is a foreign financial shock that decreases the value of the foreign assets exogenously:

$$\log \varepsilon_t^* - 0.999 \log \varepsilon_{t-1}^* = \rho_\varepsilon^* \left(\log \varepsilon_{t-1}^* - 0.999 \log \varepsilon_{t-2}^*\right) + \sigma_\varepsilon^* \omega_t^* \tag{17}$$

The parameters ρ_ε^* and σ_ε^* control the persistence of the growth rate of the shock and its size, respectively.

3.1.7 Supply Side

Intermediate value good producers use commercial land $\left(h_t^f\right)$, physical capital (k_t) and labour (l_t) and the following technology:

$$y_t = \left(\left(h_{t-1}^f\right)^{\chi} k_{t-1}^{1-\chi}\right)^{\alpha} l_t^{(1-\alpha)} \tag{18}$$

The parameter χ and α determine the share of the input components to the production of the value added good (y_t). Final good (z_t) producers use the intermediate value good and imports (m_t) and the following technology:

$$z_t = \left[\upsilon^{\frac{1}{\tau}} y_t^{\frac{\tau-1}{\tau}} + (1-\upsilon)^{\frac{1}{\tau}} m_t^{\frac{\tau-1}{\tau}}\right]^{\frac{\tau}{\tau-1}} \tag{19}$$

where υ is the value added production share. The price of the final good is given by:

$$p_t = \upsilon \left(p_t^d\right)^{1-\tau} + (1-\upsilon)\left(p_t^m\right)^{1-\tau} \tag{20}$$

where p_t^d and p_t^m are the price indices of the domestically produced and imported goods, respectively. Both intermediate value added and importers are monopolistic good producers. A fraction of the

monopolistic suppliers ($1-\xi_d$ and $1-\xi_m$) set prices based on a Calvo (1983) type pricing scheme, while those firms that 'miss' the random signal to re-optimise profits set prices based on backward indexation rules (i.e. $p_t^d = \left(\pi_{t-1}^d\right)^{\iota_d} \bar{\pi}^{1-i_d} p_{t-1}^d$ and $p_t^m = \left(\pi_{t-1}^m\right)^{\iota_m} \bar{\pi}^{1-i_m} p_{t-1}^m$).

3.1.8 Monetary policy

The behaviour of the monetary authority is described by a simple Taylor rule:

$$\frac{r_t}{r} = \left(\frac{r_{-1}}{r}\right)^{\rho_r} \left(\frac{\pi_t}{\bar{\pi}_t}\right)^{\gamma_\pi(1-\rho_r)} \left(\frac{y_t}{y}\right)^{\gamma_y(1-\rho_r)} \tag{21}$$

where ρ_r controls the policy inertia, γ_π denotes the policy reaction to inflation deviation from its target and γ_y to output gap.[6]

3.2 Estimation

The model is estimated used limited information impulse response matching techniques (Smets and Wouters (2002), Christiano *et al.* (2005), Altig *et al.* (2011)). However, as shown in Table 1, a number of parameters are calibrated prior to the estimation: As in Liu *et al.* (2016) the time discount parameters for employed tenants and outright home owner is set equal to 0.9945 $\left(\beta^{oho} = \beta^{et} = \beta = 0.9945\right)$, and the preference parameters for indebted home owners and capital producers to 0.940 $\left(\beta^{iho} = \beta^{cp}\right)$. As explained in Liu *et al.* (2016) this calibration ensures that borrowing constraints bind with equality away from the steady state. The value of the time discount factor for bankers $\left(\beta^b = 0.975\right)$ has been selected to replicate the average value of the spread between the borrowing and policy rates in the data. We again follow Liu *et al.* (2013) and Liu *et al.* (2016) and set the leverage ratio for indebted home owners, capital producers and bankers to 0.75 $\left(m^{iho} = m^{cp} = m^b = 0.75\right)$. The steady state value of hours has been set equal to 1/3 $\left(l = \frac{1}{3}\right)$, while the hours share of unemployed is 0.250 $\left(\phi^{ut} = 0.025\right)$, employed tenants 0.250 $\left(\phi^{et} = 0.250\right)$, and indebted home owners 0.300 $\left(\phi^{iho} = 0.300\right)$. We assume that the share of consumption of unemployed tenants to aggregate consumption $\left(\frac{c^{ut}}{c}\right)$ is 0.100 close to the share of hand to mouth consumers used in the literature (Gali *et al.* (2007), Burgess *et al.* (2013)). The capital share in the production function (α) is 0.330 (as in Christiano *et al.* (2005), Trabandt and Uhlig (2011) and Jermann and Quadrini (2012)). Similar to Iacoviello (2015), the share of land in the production (χ) of the value added is 0.030. The value of the Frisch elasticity (σ_L) is equal to 2 (see Fernandez-Villaverde *et al.* (2015), Swanson (2015)). The values selected for the policy parameters – $\rho_r = 0.875$, $\gamma_\pi = 1.5$ and $\gamma_y = 0.125$ – are standard in the literature. Finally, the depreciation of capital ($\delta = 0.068$), the share of value added goods in the production of the final good ($\upsilon = 0.782$) and the steady state level of foreign debt ($b^* = 1.337$) has been selected to match the consumption to final output $\left(\frac{c}{z} = 0.670\right)$, investment to final output $\left(\frac{i}{z} = 0.120\right)$, exports to final output $\left(\frac{x}{z} = 0.210\right)$ and import to final output $\left(\frac{m}{z} = 0.220\right)$ shares in the UK data (see Burgess *et al.* (2013)).

The parameters that control the dynamics of the model are selected in order to replicated the responses estimated via the empirical model to the foreign financial shock:

$$\hat{\theta} = \arg\min_{\theta} \left\{ R\left(\theta; \tilde{\theta}\right) - \widehat{R}_T \right\}' \widehat{W}_T^{-1} \left\{ R\left(\theta|\tilde{\theta}\right) - \widehat{R}_T \right\} \tag{22}$$

where $R\left(\theta; \tilde{\theta}\right)$ is the column vector of the stacked DSGE responses for all selected variables and

[6] The full description of the models, the derivations of the steady states and the linearised first order conditions and market clearing conditions can be found in the technical appendix

Table 1: Calibrated Parameters

Mnemonic	Description	Value
β	Time Discount Rate	0.995
β^{cp}	Capital Producers Time Discount Rate	0.940
β^{iho}	Indebted Home Owners Time Discount Rate	0.940
β^{b}	Bankers Time Discount Rate	0.975
κ^{cp}	Capital Producers LTV Ratio	0.750
κ^{b}	Bankers LTV Ratio	0.750
κ^{iho}	Indebted Households LTV Ratio	0.750
l	Steady State Value of Hours	0.333
ϕ_l^{ut}	Unemployed Tenants Labour Share	0.025
ϕ_l^{et}	Employed Tenants Labour Share	0.250
ϕ_l^{iho}	Indebted Home Owners Labour Share	0.300
b^*	Steady State Value of Foreign Debt	1.337
δ	Capital Depreciation Rate	0.068
α	Capital and Land Share in the Production Function	0.330
χ	Land Share in the Production Function	0.030
σ_L	Frisch Labour Elasticity	2.000
γ_π	Inflation Policy Reaction Coefficient	1.500
γ_y	Output Gap Policy Reaction Coefficient	0.125
ρ_r	Interest Rate Smoothing	0.875
ν	Value Added Production Share	0.782
ψ_b^*	Foreign Bond Adjustment Cost	0.001
$\frac{c^{ut}}{c}$	Share of Unemployed Tenants Consumption	0.100
$\bar{\pi}$	Inflation Target	1.000

time periods. This vector is function of both estimated (θ) and calibrated $\left(\tilde{\theta}\right)$ parameters. $\widehat{R}_T$ denotes its empirical counterpart. As the number of impulse responses employed in this estimation, a weighting matrix is needed to summarise this information. Similar to Christiano *et al.* (2005) and Altig *et al.* (2011) we use the diagonal element of the posterior variance covariance matrix of $\widehat{R}_T$.[7]

Table 2 reports the results from this exercise and Figure 3 in the technical appendix displays the fit of the model. At the optimised value of the objective function, we are able to match the magnitude and dynamics of the empirical response of a range of real and financial variables.

The estimates $\omega_k = 0.024$ and $\omega_h = 0.055$ in Table 2 show the importance of the value of the land (relative to the value of capital) in the collateral of capital producers which is in line with the estimate of Liu *et al.* (2016). The indebted and outright home owners have strong estimated habit formation $\left(\eta_c^{iho} = 0.944, \eta_c^{oho} = 0.942\right)$ and a significant degree of smoothing is also estimated in the consumption of bankers $\left(\eta_c^{b} = 0.719\right)$. In contrast, smoothing is estimated to be low for capital producers ($\eta_c^{cp} = 0.104$). The high degree of smoothing for most agents is required to reproduce the very persistent consumption responses seen in the empirical model. A large degree of habit

[7] The estimation and simulations of the model have been produced using Dynare 4.5.3. The model and replication files can be downloaded from authors' web pages

Table 2: Estimated Parameters

Mnemonic	Description	Value
σ_ε	Shock Standard Deviation	2.883
ω_k	Collateral Share of Capital	0.024
ω_h	Collateral Share of Land	0.055
η_c^{cp}	Capital Producers Consumption Smoothing	0.104
η_c^{iho}	Indebted Home Owners Consumption Smoothing	0.944
η_c^{oho}	Outright Home Owners Consumption Smoothing	0.942
η_c^{b}	Bankers Consumption Habit	0.719
η_c^{et}	Employed Tenants Consumption Smoothing	0.197
h^{iho}	Steady State Value of Housing of Indebted Home Owners	0.128
h^{oho}	Steady State Value of Housing of Outright Home Owners	0.546
h^{ut}	Steady State Value of Housing Rented by Unemployed Tenants	0.197
$_I$	Investment Adjustment Cost	23.009
ι_d	Price Indexation	0.613
ι_m	Price Indexation: Importers	0.195
η_h^{iho}	Indebted Home Owners Housing Smoothing	0.933
η_h^{oho}	Outright Home Owners Housing Smoothing	0.782
η_h^{et}	Employed Tenants Housing Smoothing	0.941
ρ_b^{iho}	Indebted Home owners Persistence Borrowing Constraint	0.804
ρ_b^{cp}	Capital Producers Persistence Borrowing Constraint	0.941
κ	Deposits Adjustment Cost	2.307
ϕ_D	Employed Tenants Deposit Share	0.606
θ_p	Price Mark up	1.072
ξ_d	Calvo Reset Price Probability	0.946
ξ_m	Calvo Reset Price Probability: Importers	0.885
τ	Elasticity of Substitution between Value Added and Imports	0.111

formation is also observed in terms of housing services ($\eta_h^{iho} = 0.933$, $\eta_h^{oho} = 0.782$ and $\eta_h^{et} = 0.941$) which is unsurprising since altering the level of housing services is a difficult task. Furthermore, a high degree of smoothing of housing consumption is required by the model to reproduce the responses of house prices and spreads. The high degree of inertia estimated in the borrowing constraints ($\rho_b^{iho} = 0.804$ and $\rho_b^{cp} = 0.941$) allows the adverse consequences of the shock to persist. The investment adjustment cost estimate ($\psi_I = 23$) suggests investment responds to variation to Tobin's Q only marginally, while the adjustment cost of employed tenants' deposits ($\kappa = 2.307$) indicates that agents have little desire to use their assets to smooth consumption variations during the business cycle. The Phillips curve estimates ($\iota_d = 0.613$, $\xi_d = 0.943$, $\iota_m = 0.195$ and $\xi_m = 0.885$) point to significant price stickiness. This is consistent with the discussion in Del Negro *et al.* (2015) who argue that a flatter Phillips curve is needed in order for a model to be able to justify the lack of disinflation during the Great Recession. Finally, the low trade elasticity estimates reduces the sensitivity of exports to exchange rate variations. This feature keeps the contributions of the net trade to GDP limited. This seems also to be consistent what we have observed during the crisis when the pound depreciated by more than 20% but the net trade contributions to demand had been very small (if not negative).

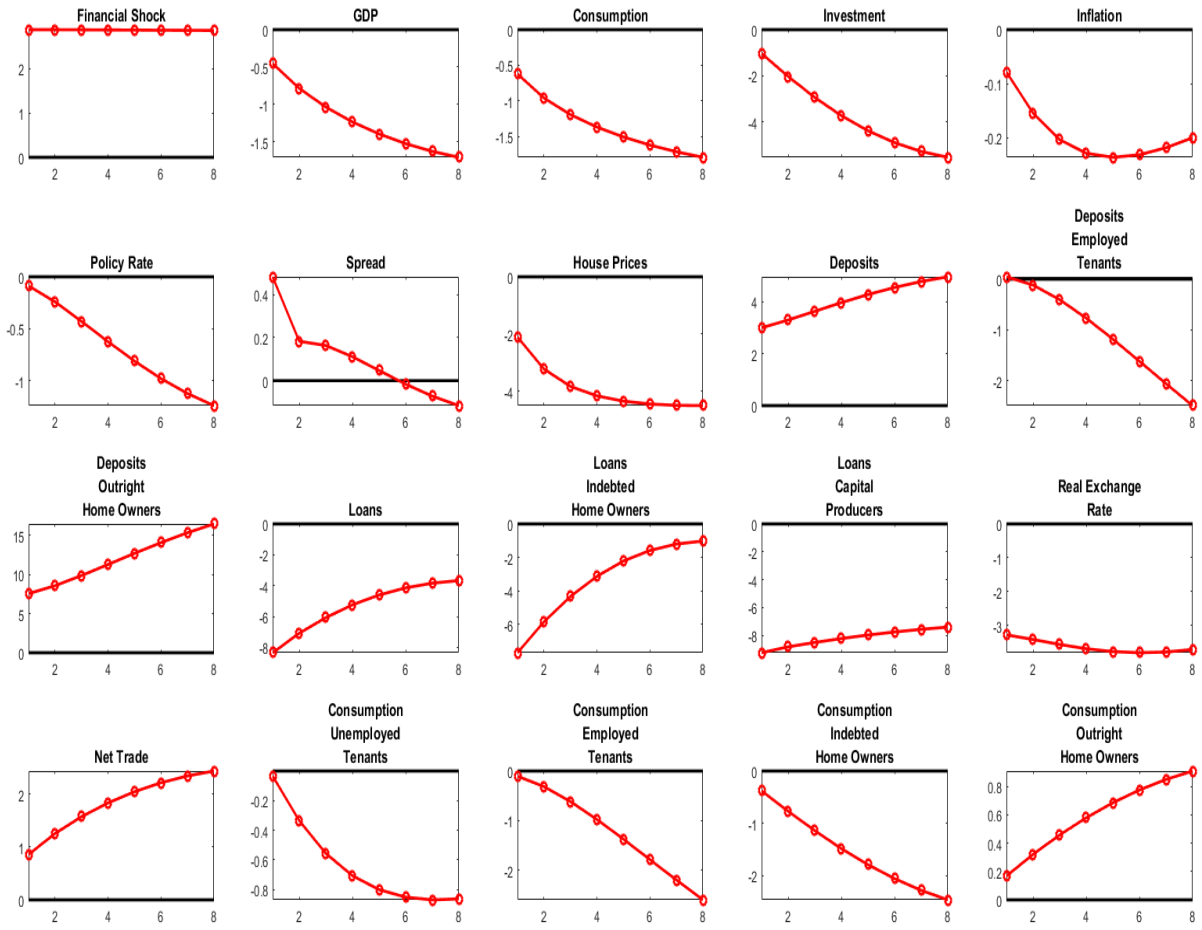

Figure 8: Response to a foreign financial shock

3.3 Impulse responses

Figure 8 shows the estimated response to the foreign financial shock. The increase in the spread $4\left(E_t\hat{r}^b_{t+1} - \hat{r}_t\right)$ indicates that the shadow price of bankers' borrowing constraint $\left(\hat{\mu}^b_t\right)$ increases. Bankers respond to this adverse situation by decreasing leverage and reducing lending to indebted home owners and capital producers. In response to higher borrowing cost, the latter agents also try to reduce their leverage by reducing land ownership. This causes house prices to fall and these agents become more financially constrained. To escape this situation they postpone consumption and investment, triggering the reduction in GDP. Lower aggregate demand implies reduced demand for labour and a lower wage. The fall in labour income reduces consumption for employed and unemployed tenants. The decline in the consumption of the latter is slower and smaller in magnitude than that of indebted home owners (over the first year of the horizon) as they are not affected directly by higher borrowing costs. However, their desire to maintain their savings implies that eventually their consumption declines. The decline in consumption for unemployed tenants is substantially smaller as they are not directly affected by the decline in asset prices and benefit income does not depend on the state of the economy. The consumption of outright home owners increases in response to lower policy rate, but this does not seem to be enough to drastically reduce the adverse aggregate effects of the shock.

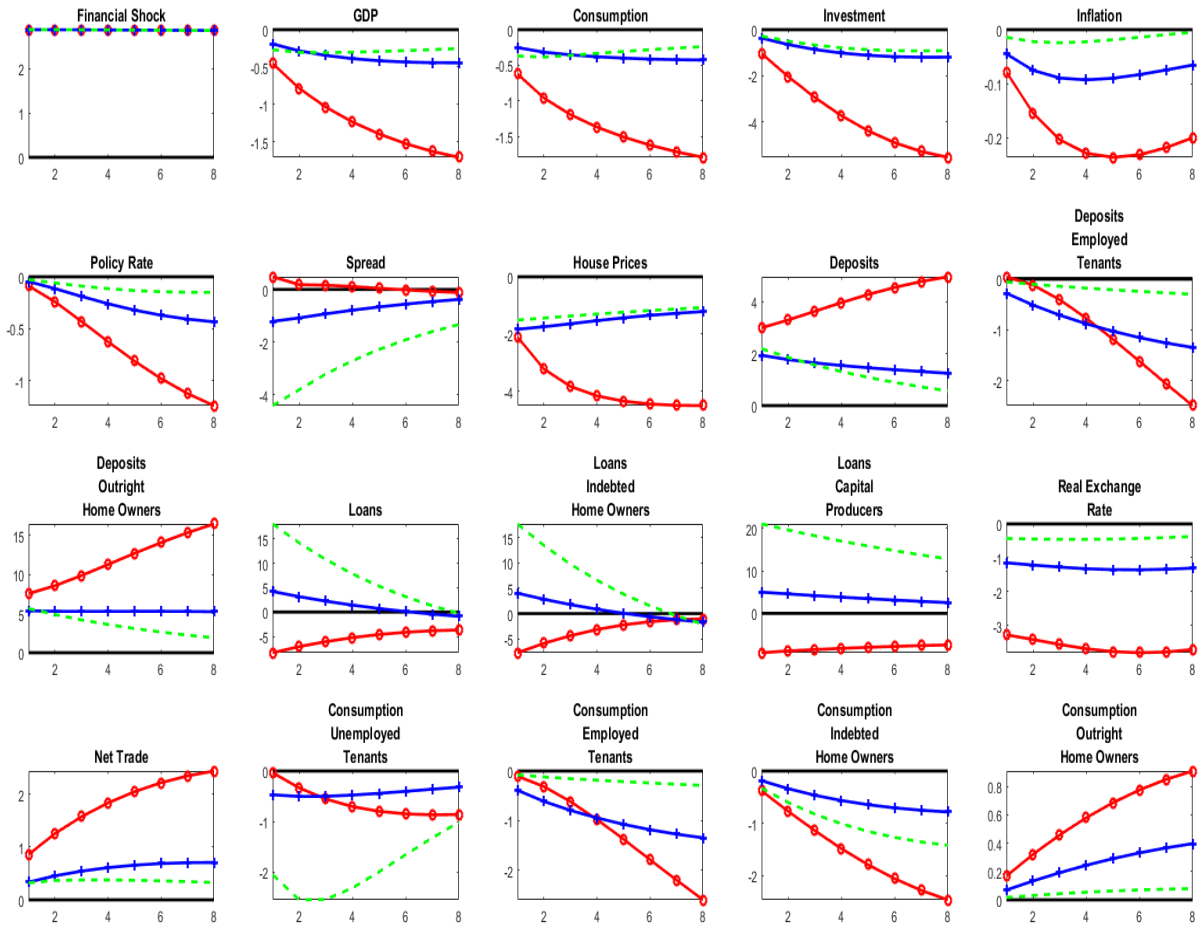

Figure 9: The Role of Heterogeneity: The red dashed-circle line represents the response derived by the estimated model. The blue dashed-cross line illustrates agents' responses when the degree of impatience is (almost) the same across all types of households. The green dashed line shows the case where the size of households – except the outright home owners – has been decreased to a large extent.

The muted effect on CPI inflation is generated by (i) the offsetting effect between domestic and import prices and (ii) relative flat Phillips curve, leads to an exchange rate depreciation. Interestingly, the valuation effects generated by the exchange rate depreciation contribute to the severity of the downturn caused by this shock. To be precise, the value of foreign assets in domestic units increases despite the price fall caused by the foreign financial shock. The banks in their attempt to return to their steady state, find it optimal to divert funding from domestic households and capital producers to foreign assets (financed by outright home owners deposits). However, the reduced production is now diverted to exports due to the exchange rate depreciation.

Does heterogeneity matter in this model economy? Figure 9 illustrates the role of heterogeneity both in terms of the severity of financial constraints and the existence of multiple agents. In the first exercise we retain all estimated parameters but we set the time discount rate for indebted house owners, capital producers and bankers to the same value $\left(\beta^{iho} = \beta^{cp} = \beta^{b} = 0.994\right)$. In other words, we attempt to simulate a situation where financial constraints are less important. The blue

dashed-cross line illustrates agents' optimal responses in this economy for the foreign financial shock. Clearly, the effects of the shock decrease dramatically and its economic impact seems negligible. In the next exercise we decrease the size of all households in the economy except the size of the outright home owners (green dashed lines). Implicitly, in this counterfactual case, we revert back to a representative agent New Keynesian model. In other words, heterogeneity across financial frictions is still present but it is too small to matter for aggregate demand. Again the impact of the shock is small in this scenario.

These simulations suggest that heterogeneity across households and financial frictions drive the effects of foreign financial shocks. In their absence, the effects of the shock are small and it is unlikely that the model can explain the severity of the recessions following events such as the recent global financial crisis. Without heterogeneity, the foreign financial disturbance resembles a demand shock. Decision makers respond to its adverse consequences by lowering the policy rate. If households are alike in ther access to financial markets, then the substitution effect can eliminate all negative effects via higher consumption and investment demand financed by lower policy rates.

4 Conclusions

We show that US financial shocks have a large aggregate effect on the UK economy. However, the effect is heterogenous when considering the distribution of households – the income and consumption of households towards the right tail of the distribution is affected by a larger amount than households on the left tail. High income and consumption households are likely to be 'wealthy hand to mouth' consumers and more exposed to financial conditions via credit constraints. Using a multiple agent DSGE model, we show that these distributional effects are crucial for the transmission mechanism. In particular, if all agents have access to financial markets then monetary authorities can easily counter the effects of foreign financial shocks by reducing the interest rate. This policy is less effective when some agents face credit constraints. As the importance of such households increases, the aggregate effects of this shock rise substantially.

It can be argued that the recent financial crisis is a prominent example of a financial shock which was then followed by a protracted recession. Our analysis shows that estimating and modelling the distributional consequences of such shocks is key to understanding the magnitude and persistence of its effects.

References

Abbate, Angela, Sandra Eickmeier, Wolfgang Lemke and Massimiliano Marcellino, 2016, The Changing International Transmission of Financial Shocks: Evidence from a Classical Time-Varying FAVAR, *Journal of Money, Credit and Banking* **48**(4), 573–601.

Alessandri, Piergiorgio and Haroon Mumtaz, 2017, Financial conditions and density forecasts for US output and inflation, *Review of Economic Dynamics* **24**(Supplement C), 66 – 78.

Altig, David, Lawrence Christiano, Martin Eichenbaum and Jesper Linde, 2011, Firm-Specific Capital, Nominal Rigidities and the Business Cycle, *Review of Economic Dynamics* **14**(2), 225–247.

Auclert, Adrien, 2017, Monetary Policy and the Redistribution Channel, *NBER Working Papers 23451*, National Bureau of Economic Research, Inc.

Bernanke, Ben S., Jean Boivin and Piotr Eliasz, 2005, Measuring the Effects of Monetary Policy: A Factor-Augmented Vector Autoregressive (FAVAR) Approach, *The Quarterly Journal of Economics* **120**(1), 387–422.

Blundell, Richard and Ben Etheridge, 2010, Consumption, Income and Earnings Inequality in Britain, *Review of Economic Dynamics* **13**(1), 76–102.

Brave, Scott and R. Andrew Butters, 2011, Monitoring financial stability: a financial conditions index approach, *Economic Perspectives* (Q I), 22–43.

Burgess, Stephen, Emilio Fernandez-Corugedo, Charlotta Groth, Richard Harrison, Francesca Monti, Konstantinos Theodoridis and Matt Waldron, 2013, The Bank of England's forecasting platform: COMPASS, MAPS, EASE and the suite of models, *Bank of England working papers 471*, Bank of England.

Calvo, Guillermo A., 1983, Staggered prices in a utility-maximizing framework, *Journal of Monetary Economics* **12**(3), 383–398.

Chowla, Shiv, Lucia Quaglietti and Lukasz Rachel, 2014, How have world shocks affected the UK economy?, *Bank of England Quarterly Bulletin* **54**(2), 167–179.

Christiano, Lawrence, Martin Eichenbaum and Charles Evans, 2005, Nominal Rigidities and the Dynamic Effects of a shock to Monetary Policy, *Journal of Political Economy* **113**, 1–45.

Cloyne, James, Clodomiro Ferreira and Paolo Surico, 2016, Monetary policy when households have debt: new evidence on the transmission mechanism, *Bank of England working papers 589*, Bank of England.

Cloyne, James S. and Paolo Surico, 2017, Household Debt and the Dynamic Effects of Income Tax Changes, *The Review of Economic Studies* **84**(1), 45–81.

Del Negro, Marco, Marc P. Giannoni and Frank Schorfheide, 2015, Inflation in the Great Recession and New Keynesian Models, *American Economic Journal: Macroeconomics* **7**(1), 168–96.

Eickmeier, Sandra and Tim Ng, 2015, How do US credit supply shocks propagate internationally? A GVAR approach, *European Economic Review* **74**, 128 – 145.

Fernandez-Villaverde, Jesus, Pablo A. Guerron-Quintana, Keith Kuester and Juan Rubio-Ramirez, 2015, Fiscal Volatility Shocks and Economic Activity, *American Economic Review* **105**(11), 3352–84.

Gali, Jordi, J. David Lopez-Salido and Javier Valles, 2007, Understanding the Effects of Government Spending on Consumption, *Journal of the European Economic Association* **5**(1), 227–270.

Gilchrist, Simon and Egon Zakrajsek, 2012, Credit spreads and business cycle fluctuations, **102**(4), 1692–720.

Giorgi, Giacomo De and Luca Gambetti, 2017, Business Cycle Fluctuations and the Distribution of Consumption, *Review of Economic Dynamics* **23**, 19–41.

Iacoviello, Matteo, 2005, House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle, *American Economic Review* **95**(3), 739–764.

Iacoviello, Matteo, 2015, Financial Business Cycles, *Review of Economic Dynamics* **18**(1), 140–164.

Iacoviello, Matteo and Raoul Minetti, 2006, International business cycles with domestic and foreign lenders, *Journal of Monetary Economics* **53**(8), 2267–2282.

Jermann, Urban and Vincenzo Quadrini, 2012, Macroeconomic Effects of Financial Shocks, *American Economic Review* **102**(1), 238–71.

Kaplan, Greg, Benjamin Moll and Giovanni L. Violante, 2017, Monetary Policy According to HANK, *American Economic Review* p. forthcoming.

Kaplan, Greg and Giovanni L. Violante, 2014, A Model of the Consumption Response to Fiscal Stimulus Payments, *Econometrica* **82**(4), 1199–1239.

Liu, Zheng, Jianjun Miao and Tao Zha, 2016, Land prices and unemployment, *Journal of Monetary Economics* **80**(C), 86–105.

Liu, Zheng, Pengfei Wang and Tao Zha, 2013, Land-Price Dynamics and Macroeconomic Fluctuations, *Econometrica* **81**(3), 1147–1184.

Mumtaz, Haroon and Angeliki Theophilopoulou, 2017, The impact of monetary policy on inequality in the UK. An empirical analysis, *European Economic Review* **98**(Supplement C), 410 – 423.

Mumtaz, Haroon and Paolo Surico, 2009, The Transmission of International Shocks: A Factor-Augmented VAR Approach, *Journal of Money, Credit and Banking* **41**, 71–100.

Prieto, Esteban, Sandra Eickmeier and Massimiliano Marcellino, 2016, Time Variation in Macro-Financial Linkages, *Journal of Applied Econometrics* **31**(7), 1215–1233. jae.2499.

Smets, Frank and Raf Wouters, 2002, Openness, imperfect exchange rate pass-through and monetary policy, *Journal of Monetary Economics* **49**(5), 947–981.

Stock, James H. and Mark W. Watson, 2012, Disentangling the Channels of the 2007-2009 Recession, *NBER Working Papers 18094*, National Bureau of Economic Research, Inc.

Swanson, Eric, 2015, A Macroeconomic Model of Equities and Real, Nominal, and Defaultable Debt, *Mimeo*, University of California Irvine.

Terrones, Marco, Ayhan Kose and Eswar Prasad, 2007, How Does Financial Globalization Affect Risk Sharing? Patterns and Channels, *IMF Working Papers 07/238*, International Monetary Fund.

Trabandt, Mathias and Harald Uhlig, 2011, The Laffer curve revisited, *Journal of Monetary Economics* **58**(4), 305 – 327.

Werning, Ivan, 2015, Incomplete Markets and Aggregate Demand, *NBER Working Papers 21448*, National Bureau of Economic Research, Inc.

A Data

Table 3 presents a list of the variables used in the main FAVAR models, their source and transformations.

No.	Variable	Country	Source	Transformation
1	Industrial Production	UK	GFD	LD
2	UK FT-Actuaries 500 index (Non-Financials)	UK	GFD	LD
3	Retail Price Index	UK	GFD	LD
4	Composite Leading Indicator	UK	GFD	N
5	Real Exports	UK	GFD	LD
6	Real Imports	UK	GFD	LD
7	Government Spending	UK	ONS	LD
8	Government Consumption	UK	ONS	LD
9	Gross Capital Formation	UK	GFD	LD
10	Consumption Expenditure	UK	GFD	LD
11	GDP Deflator	UK	GFD	LD
12	Wage	UK	GFD	LD
13	20 year Govt Bond Yield minus 3 mth yield	UK	GFD	N
14	10 year Govt Bond Yield minus 3 mth yield	UK	GFD	N
15	5 year Govt Bond Yield minus 3 mth yield	UK	GFD	N
16	Brent Oil Price	UK	GFD	N
17	Corporate Bond Spread	UK	GFD	N
18	Real House Prices	UK	GFD	N
19	Dividend Yield	UK	GFD	N
20	FT Actuaries P/E Ratio	UK	GFD	N
21	Pounds to DollarExchange Rate	UK	GFD	LD
22	Pounds to Euro Exchange Rate	UK	GFD	LD
23	Pounds to Yen Exchange Rate	UK	GFD	LD
24	Nominal Effective Exchange Rate	UK	GFD	LD
25	Real Effective Exchange Rate	UK	GFD	LD
26	Real GDP	UK	GFD	LD
27	CPI	UK	GFD	LD
28	3 month T-Bill rate	UK	GFD	N
29	FTSE All share Index	UK	GFD	LD
30	Real GDP	USA	FRED	LD
31	CPI	USA	FRED	LD
32	3 month T-Bill rate	USA	FRED	N
33	EBP	USA	http://people.bu.edu/sgilchri/Data/data.htm	N
34	FCI	USA	FRED	N
35	BAA Yield	USA	FRED	N
36	Ten Year Bond yield	USA	FRED	N

Table 3: Data series and transformations. GFD is global financial data. ONS is office of national statistics and FRED is the St Louis FED database. LD denotes log differences times a 100 while N denotes no transformation

B Difference in impulse responses across groups

Figures 10 and 11 present the posterior distribution of the difference in income and consumption responses across groups (see section 2.3.1). Note that the percentile groups are defined as: $P_1 = \left[\leq 20^{th}\right], P_2 = \left[> 20^{th} \& \leq 40^{th}\right], P_3 = [> 40^{th} \& \leq 60^{th}], P_4 = [> 60^{th} \& \leq 80^{th}], P_5 = [> 80^{th}]$.

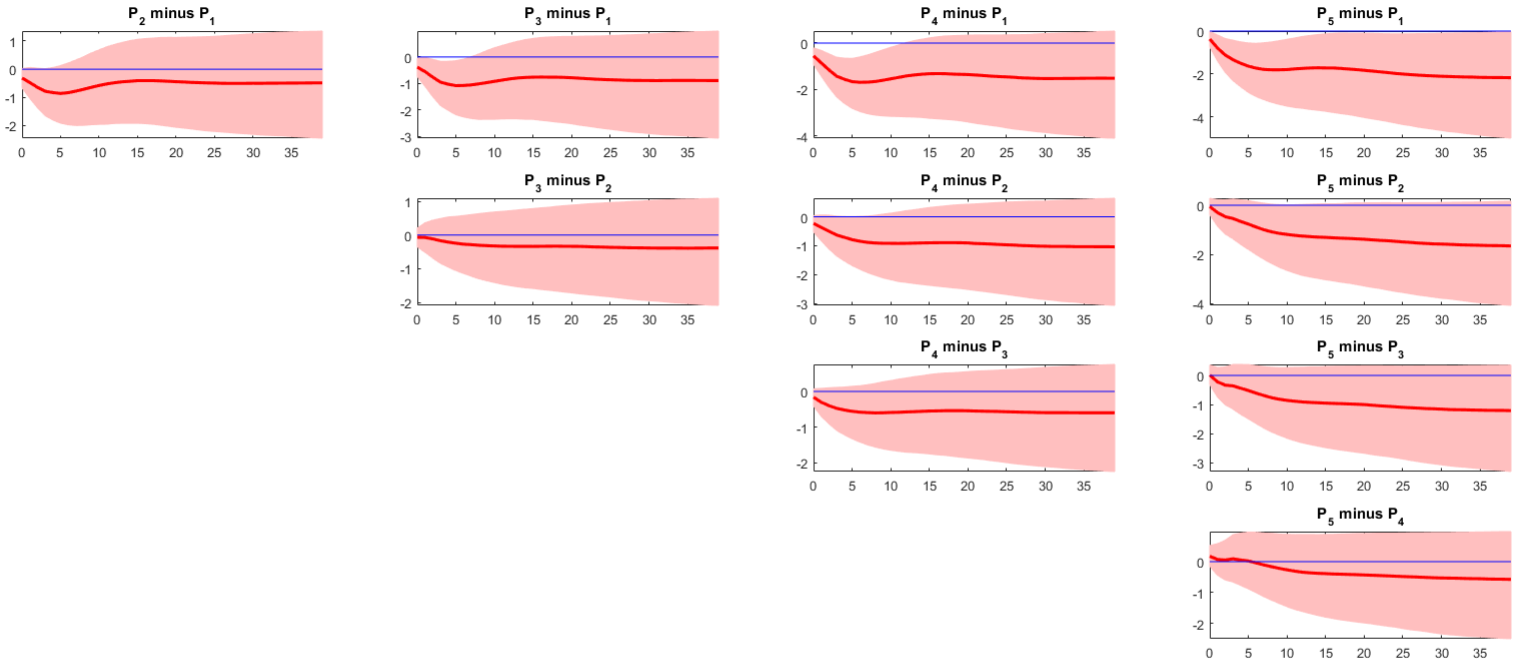

Figure 10: The posterior distribution of the difference in the income response across groups. The solid line is the median and the shaded area is the 68 percent error band.

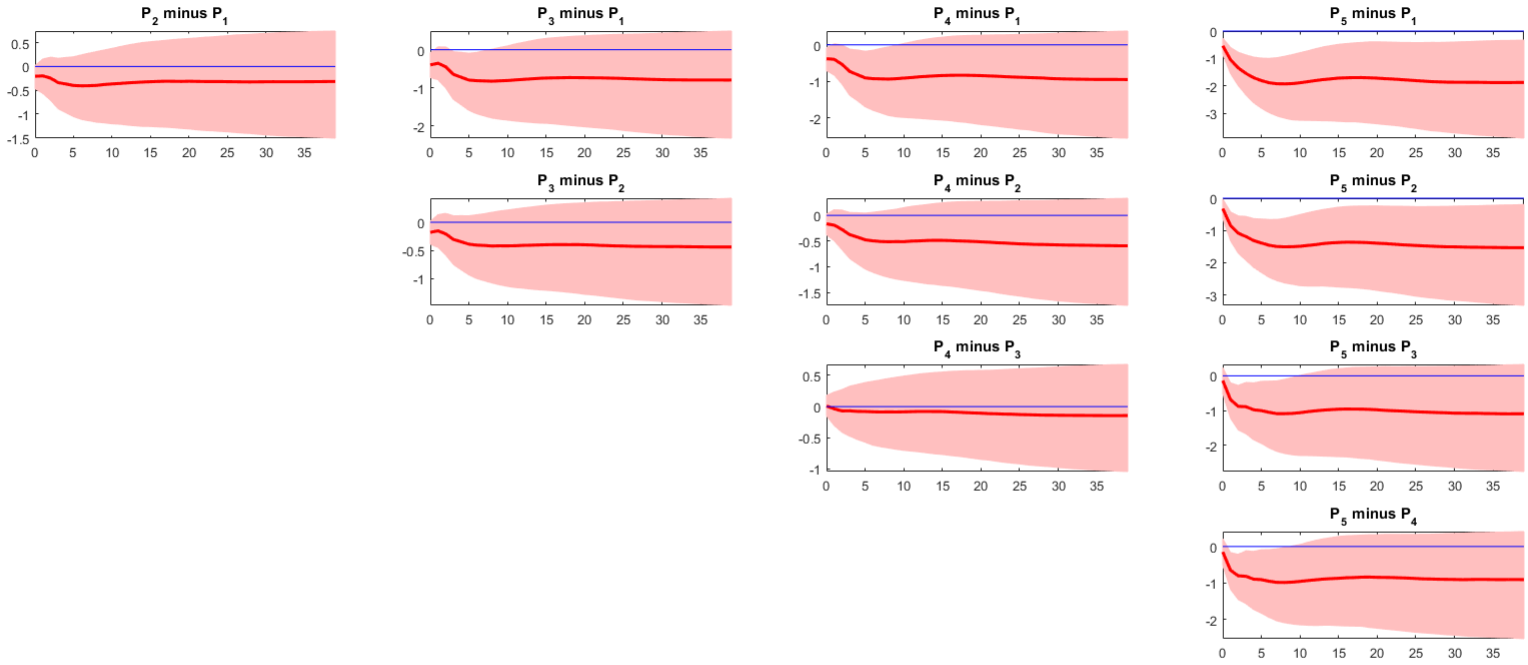

Figure 11: The posterior distribution of the difference in the consumption response across groups. The solid line is the median and the shaded area is the 68 percent error band.

C Robustness

Figure 12 presents the results of the robustness analysis discussed in section 2.3.1.

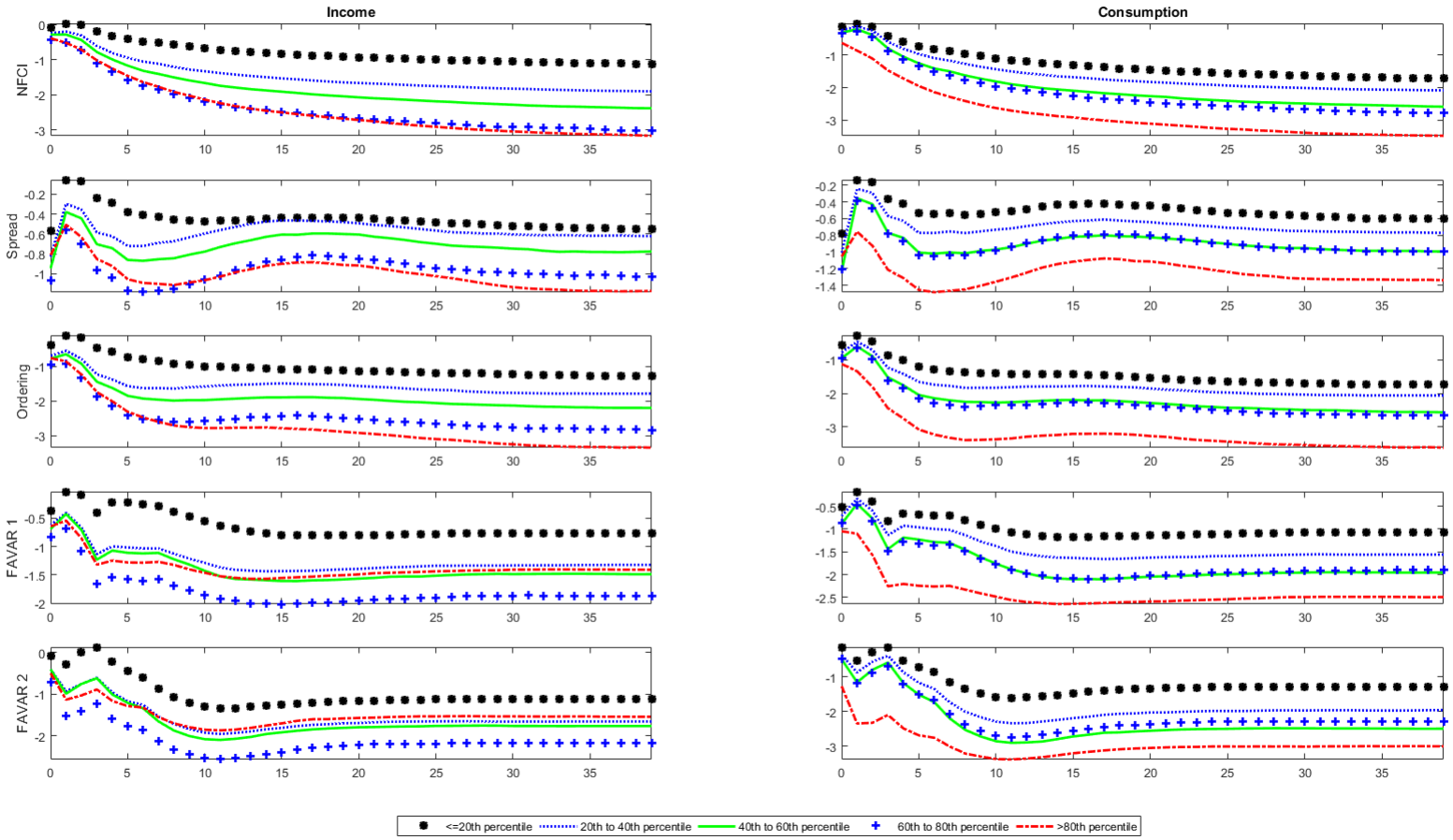

Figure 12: Sensitivity Analysis

US financial shocks and the distribution of income and consumption in the UK (Technical Appendix).

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December 2017

Abstract

1 Gibbs Sampling algorithm

Recall that the model is defined as

$$\begin{aligned}\begin{pmatrix} X_t^{US} \\ X_t^{UK} \end{pmatrix} &= \begin{pmatrix} 1 & 0 \\ 0 & \Lambda \end{pmatrix} \begin{pmatrix} X_t^{US} \\ F_t^{UK} \end{pmatrix} + \begin{pmatrix} 0 \\ v_t \end{pmatrix} \\ Z_t &= c + \sum_{p=1}^{P} B_p Z_{t-p} + \varepsilon_t, var(\varepsilon_t) = Q \\ v_{it} &= \sum_{p=1}^{P} \rho_p v_{it-p} + e_{it}, var(e_{it}) = r_i, R = diag\left([r_1, r_2, .., r_M]\right)\end{aligned}$$

where $Z_t = \begin{pmatrix} X_t^{US} \\ F_t^{UK} \end{pmatrix}$ and v_{it} denotes the ith residual, i.e. the ith column of v_t. F_t^{UK} is the matrix of K factors with F_{kt}^{UK} denoting the kth column. The prior for the factor loadings Λ is normal $N\left(\Lambda_{i0}, \Sigma_0\right)$ where Λ_0 is set to zero and Σ_0 is a diagonal matrix with diagonal elements equal to 100. The prior for $b = [\rho_1, \rho_2, ..\rho_P]$ is normal $N\left(b_0, \Sigma_{b0}\right)$ where $b_0 = 0$ and Σ_{b0} is an identity matrix. The prior for r_i is inverse Gamma $IG\left(T_0, D_0\right)$ where $T_0 = 1$ and $D_0 = 1e-5$. We use a natural conjugate prior for the VAR parameters $B = vec\left(\left[\tilde{\beta}_j, \tilde{\alpha}\right]\right), Q$ implemented via dummy observations (see Banbura *et al.* (2010)):

$$Y_{D,1} = \begin{pmatrix} \frac{diag(\gamma_1\sigma_1...\gamma_N\sigma_N)}{\tau} \\ 0_{N\times(P-1)\times N} \\ ..... \\ diag\left(\sigma_1...\sigma_N\right) \\ ..... \\ 0_{1\times N} \end{pmatrix}, and\ X_{D,1} = \begin{pmatrix} \frac{J_P \otimes diag(\sigma_1...\sigma_N)}{\tau} & 0_{NP\times 1} \\ 0_{N\times NP+1} & \\ ..... & \\ 0_{1\times NP} & I_1 \times c \end{pmatrix} \quad (1)$$

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where γ_1 to γ_N denotes the prior mean for the coefficients on the first lag, τ is the tightness of the prior on the VAR coefficients, c is the tightness of the prior on the constant terms and N is the number of endogenous variables, i.e. the columns of Z_t. In our application, the prior means are chosen as the OLS estimates of the coefficients of an AR(1) regression estimated for each endogenous variable. We use principal component estimates of the factors F_t for this purpose. We set $\tau = 0.2$. The scaling factors σ_i are set using the standard deviation of the error terms from these preliminary AR(1) regressions. Finally we set $c = 1/1000$ in our implementation indicating a flat prior on the constant. We also introduce a prior on the sum of the lagged dependent variables by adding the following dummy observations:

$$Y_{D,2} = \frac{diag\left(\gamma_1\mu_1...\gamma_N\mu_N\right)}{\lambda},\ X_{D,2} = \left(\begin{array}{cc} \frac{(1_{1\times P})\otimes diag(\gamma_1\mu_1...\gamma_N\mu_N)}{\lambda} & 0_{N\times 1} \end{array}\right) \tag{2}$$

where μ_i denotes the sample means of the endogenous variables calculated using F_t.

The Gibbs sampling algorithm for this model is now standard in the literature and involves sampling from the following conditional posterior distributions:

1. $H\left(\Lambda|F_t, R, b, B, Q\right)$. Given the factors F_t, the observation equation is set of M independent linear regressions with serial correlation

   $$X_{it}^{UK} = F_t\Lambda_i' + v_{it}$$

   where Λ_i denotes the ith row of the factor loading matrix. The serial correlaton can be dealt with via a GLS transformation of the variables:

   $$\tilde{X}_{it}^{UK} = \tilde{F}_t\Lambda_i' + e_{it}$$

   where $\tilde{X}_{it}^{UK} = X_{it}^{UK} - \sum_{p=1}^{P}\rho_p X_{it-p}^{UK}$ and $\tilde{F}_{kt} = F_{kt} - \sum_{p=1}^{P}\rho_p F_{kt-p}$. The conditional posterior is normal $N\left(M, V\right)$:

   $$\begin{aligned} V &= \left(\Sigma_0^{-1} + \frac{1}{r_i}\tilde{F}_t'\tilde{F}_t\right)^{-1} \\ M &= V\left(\Sigma_0^{-1}\Lambda_{i0} + \frac{1}{r_i}\tilde{F}_t'\tilde{X}_{it}\right) \end{aligned}$$

2. $H\left(r_i|\Lambda, F_t, b, B, Q\right)$. The conditional posterior for r_i is $IG\left(T_0 + T, e_{it}'e_{it} + D_0\right)$ where T is the sample size.

3. $H\left(b|\Lambda, F_t, R, B, Q\right)$. Given a draw of the factors, the AR coefficients are drawn for each i independently. The conditional posterior is normal $N\left(m, v\right)$

   $$\begin{aligned} v &= \left(\Sigma_{b0}^{-1} + \frac{1}{r_i}x_{it}'x_{it}\right)^{-1} \\ m &= V\left(\Sigma_{b0}^{-1}b_0 + \frac{1}{r_i}x_{it}'y_{it}\right) \end{aligned}$$

   where $y_{it} = v_{it}$ and $x_{it} = [v_{it-1}, .., v_{it-P}]$

4. $H\left(B|\Lambda, b, F_t, R, Q\right)$. The conditional posterior of the VAR coefficients is normal and given

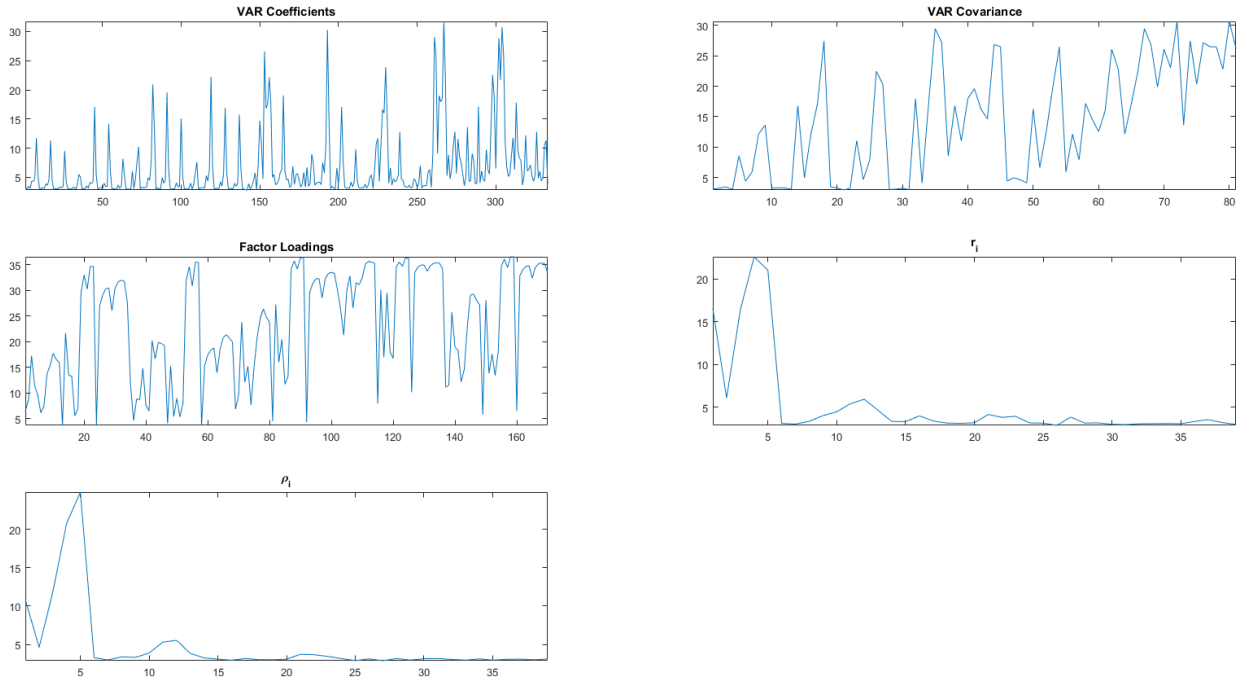

Figure 1: Inefficiency factors

by:

$$\begin{aligned} & N(B^*, Q \otimes \left(X^{*\prime} X^*\right)^{-1}) \\ B^* \quad = \quad & \left(X^{*\prime} X^*\right)^{-1} \left(X^{*\prime} Y^*\right) \end{aligned}$$

where $Y^* = [Z_t; Y_{D,1}; Y_{D,2}]$ and $X^* = [X_t; X_{D,1}; X_{D,2}]$ with $X_t = [Z_{t-1}, .., Z_{t-P}, 1]$.

5. $H\left(Q|\Lambda, F_t, b, R, B\right)$. This conditional posterior is Inverse Wishart:

$$\begin{aligned} & IW(S^*, T^*) \\ S^* \quad = \quad & (Y^* - X^*)\tilde{B}'(Y^* - X^*\tilde{B}) \end{aligned}$$

where $\tilde{B}$ is the draw of the VAR coefficients B reshaped to be conformable with X^* and T^* denotes the number of rows of Y^*.

6. $H\left(F_t|\Lambda, R, B, b, Q\right)$. Given the model parameters, the model can be written in state-space form and the factors can be drawn using the Carter and Kohn (1994) algorithm.

We employ 200,000 iterations with a burn-in of 100,000 and save every 10th draw, leaving 10,000 draws for inference. Figure 1 shows that for most parameters the estimated inefficiency factors are fairly low. Given the heavily parameterised nature of the model, this constitutes strong evidence in favour of convergence of the algorithm.

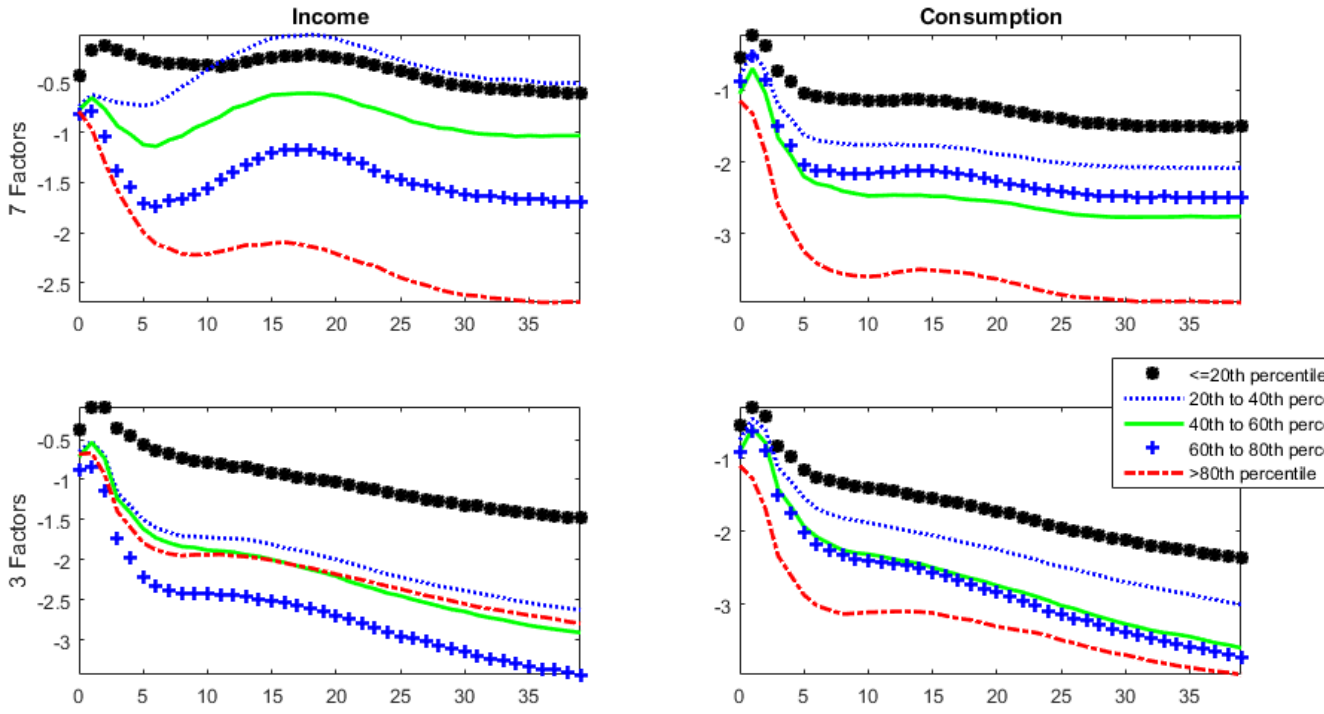

Figure 2: Sensitivity Analysis

2 Additional robustness checks

In this section we present results from the benchmark FAVAR using 7 factors and 3 factors, respectively. The estimated income and consumption impulse responses are shown in figure 2. The first column shows that the key results regarding the income response are preserved. The US financial shock has a smaller impact on the left tail of the income and consumption distribution. The second column of the figure shows that as in the benchmark case, the financial shock has a large impact on the top consumption groups, while its impact on group P_1 is fairly small in comparison.

3 Data

The extended FAVAR model that uses a factor structure for the US economy includes 91 Macroeconomic and Financial time-series. The table below lists the 91 Macroeconomic and Financial time-series. In terms of the data sources GFD refers to Global Financial Database, FRED is the Federal Reserve Bank of St Louis database. D denotes the log difference transformation (times 100), while N denotes no transformation.

Table 1: Data for the factor model.

Variable	Description	Source	Transformation
1	Industrial Production	FRED	D
2	Industrial Production: Business Equipment	FRED	D
3	Industrial Production: Consumer Goods	FRED	D
4	Industrial Production: Durable Consumer Goods	FRED	D
5	Industrial Production: Durable Materials	FRED	D
6	Industrial Production: Final Products (Market Group)	FRED	D
7	Industrial Production: Final Products and Nonindustrial Supplies	FRED	D
8	Industrial Production: Manufacturing	FRED	D
9	Industrial Production: Materials	FRED	D
10	Industrial Production: Nondurable Consumer Goods	FRED	D
11	Dow Jones Industrial Index	GFD	D
12	GDP Deflator	FRED	N
13	ISM Manufacturing: New Orders Index	FRED	N
14	ISM Manufacturing: Inventories Index	FRED	N
15	ISM Manufacturing: Supplier Deliveries Index	FRED	N
16	ISM Manufacturing: PMI Composite Index	FRED	N
17	ISM Manufacturing: Employment Index	FRED	N
18	ISM Manufacturing: Production Index	FRED	N
19	ISM Manufacturing: Prices Index	FRED	N
20	Employment	FRED	D
21	All Employees: Construction	FRED	D

Table 1: Data for the factor model.

22	All Employees: Financial Activities	FRED	D
23	All Employees: Goods-Producing Industries	FRED	D
24	All Employees: Government	FRED	D
25	All Employees: Trade, Transportation and Utilities	FRED	D
26	All Employees: Retail Trade	FRED	D
27	All Employees: Wholesale Trade	FRED	D
28	All Employees: Durable goods	FRED	D
29	All Employees: Manufacturing	FRED	D
30	All Employees: Nondurable goods	FRED	D
31	All Employees: Service-Providing Industries	FRED	D
32	All Employees: Total Nonfarm Payrolls	FRED	D
33	Real personal income excluding current transfer receipts	FRED	D
34	Business Conditions Index	GFD	N
35	Imports	Fred	D
36	Exports	Fred	D
37	Real Government Spending	Fred	D
38	Real Tax revenues	Fred	D
39	Business Investment	Fred	D
40	Real Consumption Expenditure	Fred	D
41	Real GDP	Fred	D
42	Unemployment Rate	Fred	N
43	Number of Civilians Unemployed for 15 Weeks and Over	Fred	D
44	Number of Civilians Unemployed for 15 to 26 Weeks	Fred	D
45	Number of Civilians Unemployed for 27 Weeks and Over	Fred	D
46	Number of Civilians Unemployed for 5 to 14 Weeks	Fred	D

Table 1: Data for the factor model.

47	Number of Civilians Unemployed for Less Than 5 Weeks	Fred	D
48	Average (Mean) Duration of Unemployment	Fred	D
49	Average Weekly Hours	Fred	D
50	Average Weekly Hours of Production and Nonsupervisory Employees: Goods-Producing	Fred	D
51	Average Hourly Earnings of Production and Nonsupervisory Employees: Goods-Producing	Fred	D
52	Average Hourly Earnings of Production and Nonsupervisory Employees: Construction	Fred	D
53	Average Hourly Earnings of Production and Nonsupervisory Employees: Manufacturing	Fred	D
54	Average Weekly Hours of Production and Nonsupervisory Employees: Manufacturing	Fred	D
55	Civilian Labour Force	Fred	D
56	Civilian Participation Rate	Fred	D
57	Unit Labour Cost	Fred	D
58	Nonfarm Business Sector: Real Compensation Per Hour	Fred	D
59	M2 Money	Fred	D
60	Total Consumer Credit Owned and Securitized, Outstanding	Fred	D
61	Commercial and Industrial Loans, All Commercial Banks	Fred	D
62	Real Estate Loans, All Commercial Banks	Fred	D

Table 1: Data for the factor model.

63	Producer Price Index for All Commodities	Fred	D
64	Producer Price Index by Commodity Metals and metal products: Primary nonferrous metals	Fred	D
65	Producer Price Index by Commodity for Crude Materials for Further Processing	Fred	D
66	Producer Price Index by Commodity for Finished Consumer Goods	Fred	D
67	Producer Price Index by Commodity for Finished Goods	Fred	D
68	Producer Price Index by Commodity Intermediate Materials: Supplies and Components	Fred	D
69	Consumer Price Index	Fred	D
70	Consumer Price Index for All Urban Consumers: Apparel	Fred	D
71	Consumer Price Index for All Urban Consumers: Medical Care	Fred	D
72	Consumer Price Index for All Urban Consumers: All items less shelter	Fred	D
73	Personal Consumption Expenditures: Chain-type Price Index	Fred	D
74	3 Month Treasury Bill Rate	Fred	N
75	10 year Govt Bond Yield minus 3mth T-bill rate	GFD	N
76	6mth T-Bill rate minus 3mth T-bill rate	GFD	N
77	1 year Govt Bond Yield minus 3mth T-bill rate	GFD	N
78	5 year Govt Bond Yield minus 3mth T-bill rate	GFD	N
79	Commodity Price Index	GFD	D

Table 1: Data for the factor model.

80	West Texas Intermediate Oil Price	GFD	D
81	BAA Corporate Spread	GFD	N
82	AAA Corporate Bond Spread	GFD	N
83	S&P500 Total Return Index	GFD	D
84	NYSE Stock Market Capitalization	GFD	D
85	S&P500 P/E Ratio	GFD	N
86	Pound dollar Exchange Rate	GFD	D
87	US and Canadian Dollar exchange rate	GFD	D
88	US dollar and German Mark exchange rate	GFD	D
89	Us Dollar and Japanese Yen Exchange Rate	GFD	D
90	Nasdaq Composite	GFD	D
91	NYSE Composite	GFD	D

4 DSGE Model Fit

Figure 3 displays the fit of the model. Starting from the fit of the model, it is hard to argue against of its ability to reproduce the dynamics observed in the data. If we take into account: (i) the model replicates the responses of 11 variables (not just few series) and (ii) this set contains real economy, financial and survey variables then the ability of the DSGE model to reproduce the empirical responses is satisfactory.

5 DSGE Model equations

5.1 Unemployed Tenants

Budget constraint

$$c_t^{ut} + q_t^x x_t^{ut} + r_t^h h_{t-1}^{ut} = \xi + w_t l_t^{ut} \tag{3}$$

5.2 Employed Tenants

Utility function

$$u_t^{et} = E_t \sum_{i=0}^{\infty} \left(\beta^{et}\right)^i \left\{ \log\left(c_{t+i}^{et} - \eta_c^{et} c_{t+i-1}^{et}\right) + j^{et} \log\left(h_{t+i}^{et} - \eta_h^{et} h_{t+i-1}^{et}\right) - \psi^{et} \frac{\left(l_{t+i}^{et}\right)^{1+\sigma_l}}{1+\sigma_l} \right\} \tag{4}$$

Budget constraint

$$0 = w_t l_t^{et} + \frac{r_{t-1}}{\pi_t} d_{t-1}^{et} - c_t^{et} - r_t^h h_{t-1}^{et} - d_t^{et} \left(1 + \frac{\kappa}{2}\left(\frac{d_t^{et}}{\tilde{c}_t^{et}} - \frac{d^{et}}{\tilde{c}^{et}}\right)^2\right) \tag{5}$$

Marginal utility of consumption

$$\frac{1}{c_t^{et} - \eta_c^{et} c_{t-1}^{et}} = \frac{\beta^{et}\eta_c^{et}}{E_t c_{t+1}^{et} - \eta_c^{et} c_t^{et}} + \lambda_t^{et} \tag{6}$$

Marginal utility of housing

$$\frac{j^{et}}{h_t^{et} - \eta_h^{et} h_{t-1}^{et}} = \frac{\beta^{et} j^{et} \eta_h^{et}}{h_{t+1}^{et} - \eta_h^{et} h_t^{et}} + E_t \beta^{et} \lambda_{t+1}^{et} r_{t+1}^h$$

Labour supply

$$\psi^{et}\left(l_t^{et}\right)^{\sigma_l} = \lambda_t^{et} w_t \tag{7}$$

Euler equation

$$\lambda_t^{et}\left(1 + \frac{\kappa}{2}\left(\frac{d_t^{et}}{\tilde{c}_t^{et}} - \frac{d^{et}}{\tilde{c}^{et}}\right)^2\right) + \lambda_t^{et}\kappa\left(\frac{d_t^{et}}{\tilde{c}_t^{et}} - \frac{d^{et}}{\tilde{c}^{et}}\right)\frac{d_t^{et}}{\tilde{c}_t^{et}} = \beta^{et}\lambda_{t+1}^{et}\frac{r_t}{E_t\pi_{t+1}} \tag{8}$$

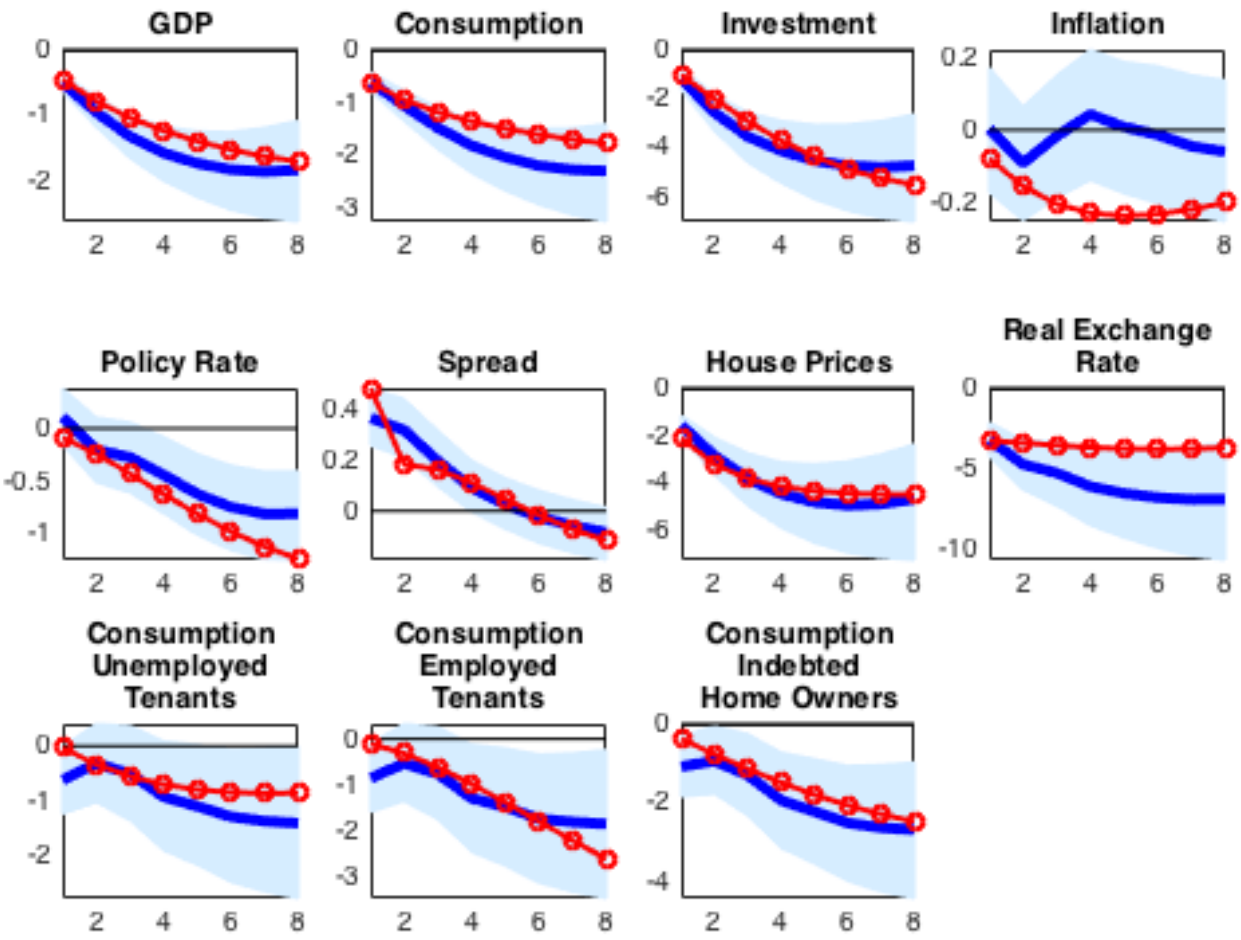

Figure 3: **DSGE Model Fit:** The blue thick and shadow area illustrate the median and the 16%-84% percentiles of the posterior distribution of the responses derived by the empirical model. The red dashed-cycle line represents the responsed derived by the estimated DSGE model

5.3 Indebted Home Owners

Utility function

$$u_t^{iho} = E_t \sum_{i=0}^{\infty} \left(\beta^{iho}\right)^i \left\{ \log\left(c_{t+i}^{iho} - \eta_c^{iho} c_{t+i-1}^{iho}\right) + j^{iho} \log\left(h_{t+i}^{iho} - \eta_h^{iho} h_{t+i-1}^{iho}\right) - \psi^{iho} \frac{\left(l_{t+i}^{iho}\right)^{1+\sigma_l}}{1+\sigma_l} \right\} \tag{9}$$

Budget constraint

$$0 = w_t l_t^{iho} + b_t^{iho} - c_t^{iho} - q_t^h \left(h_t^{iho} - h_{t-1}^{iho}\right) - \frac{r_t^b}{\pi_t} b_{t-1}^{iho} \tag{10}$$

Borrowing constraint

$$r_{t+1}^b b_t^{iho} \leq \rho_b^{iho} r_t^b b_{t-1}^{iho} + \left(1 - \rho_b^{iho}\right) m_t^{iho} q_{t+1}^h h_t^{iho} \pi_{t+1} \tag{11}$$

Lagrange equation

$$L_t^{iho} = E_t \sum_{i=0}^{\infty} \left(\beta^{iho}\right)^i \left[\begin{array}{c} \left\{ \log\left(c_{t+i}^{iho} - \eta_c c_{t+i-1}^{iho}\right) + j^{iho} \log\left(h_{t+i}^{iho} - \eta_h^{iho} h_{t+i-1}^{iho}\right) - \psi^{iho} \frac{\left(l_{t+i}^{iho}\right)^{1+\sigma_l}}{1+\sigma_l} \right\} \\ + \lambda_{t+i}^{iho} \left\{ w_t l_t^{iho} + b_t^{iho} - c_t^{iho} - q_t^h \left(h_t^{iho} - h_{t-1}^{iho}\right) - \frac{r_t^b}{\pi_t} b_{t-1}^{iho} \right\} \\ + \mu_{t+i}^{iho} \left\{ \rho_b^{iho} r_{t+i}^b b_{t+i-1}^{iho} + \left(1 - \rho_b^{iho}\right) m_{t+i}^{iho} q_{t+i+1}^h h_{t+i}^{iho} \pi_{t+i+1} - r_{t+i+1}^b b_{t+i}^{iho} \right\} \end{array} \right] \tag{12}$$

Marginal utility of consumption

$$\frac{1}{c_t^{iho} - \eta_c^{iho} c_{t-1}^{iho}} = \frac{\beta^{iho} \eta_c^{iho}}{E_t c_{t+1}^{iho} - \eta_c^{iho} c_t^{iho}} + \lambda_t^{iho} \tag{13}$$

Euler equation

$$\lambda_t^{iho} = \beta^{iho} \lambda_{t+1}^{iho} \frac{r_{t+1}^b}{E_t \pi_{t+1}} + \mu_t^{iho} r_{t+1}^b - \beta^{iho} \mu_{t+1}^{iho} \rho_b^{iho} r_{t+1}^b$$

Marginal utility of housing

$$\lambda_t^{iho} q_t^h + \frac{\beta j^{iho} \eta_h^{iho}}{h_{t+1}^{iho} - \eta_h^{iho} h_t^{iho}} = \frac{j^{iho}}{h_t^{iho} - \eta_h^{iho} h_{t-1}^{iho}} + \mu_t^{iho} \left(1 - \rho_b^{iho}\right) m_t E_t \left(q_{t+1}^h \pi_{t+1}\right) + \beta^{iho} \lambda_{t+1}^{iho} q_{t+1}^h \tag{14}$$

Labour supply

$$\psi^{iho} \left(l_t^{iho}\right)^{\sigma_l} = \lambda_t^{iho} w_t \tag{15}$$

5.4 Outright Home Owners

Utility function

$$u_t^{oho} = E_t \sum_{i=0}^{\infty} \left(\beta^{oho}\right)^i \left\{ \log\left(c_{t+i}^{oho} - \eta_c^{oho} c_{t+i-1}^{oho}\right) + j^{oho} \log\left(h_{t+i}^{oho} - \eta_h^{oho} h_{t+i-1}^{oho}\right) - \psi^{oho} \frac{\left(l_{t+i}^{oho}\right)^{1+\sigma_l}}{1+\sigma_l} \right\} \tag{16}$$

Budget constraint

$$0 = w_t l_t^{oho} + \frac{r_{t-1}}{\pi_t} d_{t-1}^{oho} + div_t - c_t^{oho} - q_t^h \left(h_t^{oho} - h_{t-1}^{oho} \right) - d_t^{oho} - \tau \tag{17}$$

Lagrange equation

$$L_t^{oho} = E_t \sum_{i=0}^{\infty} \left(\beta^{oho} \right)^i \left[\begin{array}{c} \left\{ \log \left(c_{t+i}^{oho} - \eta_c^{oho} c_{t+i-1}^{oho} \right) + j^{oho} \log \left(h_{t+i}^{oho} - \eta_h^{oho} h_{t+i-1}^{oho} \right) - \psi^{oho} \frac{\left(l_{t+i}^{oho} \right)^{1+\sigma_l}}{1+\sigma_l} \right\} \\ + \lambda_{t+i}^{iho} \left\{ w_t l_t^{oho} + \frac{r_{t-1}}{\pi_t} d_{t-1}^{oho} + div_t - c_t^{oho} - q_t^h \left(h_t^{oho} - h_{t-1}^{oho} \right) - d_t^{oho} \right\} \end{array} \right] \tag{18}$$

Marginal utility of consumption

$$\frac{1}{c_t^{oho} - \eta_c^{oho} c_{t-1}^{oho}} = \frac{\beta^{oho} \eta_c^{oho}}{E_t c_{t+1}^{oho} - \eta_c^{oho} c_t^{oho}} + \lambda_t^{oho} \tag{19}$$

Euler equation

$$\lambda_t^{oho} = \beta^{oho} \lambda_{t+1}^{oho} \frac{r_t}{E_t \pi_{t+1}} \tag{20}$$

Marginal utility of housing

$$\lambda_t^{oho} q_t^h + \frac{\beta^{oho} j^{oho} \eta_h^{oho}}{h_{t+1}^{oho} - \eta_h^{oho} h_t^{oho}} = \frac{j^{oho}}{h_t^{oho} - \eta_h^{oho} h_{t-1}^{oho}} + \beta^{oho} \lambda_{t+1}^{iho} q_{t+1}^h \tag{21}$$

5.5 Capital Producers

Utility function

$$u_t^{cp} = E_t \sum_{i=0}^{\infty} \left(\beta^{cp} \right)^i \log \left(c_{t+i}^{cp} - \eta_c^{cp} c_{t+i-1}^{cp} \right) \tag{22}$$

Budget constraint

$$0 = r_t^h h_{t-1}^{cp} + r_t^k k_{t-1} + b_t^{cp} - c_t^{cp} - i_t - \frac{r_t^b}{\pi_t} b_{t-1}^{cp} - q_t^h \left(h_t^{cp} - h_{t-1}^{cp} \right)$$

Capital accumulation

$$k_t = (1 - \delta) k_{t-1} + \left(1 - \frac{\psi}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right) i_t \tag{23}$$

Borrowing constraint

$$r_{t+1}^b b_t^{cp} \leq \rho_b^{cp} r_t^b b_{t-1}^{cp} + \left(1 - \rho_b^{cp} \right) m_t^{cp} \left(\omega_k q_{t+1} k_t \pi_{t+1} + \omega_h q_{t+1}^h h_t^{cp} \pi_{t+1} \right) \tag{24}$$

Lagrange equation

$$L_t^{cp} = E_t \sum_{i=0}^{\infty} (\beta^{cp})^i \left[\begin{array}{c} \log\left(c_{t+i}^{cp} - \eta_c^{cp} c_{t+i-1}^{cp}\right) \\ +\lambda_{t+i}^{cp} \left\{ r_{t+i}^h h_{t+i-1}^{cp} + r_{t+i}^k k_{t+i-1} + b_{t+i}^{cp} - c_{t+i}^{cp} - i_{t+i} - \frac{r_{t+i}^b}{\pi_{t+i}} b_{t+i-1}^{cp} - q_{t+i}^h \left(h_{t+i}^{cp} - h_{t+i-1}\right) \right\} \\ +\mu_{t+i}^{cp} \left\{ \rho_b^{cp} r_{t+i}^b b_{t+i-1}^{cp} + \left(1-\rho_b^{cp}\right) m_{t+i}^{cp} \left(\omega_k q_{t+i+1} k_{t+i} \pi_{t+i+1} + \omega_h q_{t+i+1}^h h_{t+i}^{cp} \pi_{t+i+1}\right) - r_{t+i+1}^b b_{t+} \right. \\ \left. +\varpi_{t+i} \left((1-\delta) k_{t+i-1} + \left(1 - \frac{\psi}{2}\left(\frac{i_{t+i}}{i_{t+i-1}} - 1\right)^2\right) i_{t+i} - k_{t+i} \right) \end{array} \right] \tag{25}$$

Marginal utility of consumption

$$\frac{1}{c_t^{cp} - \eta_c^{cp} c_{t-1}^{cp}} - \frac{\beta^{cp} \eta_c^{cp}}{E_t c_{t+1}^{cp} - \eta_c^{cp} c_t^{cp}} = \lambda_t^{cp} \tag{26}$$

Euler equation

$$\lambda_t^{cp} = \beta^{cp} \lambda_{t+1}^{cp} \frac{r_{t+1}^b}{E_t \pi_{t+1}} + \mu_t^{cp} r_{t+1}^b - \beta^{cp} \mu_{t+1}^{cp} \rho_b^{cp} r_{t+1}^b$$

Tobin's Q equation

$$q_t = \beta^{cp} \frac{\lambda_{t+1}^{cp}}{\lambda_t^{cp}} \left(r_{t+1}^k + (1-\delta) q_{t+1} \right) + \frac{\mu_t^{cp}}{\lambda_t^{cp}} \left(1 - \rho_b^{cp}\right) m_t^{cp} \omega_k q_{t+1} \pi_{t+1} \tag{27}$$

Housing Q equation

$$q_t^h = \beta^{cp} \frac{\lambda_{t+1}^{cp}}{\lambda_t^{cp}} \left(q_{t+1}^h + r_{t+1}^h \right) + \frac{\mu_t^{cp}}{\lambda_t^{cp}} \left(1 - \rho_b^{cp}\right) m_t^{cp} \omega_h q_{t+1}^h \pi_{t+1}$$

Investment equation

$$1 = \left[1 - \frac{\psi}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 - \psi \left(\frac{i_t}{i_{t-1}} - 1 \right) \frac{i_t}{i_{t-1}} \right] q_t + \beta^{cp} \frac{\lambda_{t+1}^{cp}}{\lambda_t^{cp}} q_{t+1} \psi \left(\frac{i_{t+1}}{i_t} - 1 \right) \left(\frac{i_{t+1}}{i_t} \right)^2 \tag{28}$$

5.6 Banks

Utility function

$$u_t^b = E_t \sum_{i=0}^{\infty} \left(\beta^b\right)^i \log\left(c_{t+i}^b - \eta_c^b c_{t+i-1}^b \right) \tag{29}$$

Budget constraint

$$0 = d_t + \frac{r_t^b}{\pi_t} b_{t-1} + \frac{s_t r_{t-1}^* b_{t-1}^*}{\pi_t^*} - c_t^b - \frac{r_{t-1}^d}{\pi_t} d_{t-1} - b_t - \frac{s_t b_t^*}{\varepsilon_t^*} \tag{30}$$

Borrowing constraint

$$d_t \leq m_t^b b_t + \frac{s_t b_t^*}{\varepsilon_t^*}$$

Lagrange equation

$$L_t^b = E_t \sum_{i=0}^{\infty} \left(\beta^b\right)^i \left[\begin{array}{c} \log\left(c_{t+i}^b - \eta_c^b c_{t+i-1}^b\right) \\ +\lambda_{t+i}^b \left\{ \begin{array}{c} d_{t+i} + \frac{r_{t+i}^b}{\pi_{t+i}} b_{t+i-1} + \frac{s_{t+i} r_{t+i-1}^* b_{t+i-1}^*}{\pi_{t+i}^*} - c_{t+i}^b \\ -\frac{r_{t+i-1}^d}{\pi_{t+i}} d_{t+i-1} - b_{t+i} - \frac{s_{t+i} b_{t+i}^*}{\varepsilon_{t+i}^*} - \end{array} \right\} \\ +\mu_{t+i}^b \left\{ m_{t+i}^b b_{t+i} + \frac{s_{t+i} b_{t+i}^*}{\varepsilon_{t+i}^*} - d_{t+i} \right\} \end{array} \right] \tag{31}$$

Marginal utility of consumption

$$\frac{1}{c_t^b - \eta_c^b c_{t-1}^b} - \frac{\beta^b \eta_c^b}{E_t c_{t+1}^b - \eta_c^b c_t^b} = \lambda_t^b \tag{32}$$

Euler equations

$$\lambda_t^b = \beta^b E_t \lambda_{t+1}^b \frac{r_t}{\pi_{t+1}} \tag{33}$$

$$\lambda_t^b = \beta^b E_t \lambda_{t+1}^b \frac{r_{t+1}^b}{\pi_{t+1}} + \mu_t^b m_t^b \tag{34}$$

$$s_t = E_t s_{t+1} \frac{\frac{r_t^*}{\pi_{t+1}}}{\frac{r_t}{\pi_{t+1}}} \varepsilon_t^* \tag{35}$$

$$\frac{r_t}{\pi_{t+1}} = \frac{r_{t+1}^b}{\pi_{t+1}} + \frac{\mu_t^b m_t^b}{\beta^b E_t \lambda_{t+1}^b} \tag{36}$$

5.7 Intermediate Good Producers

Production function

$$y_t = \left(\left(h_{t-1}^f\right)^{\chi} k_{t-1}^{1-\chi}\right)^{\alpha} l_t^{(1-\alpha)} \tag{37}$$

Profit function

$$div_t = y_t - w_l l_t - r_t^k k_{t-1} - r_t^h h_{t-1}^f + mc_t \left\{ \left[\left(h_{t-1}^f\right)^{\chi} k_{t-1}^{1-\chi} \right]^{\alpha} l_t^{(1-\alpha)} - y_t \right\} \tag{38}$$

Demand for labour

$$mc_t = \frac{\frac{w_t}{\overline{p}_t}}{\frac{(1-\alpha) y_t}{l_t}} \tag{39}$$

Demand for capital

$$mc_t = \frac{r_t^k}{\frac{\alpha(1-\chi) y_t}{k_{t-1}}} \tag{40}$$

Demand for comercial property

$$mc_t = \frac{r_t^h}{\frac{\alpha \chi y_t}{h_{t-1}^f}}$$

Phillips Curve

$$f_{1,t} = \lambda_t mc_t y_t^d + \beta\xi_y E_t \left(\frac{\pi_t^{i_d} \bar{\pi}_{t+1}^{1-i_d}}{\pi_{t+1}} \right)^{-\frac{\theta_p}{\theta_p - 1}} f_{1,t+1} \tag{41}$$

$$f_{2,t} = \lambda_t \breve{\pi}_t y_t^d + \beta\xi_d E_t \left(\frac{\pi_t^{i_y} \bar{\pi}_{t+1}^{1-i_y}}{\pi_{t+1}} \right)^{-\frac{1}{\theta_p - 1}} \left(\frac{\breve{\pi}_t}{\breve{\pi}_{t+1}} \right) f_{2,t+1} \tag{42}$$

$$0 = \theta_p f_{1,t} - f_{2,t} \tag{43}$$

$$1 = \xi_d \left(\frac{\pi_{t-1}^{i_d} \bar{\pi}_{t+1}^{1-i_d}}{\pi_t} \right)^{-\frac{1}{\theta_p - 1}} + (1 - \xi_d) \breve{\pi}_t^{-\frac{1}{\theta_p - 1}} \tag{44}$$

where $\breve{\pi}_t \equiv \frac{p_t^{new}}{p_t}$.

Price dispersion

$$v_t^p = \xi_d \left(\frac{\pi_{t-1}^{i_y} \pi^{1-i_y}}{\pi_t} \right)^{-\frac{\theta_p}{\theta_p - 1}} v_{t-1}^p + (1 - \xi_d) \breve{\pi}_t^{-\frac{\theta_p}{\theta_p - 1}} \tag{45}$$

5.8 Final Good Producers

Production function

$$z_t = \left[\upsilon^{\frac{1}{\tau}} y_t^{\frac{\tau-1}{\tau}} + (1 - \upsilon)^{\frac{1}{\tau}} m_t^{\frac{\tau-1}{\tau}} \right]^{\frac{\tau}{\tau-1}} \tag{46}$$

CPI Price Index

$$p_t = \upsilon \left(p_t^d \right)^{1-\tau} + (1 - \upsilon) \left(p_t^m \right)^{1-\tau} \tag{47}$$

Demand for imports

$$m_t = (1 - \upsilon) z_t \left(\bar{p}_t^m \right)^{-\tau} \tag{48}$$

Demand for value added

$$y_t = \upsilon z_t \left(\bar{p}_t^d \right)^{-\tau} \tag{49}$$

5.9 Importers

Marginal Cost

$$mc_t^m \equiv \frac{s_t p_t^*}{p_t^m}$$

Phillips Curve

$$g_{1,t} = \lambda_t m c_t^m c_{t+j}^m + \beta \xi_m E_t \left(\frac{\left(\pi_t^m\right)^{\iota_m} \bar{\pi}_{t+1}^{1-\iota_m}}{\pi_{t+1}^m} \right)^{-\frac{\theta_m}{\theta_m - 1}} g_{1,t+1} \tag{50}$$

$$g_{2,t} = \lambda_t \breve{\pi}_t^m c_{t+j}^m + \beta \xi_m E_t \left(\frac{\left(\pi_t^m\right)^{\iota_m} \bar{\pi}_{t+1}^{1-\iota_m}}{\pi_{t+1}^m} \right)^{-\frac{1}{\theta_m - 1}} \left(\frac{\breve{\pi}_t^m}{\breve{\pi}_{t+1}^m} \right) g_{2,t+1} \tag{51}$$

$$0 = \theta_m g_{1,t} - g_{2,t} \tag{52}$$

$$1 = \xi_m \left(\frac{\left(\pi_{t-1}^m\right)^{\iota_m} \bar{\pi}_t^{1-\iota_m}}{\pi_t^m} \right)^{-\frac{1}{\theta_m - 1}} + (1 - \xi_m) \left(\breve{\pi}_t^m\right)^{-\frac{1}{\lambda_m - 1}} \tag{53}$$

where $\breve{\pi}_t^m = \frac{p_t^{m,new}}{p_t^m}$

Price dispersion

$$\upsilon_t^m = \xi_m \left(\frac{\left(\pi_{t-1}^m\right)^{\iota_m} \bar{\pi}_t^{1-\iota_m}}{\pi_t^m} \right)^{-\frac{\theta_m}{\theta_m - 1}} \upsilon_{t-1}^m + (1 - \xi_m) \left(\breve{\pi}_t^m\right)^{-\frac{\theta_m}{\theta_m - 1}} \tag{54}$$

5.10 Government

Budget constraint

$$b_t^g + \xi = \frac{r_{t-1} b_{t-1}^g}{\pi_t} + \xi \tag{55}$$

Balanced budget

$$b_t^g = 0 \tag{56}$$

5.11 Monetary policy

Reaction function

$$\frac{r_t}{r} = \left(\frac{r_{-1}}{r}\right)^{\rho_r} \left(\frac{\pi_t}{\bar{\pi}_t}\right)^{\gamma_\pi (1-\rho_r)} \left(\frac{y_t}{y}\right)^{\gamma_y (1-\rho_r)} \tag{57}$$

5.12 Market Clearing

Labour

$$l_t = l_t^{ut} + l_t^{et} + l_t^{iho} + l_t^{oho} \tag{58}$$

Debt

$$b_t = b_t^{iho} + b_t^{cp} \tag{59}$$

Deposits

$$d_t = d_t^{et} + d_t^{oho} \tag{60}$$

$$h_t^{cp} = h_t^{ut} + h_t^{et} + h_t^f \tag{61}$$

$$h_t = h_t^{iho} + h_t^{oho} + h_t^{cp} = 1 \tag{62}$$

5.13 Steady States

Steady-state hours are calibrated ($l = 1/3$), we proceed by calibrating the following ratios with respect to the labour supplied by the households

$$1 = \frac{l^{ut}}{l} + \frac{l^{et}}{l} + \frac{l^{iho}}{l} + \frac{l^{oho}}{l} \tag{63}$$

$$\frac{l^{ut}}{l} = 0.1 \tag{64}$$

$$\frac{l^{et}}{l} = \frac{l^{iho}}{l} = \frac{l^{oho}}{l} = 0.3 \tag{65}$$

and this pins down the level of labour supply of each household. Similarly the supply of housing is fixed $h_t = 1$, meaning that $h = 1$. As with hours, we calibrate the ratios of rental housing and housing owned by households.

$$h = h^{iho} + h^{oho} + h^{cp} = 1 \tag{66}$$

$$h^{iho} = 0.25 \tag{67}$$

$$h^{iho} = 0.25 \tag{68}$$

$$h^{cp} = 0.50 \tag{69}$$

$$(1 - \varsigma)\, h^{oho} = h^{ut} + h^{et} \tag{70}$$

The value of the interest rate is given by

$$r = \frac{\bar{\pi}}{\beta^{oho}} \tag{71}$$

$$r = \frac{\bar{\pi}}{\beta^{et}} \tag{72}$$

The model pins down the value of the time discount factor for employed tenants

$$\beta^{oho} = \beta^{et} = \beta \tag{73}$$

Steady state value of the borrowing rate is give by bankers' first order conditions

$$r^b = \frac{1 - \left(1 - \frac{\beta^b}{\beta}\right) m^b \bar{\pi}}{\beta^b}$$

The euler equation of the indebted home owners can be used to obtain the steady state value of the Lagrange multiplier associated with her borrowing constraint

$$\frac{\mu^{iho}}{\lambda^{iho}} = \frac{1 - \frac{\beta^{iho}}{\bar{\pi}} r^b}{r^b \left(1 - \beta^{iho} \rho_b^{iho}\right)} \tag{74}$$

and the same steps are applied to calculate the steady state value of the Lagrange multiplier associated with capital producers' borrowing constraint

$$\frac{\mu^{cp}}{\lambda^{cp}} = \frac{1 - \frac{\beta^{cp}}{\bar{\pi}} r^b}{r^b \left(1 - \beta^{cp} \rho_b^{cp}\right)} \tag{75}$$

The combination of the investment and Tobin's Q equations delivers the steady state value of the rental rate of capital

$$r^k = \frac{1 - \left(\frac{1 - \frac{\beta^{cp}}{\bar{\pi}} r^b}{r^b \left(1 - \beta^{cp} \rho_b^{cp}\right)}\right) \left(1 - \rho_b^{cp}\right) m^{cp} \omega_k \bar{\pi} - \left(1 - \delta\right) \beta^{cp}}{\beta^{cp}} \tag{76}$$

Using the demand for capital and Philips curve pricing equations we obtain the steady state value of capital

$$\frac{y}{k} = \frac{1}{\alpha \left(1 - \chi\right)} \frac{r^k}{mc}$$

$$\frac{y}{k} = \left(h^{cp}\right)^{\alpha\chi} k^{(1-\chi)\alpha - 1} l^{(1-\alpha)}$$

$$k = \left(\frac{\frac{1}{\alpha(1-\chi)} \frac{r^k}{mc}}{\left(h^{cp}\right)^{\alpha\chi} l_t^{(1-\alpha)}} \right)^{\frac{1}{(1-\chi)\alpha - 1}} \tag{77}$$

which can be used to calculate the steady state value of investment, output

$$i = \delta k \tag{78}$$

$$y = \left(h^{cp}\right)^{\alpha\chi} k^{(1-\chi)\alpha} l^{(1-\alpha)} \tag{79}$$

and, consequently, aggregated consumption

$$c = y - i \tag{80}$$

The demand for residential housing is used to find out the steady state value of the rental rate of housing

$$r^h = mc \frac{\alpha\chi y}{h^{cp}} \tag{81}$$

The steady state value of housing prices is given by

$$q^h = \frac{\beta^{cp} r^h}{1 - \beta^{cp} - \left(\frac{1 - \frac{\beta^{cp}}{\bar{\pi}} r^b}{r^b \left(1 - \beta^{cp} \rho_b^{cp}\right)}\right) \left(1 - \rho_b^{cp}\right) m^{cp} \omega_h \bar{\pi}} \tag{82}$$

The steady state value of capital producers' borrowing is given by the borrowing constraint

$$b^{cp} = \frac{m^{cp} \left(\omega_k k + \omega_h q^h h^{cp}\right)}{r^b} \tag{83}$$

while their consumption can be calculated by the budget constraint

$$c^{cp} = r^h h^{cp} + r^k k + \left(1 - \frac{r^b}{\pi}\right) b^{cp} - i \tag{84}$$

and this pins down the value of their marginal utility to consume

$$\lambda^{cp} = \frac{1 - \beta^{cp}\eta_c^{cp}}{\left(1 - \eta^{cp}\right) c^{cp}} \tag{85}$$

From the borrowing constraint of the indebted home owners we obtain their total amount of borrowing

$$b^{iho} = \frac{m^{iho} q^h h^{iho} \bar{\pi}}{r^b} \tag{86}$$

From their budget constraint we calculate the steady state value of their consumption level

$$c^{iho} = w l^{iho} + \left(1 - \frac{r^b}{\bar{\pi}}\right) b^{iho} \tag{87}$$

The steady state value of their marginal utility is

$$\lambda^{iho} = \frac{1 - \beta^{iho}\eta_c^{iho}}{\left(1 - \eta^{iho}\right) c^{iho}} \tag{88}$$

The steady state value of depositis is given by bankers' borrowing constraint

$$d = m^b b + b^* \tag{89}$$

Which can be used to calculate the steady state value of bankers' consumption

$$c^b = \left(\left(1 - \frac{r}{\bar{\pi}}\right) m^b + \frac{r^b}{\bar{\pi}} - 1\right) b \tag{90}$$

And their maginal utility of consumption

$$\lambda^b = \frac{1 - \beta^b \eta_c^b}{\left(1 - \eta^b\right) c^b} \tag{91}$$

While the Lagrange multiplier associated with the bankers' borrowing constraint is given by

$$\mu^b = \lambda^b \left(1 - \frac{\beta^b}{\beta}\right) \tag{92}$$

We calibrate the steady state of deposits made by employed tenants $\left(\frac{d^{et}}{d}\right)$ and outright home owners $\left(\frac{d^{oho}}{d}\right)$ to be 30% and 70%, respectively. We this information we can calculate the steady state value of the consumption of the employed tenants and outright home owners

$$c^{et} = w l^{et} + \left(\frac{1}{\beta} - 1\right) d^{et} - r^h h^{et} \tag{93}$$

$$j_{oho} = \lambda^{oho} q^h \left(1 - \beta^{oho}\right) \frac{\left(1 - \eta_h^{oho}\right) h^{oho}}{1 - \beta^{oho} \eta_h^{oho}} \tag{94}$$

$$j_{iho} = \lambda^{iho} q^h \left(1 - \frac{\mu^{iho}}{\lambda^{iho}} \left(1 - \rho_b^{iho}\right) m\bar{\pi} - \beta^{iho}\right) \frac{\left(1 - \eta_h^{iho}\right) h^{iho}}{1 - \beta \eta_h^{iho}} \tag{95}$$

5.14 Linearised Equations

$$\hat{c}_t^{ut} + \frac{r^h h^{ut}}{c^{ut}}\left(\hat{r}_t^h + h_{t-1}^{ut}\right) = \frac{wl^{ut}}{c^{ut}}\left(\hat{w}_t + l_t^{ut}\right) \tag{96}$$

$$\hat{r}_{t+1}^b + \hat{b}_t^{iho} = \rho^{iho}\left(\hat{r}_t^b + \hat{b}_{t-1}^{iho}\right) + \left(1-\rho^{iho}\right) m^{iho}\left(\hat{q}_{t+1}^h + \hat{h}_t^{iho} + \hat{\pi}_{t+1}\right) \tag{97}$$

$$\hat{\lambda}_t^{iho}\left(1-\beta^{iho}\eta_c^{iho}\right)\left(1-\eta_c^{iho}\right) = -\left(1+\beta^{iho}\left(\eta_c^{iho}\right)^2\right)\hat{c}_t^{iho} + \eta_c^{iho}\hat{c}_{t-1}^{iho} + \beta^{iho}\eta_c^{iho}\hat{c}_{t+1}^{iho} \tag{98}$$

$$\begin{aligned}\hat{\lambda}_t^{iho} = \frac{\beta^{iho}r^b}{\bar{\pi}}\left(\hat{\lambda}_{t+1}^{iho} + \hat{r}_{t+1}^b + \hat{\pi}_{t+1}\right) &+ \frac{1-\frac{\beta^{iho}r^b}{\bar{\pi}}}{1-\beta^{iho}\rho^{iho}}\left(\hat{\mu}_t^{iho} + \hat{r}_{t+1}^b\right) \\ &- \frac{\beta^{iho}\rho^{iho}\left(1-\frac{\beta^{iho}r^b}{\bar{\pi}}\right)}{1-\beta^{iho}\rho^{iho}}\left(\hat{\mu}_{t+1}^{iho} + \hat{r}_{t+1}^b\right)\end{aligned} \tag{99}$$

Set

$$j_{iho} = \lambda^{iho}q^h\left(1-\eta_h^{iho}\right)^2 h^{iho}$$

$$\begin{aligned}\left[1+\beta^{iho}\left(\eta_h^{iho}\right)^2\right]\hat{h}_t^{iho} &= \eta_h^{iho}\hat{h}_{t-1}^{iho} + \beta^{iho}\eta_h^{iho}\hat{h}_{t+1}^{iho} + \frac{\left(1-\frac{\beta^{iho}}{\bar{\pi}}r^b\right)\left(1-\rho_b^{iho}\right)m\bar{\pi}}{r^b\left(1-\beta^{iho}\rho_b^{iho}\right)}\left(\hat{\mu}_t^{iho} + \hat{q}_{t+1}^h + \hat{\pi}_{t+1}\right) \\ &- \left(\hat{\lambda}_t^{iho} + \hat{q}_t^h\right) + \beta^{iho}\left(\hat{\lambda}_{t+1}^{iho} + \hat{q}_{t+1}^h\right)\end{aligned} \tag{100}$$

$$\hat{l}_t^{iho} = \frac{1}{\sigma_l}\left(\hat{\lambda}_t^{iho} + \hat{w}_t\right) \tag{101}$$

$$\hat{\lambda}_t^{oho}\left(1-\beta^{oho}\eta_c^{oho}\right)\left(1-\eta_c^{oho}\right) = -\left(1+\beta^{oho}\left(\eta_c^{oho}\right)^2\right)\hat{c}_t^{oho} + \eta_c^{oho}\hat{c}_{t-1}^{oho} + \beta^{oho}\eta_c^{oho}\hat{c}_{t+1}^{oho} \tag{102}$$

$$\hat{\lambda}_t^{oho} = \hat{\lambda}_{t+1}^{oho} + \hat{r}_t + \hat{\pi}_{t+1} \tag{103}$$

Set

$$j_{oho} = \lambda^{oho}q^h\left(1-\eta_h^{oho}\right)^2 h^{oho}$$

$$\left[1+\beta^{oho}\left(\eta_h^{oho}\right)^2\right]\hat{h}_t^{oho} = \eta_h^{oho}\hat{h}_{t-1}^{oho} + \beta^{oho}\eta_h^{oho}\hat{h}_{t+1}^{oho} - \left(\hat{\lambda}_t^{oho} + \hat{q}_t^h\right) + \beta^{oho}\left(\hat{\lambda}_{t+1}^{iho} + \hat{q}_{t+1}^h\right) \tag{104}$$

$$\begin{aligned}\hat{c}_t^{cp} = \frac{r^h h^{cp}}{c^{cp}}\left(\hat{r}_t^h + \hat{h}_{t-1}^{cp}\right) + \frac{r^k k}{c^{cp}}\left(\hat{r}_t^k + \hat{k}_{t-1}\right) + \frac{b^{cp}}{c^{cp}}\hat{b}_t^{cp} - \frac{i}{c^{cp}}\hat{i}_t - \frac{r^b}{\bar{\pi}}\frac{b^{cp}}{c^{cp}}\left(\hat{b}_{t-1}^{cp} + \hat{r}_t^b - \hat{\pi}_t\right) \\ - \frac{q^h h^{cp}}{c^{cp}}\left(\hat{h}_t^{cp} - \hat{h}_{t-1}^{cp}\right)\end{aligned} \tag{105}$$

$$\hat{k}_t = (1-\delta)\,\hat{k}_{t-1} + \delta\hat{i}_t \tag{106}$$

$$\hat{r}^b_{t+1} + \hat{b}^{cp}_t = \rho^{cp}_b \left(\hat{r}^b_t + \hat{b}^{cp}_{t-1} \right) + \left(1 - \rho^{cp}_b\right) m^{cp} \left[\omega_k \left(\hat{q}_{t+1} + \hat{k}_t + \hat{\pi}_{t+1} \right) + \omega_h \left(\hat{q}^h_{t+1} + \hat{h}^{cp}_t + \hat{\pi}_{t+1} \right) \right] \tag{107}$$

$$\hat{\lambda}^{cp}_t \left(1 - \beta^{cp}\eta^{cp}_c\right)\left(1 - \eta^{cp}_c\right) = -\left(1 + \beta^{cp}\left(\eta^{cp}_c\right)^2\right)\hat{c}^{cp}_t + \eta^{cp}_c \hat{c}^{cp}_{t-1} + \beta^{cp}\eta^{cp}_c \hat{c}^{cp}_{t+1} \tag{108}$$

$$\hat{\lambda}^{cp}_t = \frac{\beta^{cp} r^b}{\bar{\pi}} \left(\hat{\lambda}^{cp}_{t+1} + \hat{r}^b_{t+1} + \hat{\pi}_{t+1} \right) + \frac{1 - \frac{\beta^{cp} r^b}{\bar{\pi}}}{1 - \beta^{cp}\rho^{cp}} \left(\hat{\mu}^{cp}_t + \hat{r}^b_{t+1} \right) - \frac{\beta^{cp}\rho^{cp}\left(1 - \frac{\beta^{cp} r^b}{\bar{\pi}}\right)}{1 - \beta^{cp}\rho^{cp}} \left(\hat{\mu}^{cp}_{t+1} + \hat{r}^b_{t+1} \right) \tag{109}$$

$$\begin{aligned} \hat{q}_t &= \beta^{cp}\left(r^k + (1-\delta)\right)\left(\hat{\lambda}^{cp}_{t+1} - \hat{\lambda}^{cp}_t\right) + \beta^{cp}\left(r^k \hat{r}^k_{t+1} + (1-\delta)\hat{q}_{t+1}\right) \\ &+ \frac{\mu^{cp}}{\lambda^{cp}}\left(1 - \rho^{cp}\right) m^{cp}\omega_k \bar{\pi}\left(\hat{\mu}^{cp}_t - \lambda^{cp}_t + \hat{q}_{t+1} + \hat{\pi}_{t+1}\right) \end{aligned} \tag{110}$$

$$\begin{aligned} \hat{q}^h_t &= \frac{\beta^{cp}\left(q^h + r^h\right)}{q^h}\left(\hat{\lambda}^{cp}_{t+1} - \hat{\lambda}^{cp}_t\right) + \frac{\beta^{cp}}{q^h}\left(q^h \hat{q}^h_{t+1} + r^h \hat{r}^h_{t+1}\right) \\ &+ \frac{\mu^{cp}}{\lambda^{cp}}\left(1 - \rho^{cp}\right) m^{cp}\omega_h \bar{\pi}\left(\hat{\mu}^{cp}_t - \lambda^{cp}_t + \hat{q}^h_{t+1} + \hat{\pi}_{t+1}\right) \end{aligned} \tag{111}$$

$$\begin{aligned} \hat{c}^b_t &= \frac{d}{c^b}\hat{d}_t + \frac{r^b b}{\bar{\pi} c^b}\left(\hat{b}_{t-1} + \hat{r}^b_t - \hat{\pi}_t\right) + \frac{r^* b^*}{\bar{\pi}^* c^b}\left(\hat{s}_t + \hat{b}^*_{t-1} + \hat{r}^*_{t-1} - \hat{\pi}^*_t\right) - \frac{rd}{\bar{\pi} c^b}\left(\hat{d}_{t-1} + \hat{r}_{t-1} - \hat{\pi}_t\right) \\ &- \frac{b}{c^b}\hat{b}_t - \frac{b^*}{c^b}\left(\hat{s}_t + \hat{b}^*_t - \hat{\epsilon}^*_t\right) \end{aligned} \tag{112}$$

$$\hat{d}_t = \frac{m^b b}{d}\hat{b}_t + \frac{b^*}{d}\left(\hat{s}_t + \hat{b}^*_t - \hat{\epsilon}^*_t\right) \tag{113}$$

$$\hat{\lambda}^b_t \left(1 - \beta^b \eta^b_c\right)\left(1 - \eta^b_c\right) = -\left(1 + \beta^b\left(\eta^b_c\right)^2\right)\hat{c}^b_t + \eta^b_c \hat{c}^b_{t-1} + \beta^b \eta^b_c \hat{c}^b_{t+1} \tag{114}$$

$$\hat{\lambda}^b_t = \frac{\beta^b}{\beta}\left(\hat{\lambda}^b_{t+1} + \hat{r}_{t-1} - \hat{\pi}_t\right) + \frac{\mu^b}{\lambda^b}\hat{\mu}^b_t \tag{115}$$

$$\hat{\lambda}^b_t = \frac{\beta^b r^b}{\bar{\pi}}\left(\hat{\lambda}^b_{t+1} + \hat{r}_{t-1} - \hat{\pi}_t\right) + \frac{\mu^b m^b}{\lambda^b}\hat{\mu}^b_t \tag{116}$$

$$\hat{s}_t - \hat{s}_{t+1} = \left(\hat{r}^*_t - \hat{\pi}^*_{t+1}\right) - \left(\hat{r}_t - \hat{\pi}_{t+1}\right) - \psi_{nfa}\widehat{nfa}_t \tag{117}$$

$$\hat{y}_t = \alpha\left(\chi \hat{h}^f_{t-1} + (1-\chi)\hat{k}_{t-1}\right) + (1-\alpha)\,\hat{l}_t \tag{118}$$

$$\widehat{mc}_t = \hat{w}_t - \left(\hat{y}_t - \hat{l}_t\right) - \hat{\bar{p}}_t \tag{119}$$

$$\widehat{mc}_t = \hat{r}_t^k - \left(\hat{y}_t - \hat{k}_{t-1}\right) \tag{120}$$

$$\widehat{mc}_t = \hat{r}_t^h - \left(\hat{y}_t - \hat{h}_{t-1}^f\right) \tag{121}$$

$$\hat{\pi}_t^d = \frac{\beta}{1+\beta\kappa_y}\hat{\pi}_{t+1}^d + \frac{\kappa_y}{1+\beta\kappa_y}\hat{\pi}_{t-1}^d + \frac{\left(1-\xi_y\right)\left(1-\beta\xi_y\right)}{\xi_y\left(1+\beta\kappa_y\right)}\widehat{mc}_t \tag{122}$$

$$\widehat{nfa}_t = \frac{1-\psi_{nfa}}{\beta}\widehat{nfa}_{t-1} + \frac{1}{\beta}\left(\Delta\hat{s}_t + \hat{r}_{t-1}^* - \hat{\pi}_t^*\right) + \frac{x}{nfa}\left(\hat{s}_t + \hat{x}_t\right) - \frac{m}{nfa}\left(\hat{s}_t + \hat{m}_t\right) \tag{123}$$

$$\hat{l}_t = \frac{l^{ut}}{l}\hat{l}_t^{ut} + \frac{l^{et}}{l}\hat{l}_t^{et} + \frac{l^{iho}}{l}\hat{l}_t^{iho} + \frac{l^{oho}}{l}\hat{l}_t^{oho} \tag{124}$$

$$\hat{b}_t = \frac{b^{iho}}{b}\hat{b}_t^{iho} + \frac{b^{cp}}{b}\hat{b}_t^{cp} \tag{125}$$

$$\hat{d}_t = \frac{d^{et}}{d}\hat{d}_t^{et} + \frac{d^{oho}}{d}\hat{d}_t^{oho} \tag{126}$$

$$0 = h^{iho}\hat{h}_t^{iho} + h^{oho}\hat{h}_t^{oho} + h^{cp}\hat{h}_t^{cp} \tag{127}$$

$$\hat{z}_t = \frac{c}{z}\hat{c}_t + \frac{i}{z}\hat{i}_t + \frac{x}{z}\hat{x}_t \tag{128}$$

$$\hat{h}^{cp} = \frac{h^{ut}}{h^{cp}}\hat{h}_t^{ut} + \frac{h^{et}}{h^{cp}}\hat{h}_t^{et} + \frac{h^f}{h^{cp}}\hat{h}_t^f \tag{129}$$

$$\hat{y}_t = \hat{z}_t - \tau\hat{\bar{p}}_t \tag{130}$$

$$\hat{m}_t = \hat{z}_t - \tau \hat{\bar{p}}_t^m \tag{131}$$

$$\hat{\pi} = \nu \hat{\pi}_t^d + (1-\nu)\,\hat{\pi}_t^m \tag{132}$$

$$\hat{\pi}_t^m = \frac{\beta}{1+\beta\kappa_m}\hat{\pi}_{t+1}^m + \frac{\kappa_m}{1+\beta\kappa_m}\hat{\pi}_{t-1}^m + \frac{(1-\xi_m)(1-\beta\xi_m)}{\xi_m(1+\beta\kappa_m)}\left(\hat{q}_t - \hat{\bar{p}}_t^m\right) \tag{133}$$

$$\hat{c}_t^{et} = \frac{wl^{et}}{c^{et}}\left(\hat{w}_t + \hat{l}_t^{et}\right) + \frac{rd^{et}}{c^{et}}\left(\hat{d}_t^{et} + \hat{r}_{t-1} - \hat{\pi}_t\right) - \frac{r^h h^{et}}{c^{et}}\left(\hat{r}_t^h + \hat{h}_{t-1}^{et}\right) - \frac{d^{et}}{c^{et}}\hat{d}_t^{et} \tag{134}$$

$$\hat{\lambda}_t^{et}\left(1-\beta^{et}\eta_c^{et}\right)\left(1-\eta_c^{et}\right) = -\left(1+\beta^{et}\left(\eta_c^{et}\right)^2\right)\hat{c}_t^{et} + \eta_c^{et}\hat{c}_{t-1}^{et} + \beta^{et}\eta_c^{et}\hat{c}_{t+1}^{et} \tag{135}$$

$$\left[1+\beta^{et}\left(\eta_h^{et}\right)^2\right]\hat{h}_t^{et} = \eta_h^{et}\hat{h}_{t-1}^{et} + \beta^{et}\eta_h^{et}\hat{h}_{t+1}^{et} - \beta^{et}\left(\hat{\lambda}_{t+1}^{et} + \hat{r}_{t+1}^h\right) \tag{136}$$

$$\hat{\lambda}_t^{et} = \hat{\lambda}_{t+1}^{et} + \hat{r}_t - \hat{\pi}_{t+1} + \kappa\left(\hat{d}_t^{et} - \hat{c}_t^{et}\right)$$

References

Banbura, Marta, Domenico Giannone and Lucrezia Reichlin, 2010, Large Bayesian vector auto regressions, *Journal of Applied Econometrics* **25**(1), 71–92.

Carter, C. K. and R. Kohn, 1994, On Gibbs Sampling for State Space Models, *Biometrika* **81**(3), pp. 541–553.

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This working paper has been produced by
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