DSGE Models & the Great Recession

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Introduction

- A DSGE model is estimated for the US over the period 1947.1 to 2007.4
- DSGE model used is the popular benchmark Smets and Wouters 2007 model from their paper "*Shocks & Frictions in US Business Cycles: A Bayesian DSGE Approach*"
- Increasingly, DSGE models are being used by central banks for both policy analysis and forecasting, but…
- Where were the DSGE models during the recent global financial crisis?
- **Goal: To examine the output from a DSGE model for the US in the run up to the 2008-2009 Great Recession**

Great Recession: 2008 - 2009

According to Baily et. al (2008), the **origins** of the financial crisis lie in

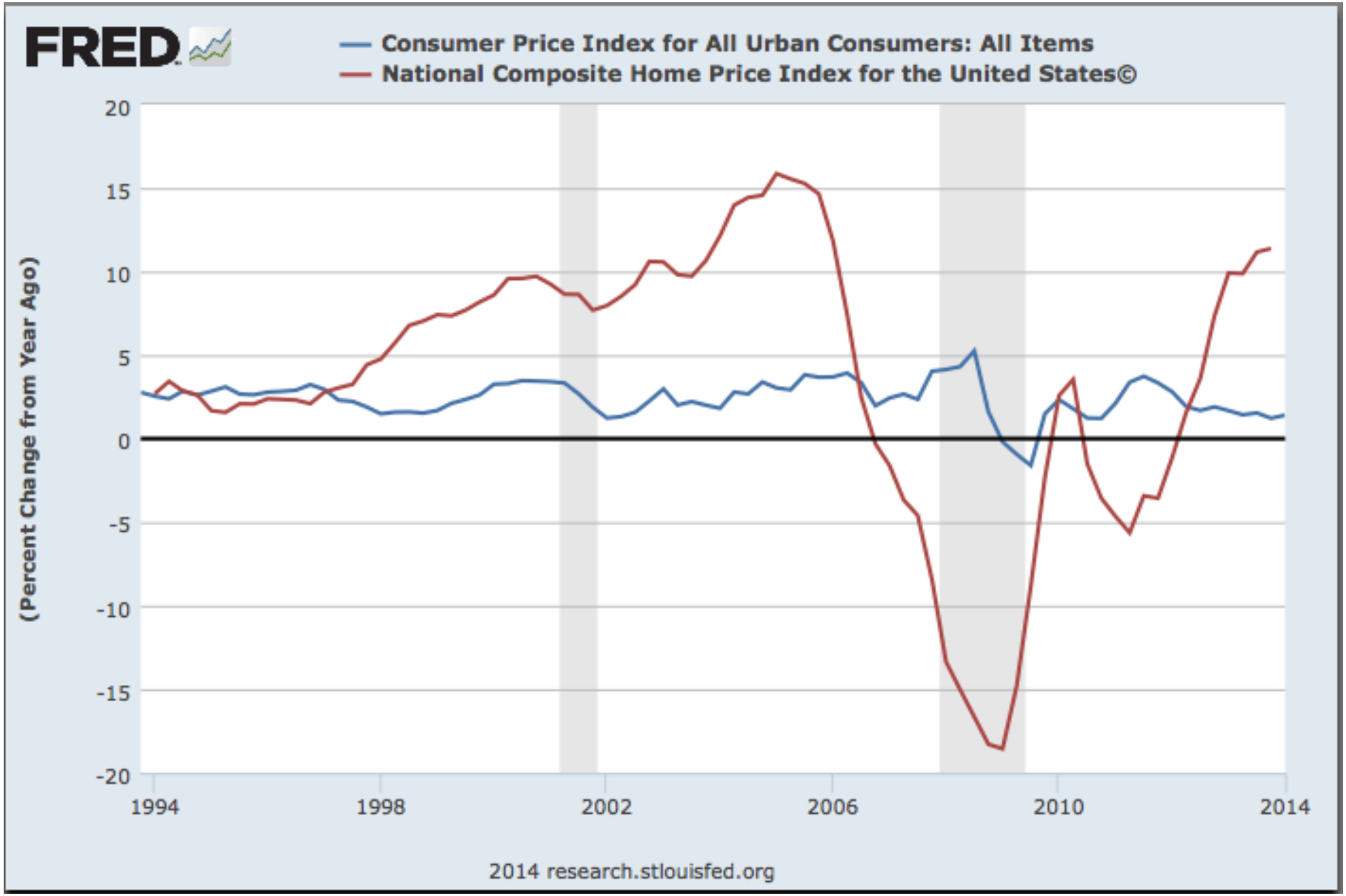
> "…an asset price bubble that interacted with new kinds of financial innovation that masked risk…"

From Verick & Islam (2010), "*The Great Recession of 2008 – 2009: Causes, Consequences & Policy Responses*"

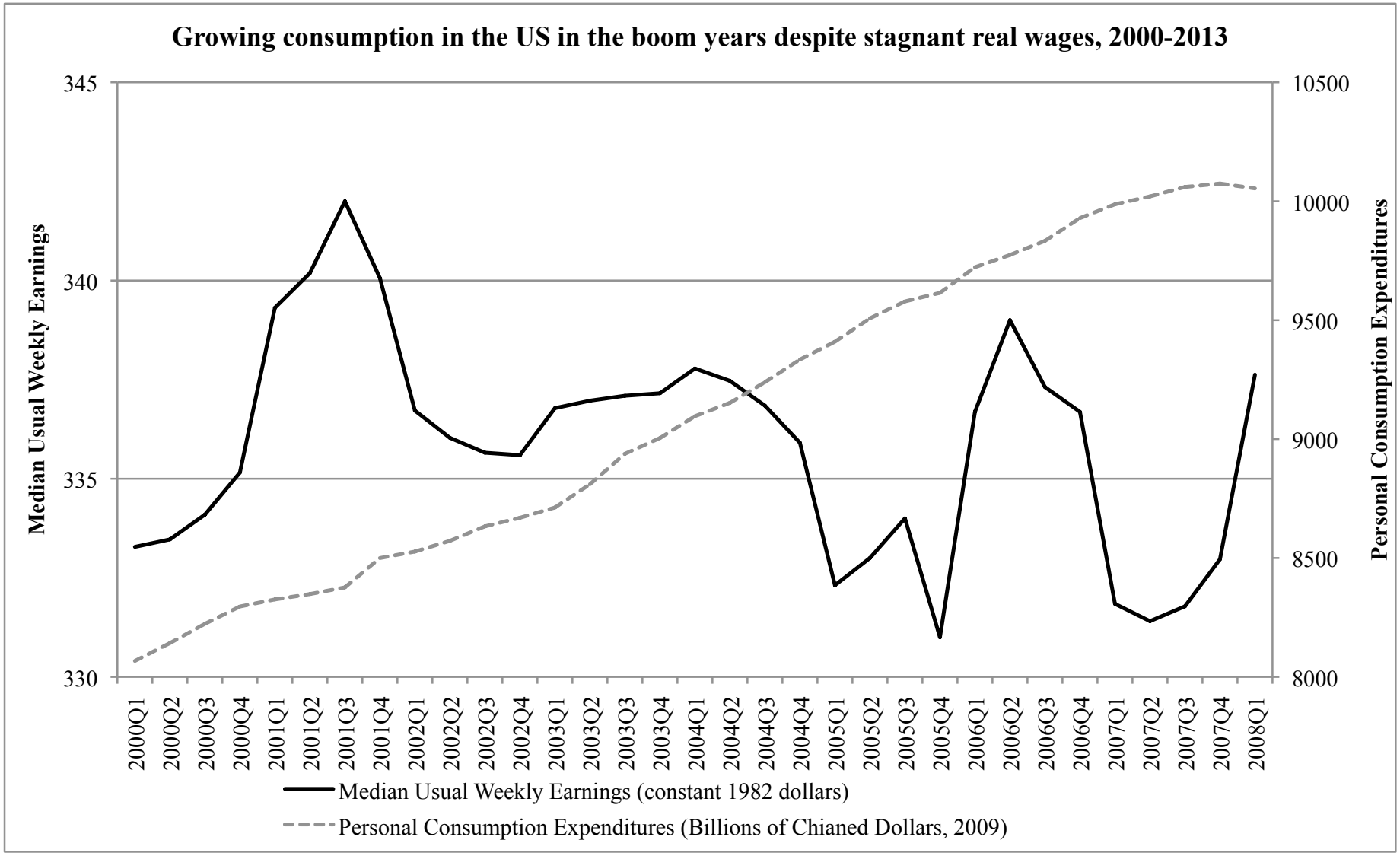
<u>Warning Signs:</u>

1. Loose monetary policy
2. Change in attitude towards risk
3. Lax financial regulation
4. Global imbalances

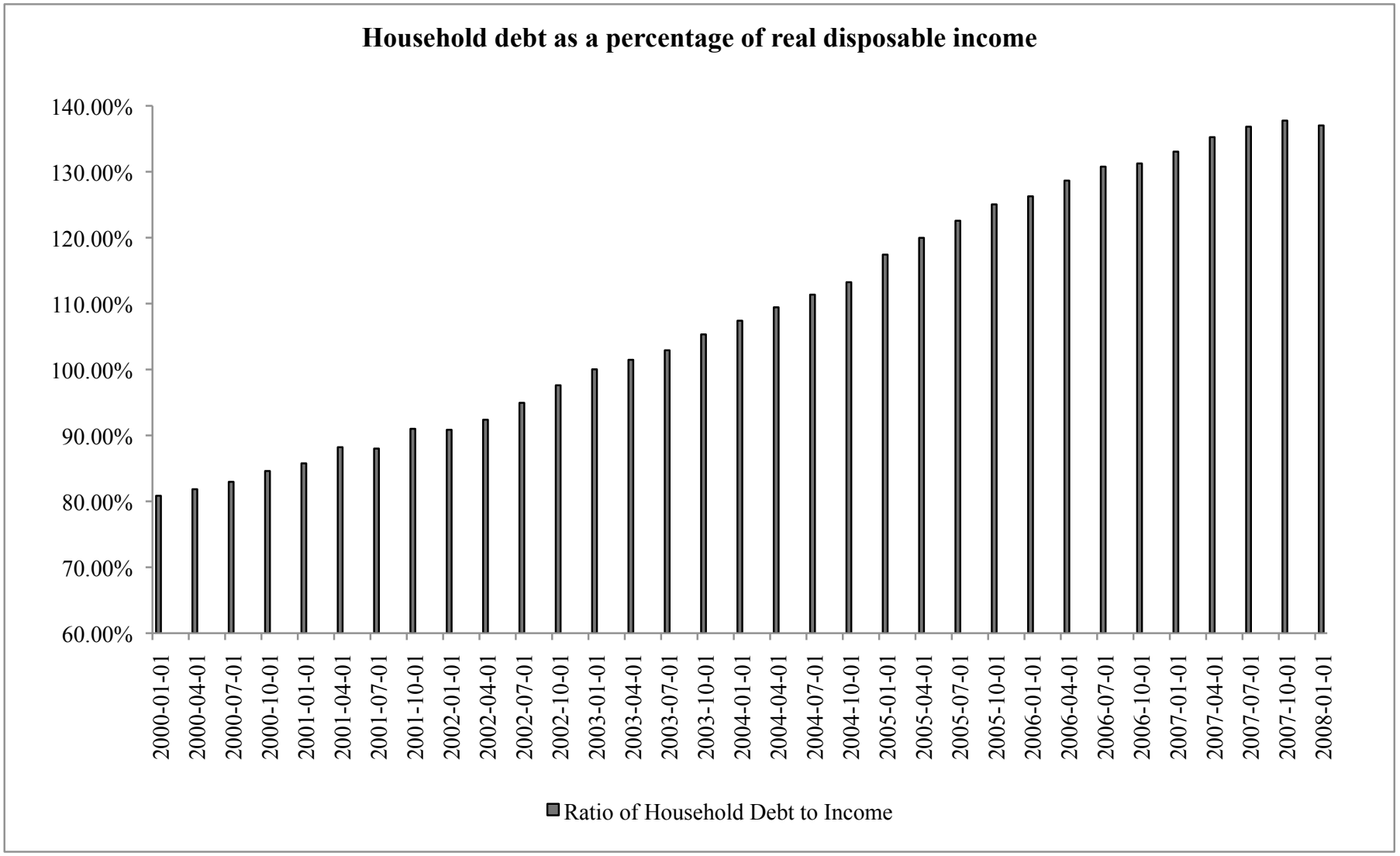
After 2001: Housing market was a key driver in recovery…



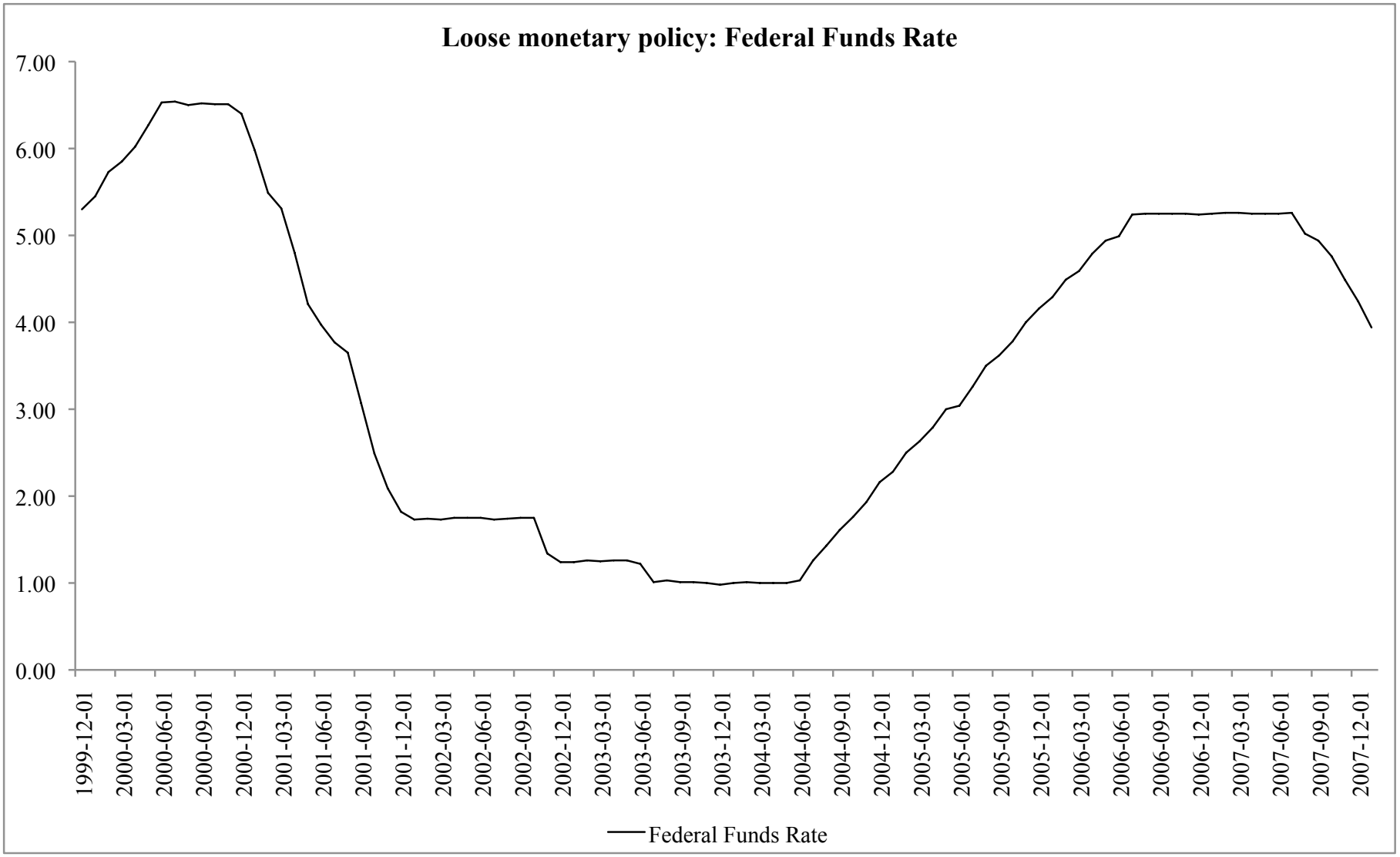
…and helped fuel 'wealth-driven' consumption…



…as household debt-to-income increased…



Loose monetary policy…



Financial Innovation & the trigger for the crisis

Financial Innovation:

- 'Great Moderation' period - perceived low volatility as a result of "structural change and improved macroeconomic policy" (Bernanke, 2004), which gave rise to an underestimation of risk
- This underestimation of risk was coupled with loose monetary policy.
- Low interest rates allowed lenders to target 'riskier' segments of the market e.g. subprime and alt-A loans
- Subprime loans were re-packaged as mortgage-backed securities and sold as securities to investors, which allowed lenders to remove 'subprime' risky loans from their balance sheets & acquire additional lending

Trigger:

From Astley et al. (2009), once the Federal Reserve began increasing interest rates, delinquency rates on home loans began to increase, as subprime borrowers struggled to meet mortgage repayments.

This led to the unravelling of the housing market which was further aggravated by the complex nature of financial innovation. Financial institutions struggled to assess their exposure to the losses, and began hoarding liquidity.

Benchmark macroeconomic model: DSGE Model

Dynamic **S**tochastic **G**eneral **E**quilibrium model

- Dynamic: study how the economy evolves
- Stochastic: the economy is affected by random shocks
- General Equilibrium: households, firms and government interact in markets that clear every period

Three agents exist in the model

- Households
- Firms
- Monetary Authority

As in Christiano, Eichenbaum & Evans (2005), "*Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy*"

Nominal rigidities – price and wage stickiness

Adjustment costs – habit parameter, cost adjustment function

DSGE Models & Central Banks

Central Banks increasingly rely on DSGE model for policy analysis and prescriptions. According to Tovar (2008) "DSGE Models and Central Banks"

- Provide a coherent framework for policy analysis
- Identify the source of fluctuations
- Answer questions about structural changes
- Forecast and predict the effect of policy changes
- Perform counterfactual experiments

The following central banks have developed their own respective DSGE models for policy analysis:

- European Central Bank
- Federal Reserve
- Bank of England
- Bank of Japan
- IMF

The Log-Linearized Model: Supply Side

Aggregate production function:

$$y_t = \phi_p\left(\alpha k_t^s + (1-\alpha) l_t + \varepsilon_t^a\right)$$

where y_t is GDP, k_t^s represents capital in use, and l_t is labor input, ϕ_p is fixed costs in production, α is share of captial in production and ε_t^a is total factor productivity

Total factor productivity is assumed to evolve according to the following first order autoregressive process with an i.i.d-normal error term:

$$\varepsilon_t^a = \rho_a \ \varepsilon_{t-1}^a + \eta_t^a$$

The Log-Linearized Model: Demand Side

The aggregate resource constraint is given as:

$$y_t = c_y c_t + i_y i_t + z_y z_t + \varepsilon_t^g$$

where y_t is GDP, c_t is consumption, i_t is investment, z_t is capital utilisation, and ε_t^g is exogenous spending. c_y, i_y, and z_y represent the steady states of consumption, investment, and capital utilisation.

Exogenous spending is assumed to follow a first-order autoregressive process with an i.i.d. normal error term:

$$\varepsilon_t^g = \rho_g \, \varepsilon_{t-1}^g + \eta_t^g + \rho_{ga} \, \eta_t^a$$

Exogenous spending has two components: an element relating to government spending and an element relating to productivity

The Log-Linearized Model: Consumption

Consumption is determined by:

$$c_t = c_1 c_{t-1} + (1 - c_1) E_t c_{t+1} + c_2 (l_t - E_t l_{t+1}) - c_3 (r_t - E_t \pi_{t+1} + \varepsilon_t^b)$$

where r_t is the interest rate on a one-period bond and π_t is the inflation rate.

ε_t^b is a 'risk premium' shock. c_1, c_2, c_3 are constant parameters, which are functions of deeper structural parameters

The risk premium shock is assumed to follow a first order autoregressive process with an i.i.d. normal error term as follows:

$$\varepsilon_t^b = \rho_b \, \varepsilon_{t-1}^b + \eta_t^b$$

The risk premium shock determines the willingness of households to hold the one period bond. It can also be seen as a type of preference shock that influences the short-term consumption-saving decision.

The Log-Linearized Model: Investment

Investment is determined by:

$$i_t = i_1 i_{t-1} + (1 - i_1) E_t i_{t+1} + i_2 q_t + \varepsilon_t^i$$

where

$$q_t = q_1 E_t q_{t+1} + \left(1 - q_1\right) E_t r_{t+1}^k - \left(r_t - \pi_{t+1} + \varepsilon_t^b\right)$$

and

$$k_t = k_1 k_{t-1} + \left(1 - k_1\right) i_t + k_2 \varepsilon_t^i$$

Investment depends of lagged investment, expected future investment, the real value existing capital stock and an investment-specific technology shock process.

The investment specific technology shock is assumed to follow a first-order Autoregressive process with an i.i.d normal error term:

$$\varepsilon_t^i = \rho_i \ \varepsilon_{t-1}^i + \ \eta_t^i$$

The Log-Linearized Model: Prices

Price inflation is determined by the New Keynesian Phillips curve:

$$\pi_t = \pi_1 \pi_{t-1} + \pi_2 E_t \pi_{t+1} - \pi_3 \mu_t^p + \varepsilon_t^p$$

where $$\mu_t^p = mpl_t - w_t = \alpha\left(k_t^s - l_t\right) + \varepsilon_t^a - w_t$$

The price mark - up $\left(\mu_t^p\right)$ is equal to the difference between the marginal product of labour and the real wage. The marginal product of labour is a positive function of the capital - labour ratio and TFP

The price mark-up shock is assumed to follow an ARMA(1,1) process with an i.i.d normal price mark up shock.

$$\varepsilon_t^p = \rho_p \varepsilon_t^p + \eta_t^p - \mu_p \eta_{t-1}^p$$

The inclusion of the MA term is designed to capture high-frequency fluctuations in inflation

The Log-Linearized Model: Wages

As with prices, wages are assumed to be 'sticky':

$$w_t = w_1 w_{t-1} + (1 - w_1)(E_t w_{t+1} + E_t \pi_{t+1}) - w_2 \pi_t + w_3 \pi_{t-1} - w_4 \mu_t^w + \varepsilon_t^w$$

where

$$\mu_t^w = w_t - mrs_t = w_t - \left(\sigma_l l_t + \frac{1}{1-\lambda}(c_t - \lambda c_{t-1}) \right)$$

The real wage is a function of expected and past real wage, current and past inflation, the wage mark-up and a wage mark-up disturbance term.

Wages are assumed to be 'sticky', and equal the difference between the real wage and the marginal rate of substitution (mrs). Sticky wages will gradually adjust so the real wage equates with the cost and benefits of working.

The wage mark-up shock is assumed to follow an ARMA(1,1) process with an i.i.d normal error term:

$$\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w - \mu_w \eta_{t-1}^w$$

The Log-Linearized Model: Monetary Policy

Finally, the model is closed by adding the following monetary rule. The Central Bank sets short term interest rates as follows:

$$r_t = \rho r_{t-1} + (1-\rho)\left[r_\pi \pi_t + \mathrm{r_y}\left(y_t - y_t^p\right)\right] + r_{\Delta y}\left[\left(y_t - y_t^p\right) - \left(y_{t-1} - y_{t-1}^p\right)\right] + \varepsilon_t^r$$

The interest rate depends on last periods interest rate, inflation, the output gap (defined as the difference between output and potential output) and the change in the output gap.

There is a monetary policy shock process which is assumed to follow an autogressive process with an i.i.d normal error term:

$$\varepsilon_t^r = \rho_R \varepsilon_{t-1}^r + \eta_t^{\mathrm{r}}$$

Bayesian Estimation Methodology

Bayes theorem:

$$p(\theta \mid y) \propto p(\theta) \text{ x } L(\theta \mid y)$$

where

$p(\theta) =$ prior information

$L(\theta \mid y) =$ likelihood function

$p(\theta \mid y) =$ posterior

From An & Schorfheide (2006), "*Bayesian Analysis of DSGE Models*"

1. Solve the linear rational expectations model
2. Transform the model in to State Space form by adding observation equations
3. Kalman filter to evaluate the likelihood function
4. Combine this likelihood function with the prior distribution of the parameters to form the posterior density function
5. Derive the posterior distribution of parameters using a Monte Carlo Markov Chain algorithm – or the Metropolis-Hastings algorithm

Dataset

Model Sample: 1947.1 to 2007.4
Data Source - FRED

Real GDP	Billions Chained 1996 Dollars
Consumption	Nominal Personal Consumption Expenditures
Investment	Fixed Private Domestic Investment
Inflation Rate	Implicit Price Deflator of GDP expressed quarterly
Interest Rate	Federal Fund Rate expressed quarterly
Real Wage	Hourly compensation for the NFB sector
Hours Worked	Hours for the NFB sector

Aggregate real variables are expressed per capita, deflated using the GDP deflator, and expressed as 100 times log. All variables are seasonally adjusted

Prior Selection

Prior's are set in accordance with the literature:

> Smets & Wouters (2003, 2007), "*Shocks & Frictions in US Business Cycles: A Bayesian DSGE Approach*"

Prior selection:

(a) Fixed parameters:

- (a) Example: Discount rate – calibrated at 0.99 – implies an annual steady state real interest rate of 4%
- (b) Example: Depreciation rate – calibrated at 0.025 per quarter – implies annual depreciation on capital equal to 10

(b) Remaining parameters:

- (a) Need to provide assumptions regarding the prior distribution of the remaining parameters
- (b) Example: shock processes are assumed to be distributed as an inverted Gamma distribution to guarantee a positive variance

Prior and Posterior Parameters

		Prior Distribution			Posterior Distribution		
		Distribution	Mean	Standard Deviation	Mean	5%	95%
Elasticity of Captial Adjustment Cost Function	csadjcost	Normal	4	1.5	7.1978	5.6514	8.7303
Elasticity of Intertemporal Subsitution	csigma	Normal	1.5	0.375	1.2857	1.0802	1.4924
Habit Parameter	chabb	Beta	0.7	0.1	0.8128	0.749	0.8778
Degree of Wage Stickiness	cprobw	Beta	0.5	0.1	0.7817	0.7273	0.8376
Elasticity of labour supply w.r.t. Real wage	csigl	Normal	2	0.75	2.3801	1.5092	3.2023
Degree of Price Stickiness	cprobp	Beta	0.5	0.1	0.5489	0.5	0.5928
Wage Indexation	cindw	Beta	0.5	0.15	0.5373	0.3864	0.6757
Inflation Indexation	cindp	Beta	0.5	0.15	0.2508	0.1269	0.3662

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Elasticity of the Capital Utilisation Adjustment Cost Function	czcap	Beta	0.5	0.15	0.6065	0.483	0.7349
Share of Fixed Costs in Production	cfc	Normal	1.25	0.125	1.6888	1.5714	1.8224
Policy Controlled Interest Rate in Response to Inflation	crpi	Normal	1.5	0.25	1.8963	1.6601	2.1347
Degree of Interest Rate Smoothing	crr	Beta	0.75	0.1	0.8808	0.8562	0.9051
Policy Controlled Interest Rate in Response to Output Gap	cry	Normal	0.125	0.5	0.1238	0.0852	0.163
Policy Controlled Interest Rate in Response to the Output Gap change	crdy	Normal	0.125	0.5	0.1014	0.0723	0.1311

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Prior and Posterior Shock Process

		Prior Distribution			Posterior Distribution		
		Distribution	Mean	Standard Deviation	Mean	5%	95%
Shock Processes							
Total Factor Productivity	ea	Inverse Gamma	0.1	2	0.5552	0.5062	0.6049
Investment Specific Technology	eqs	Inverse Gamma	0.1	2	0.5499	0.4687	0.6297
Risk Premium	eb	Inverse Gamma	0.1	2	0.3624	0.3145	0.4112
Exogenous Spending	eg	Inverse Gamma	0.1	2	0.6627	0.6127	0.712
Price Mark-Up	ep	Inverse Gamma	0.1	2	0.2145	0.1812	0.2494
Wage Mark-Up	ew	Inverse Gamma	0.1	2	0.2457	0.2172	0.2737
Monetary Policy Shocks	em	Inverse Gamma	0.1	2	0.2274	0.2082	0.2461
Autoregressive Parameters of the Shock Processes							
Total Factor Productivity	crhoa	Beta	0.5	0.2	0.976	0.9666	0.9858
Risk Premium	crhob	Beta	0.5	0.2	0.1587	0.0489	0.262
Exogenous Spending	crhog	Beta	0.5	0.2	0.958	-0.9422	0.9741
Investment Specific Technology	crhoqs	Beta	0.5	0.2	0.6553	0.5759	0.7298
Monetary Policy Shocks	crhoms	Beta	0.5	0.2	0.2188	0.1257	0.3114
Price Mark-Up	crhopinf	Beta	0.5	0.2	0.9773	0.9609	0.9946
Wage Mark-Up	crhow	Beta	0.5	0.2	0.9656	0.9459	0.9865

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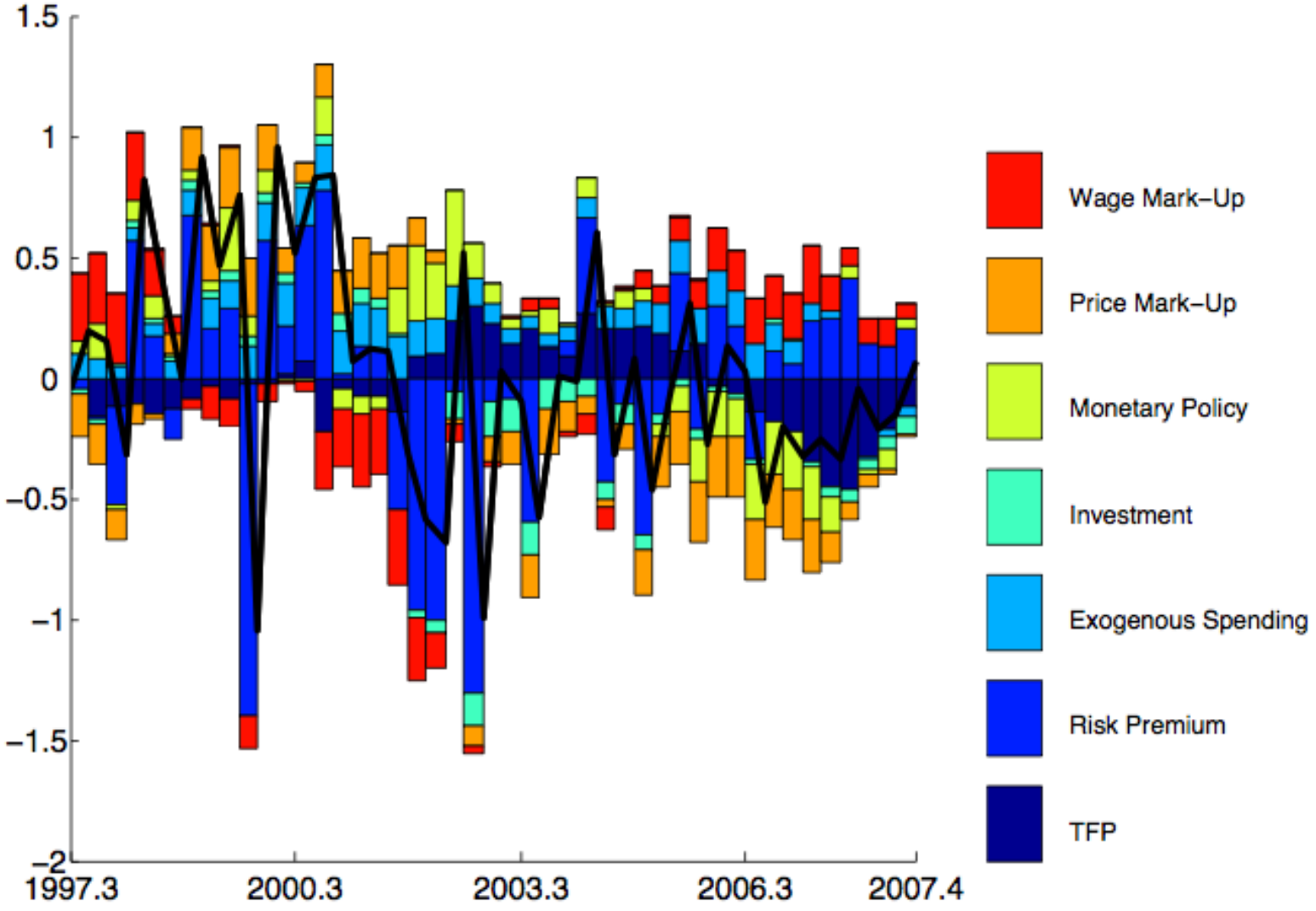
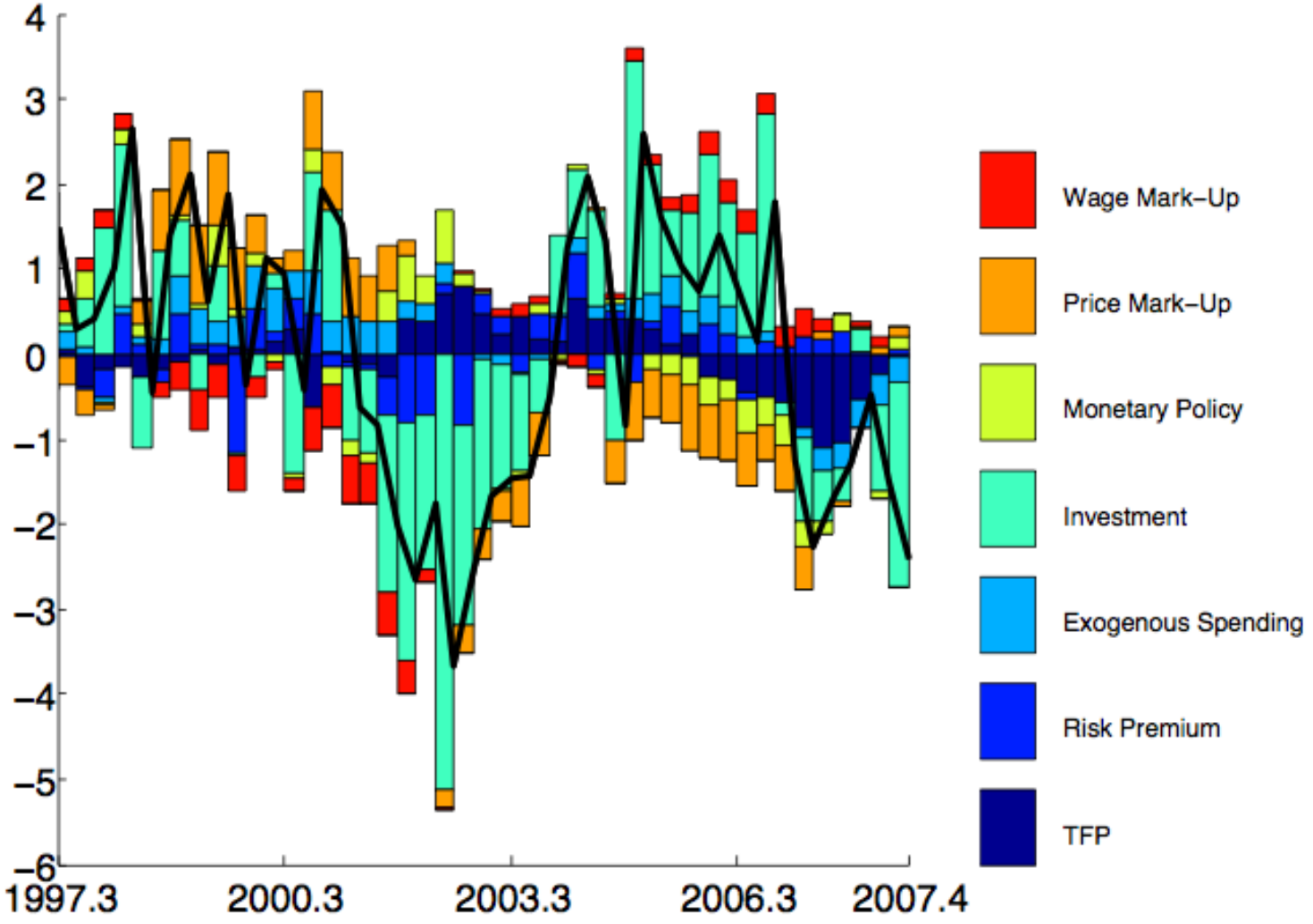
Variance Decomposition

	Variance Decomposition - In Percent (%)						
	TFP Shock	**Risk Premium Shock**	**Exogenous Spending Shock**	**Investment Specific Shock**	**Monetary Policy Shock**	**Price Mark-Up Shock**	**Wage Mark-Up Shock**
Output	15.85	26.61	25.49	19.7	6.52	2.89	2.94
Consumption	7.47	71.48	0.95	0.98	10.81	2.49	5.82
Investment	4.95	6.08	1.59	78.27	4.31	3.15	1.65
Inflation	4.61	0.59	0.86	2.39	6.88	46.27	38.4
Interest Rate	7.06	5.02	3.35	10.94	12.25	29.71	31.67
Hours Worked	6.36	6.03	10.31	15.11	7.15	13.75	41.29
Real Wage	11.28	0.71	0.13	1.77	1.01	42.66	42.44

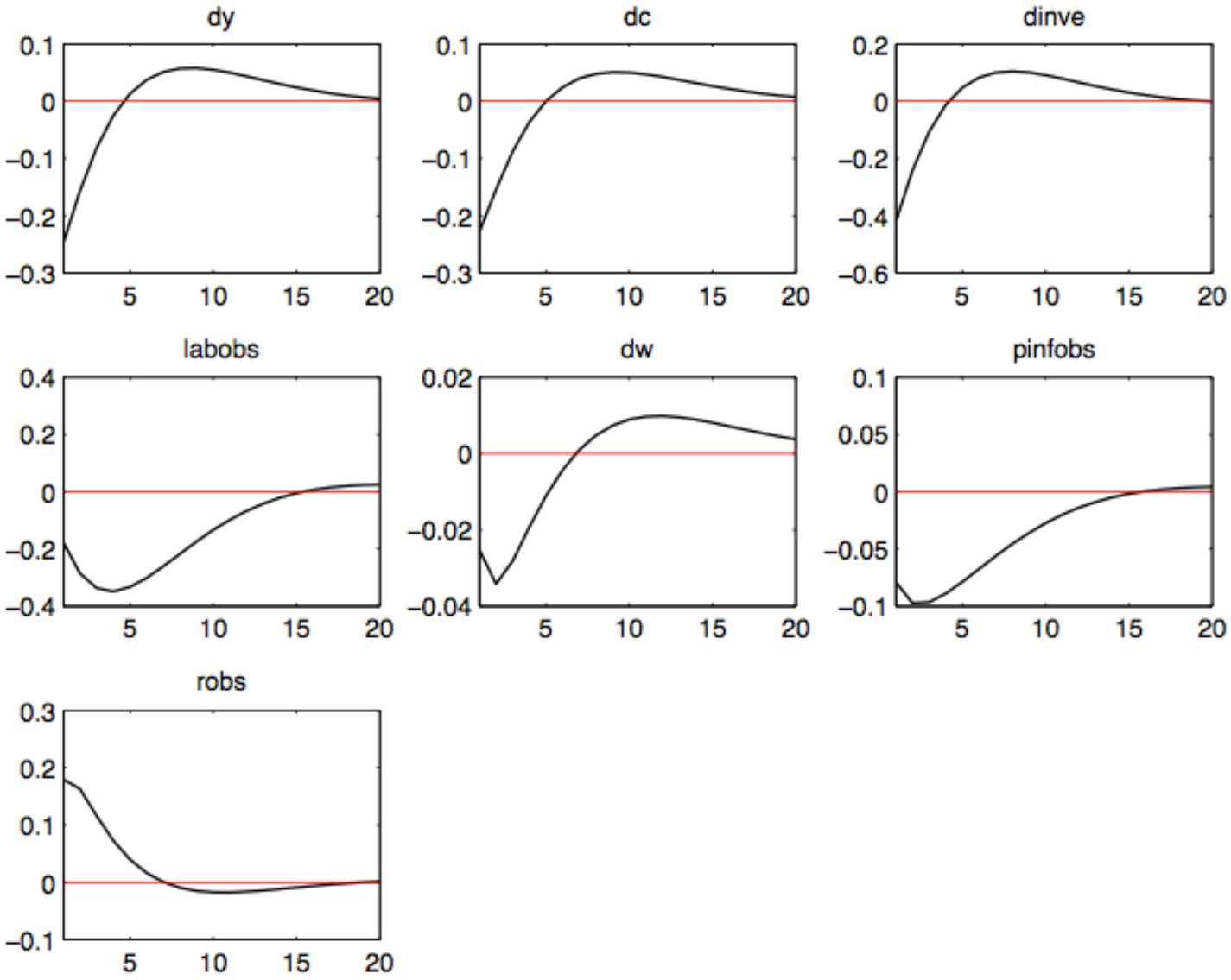
Historical Shock Decomposition: Consumption



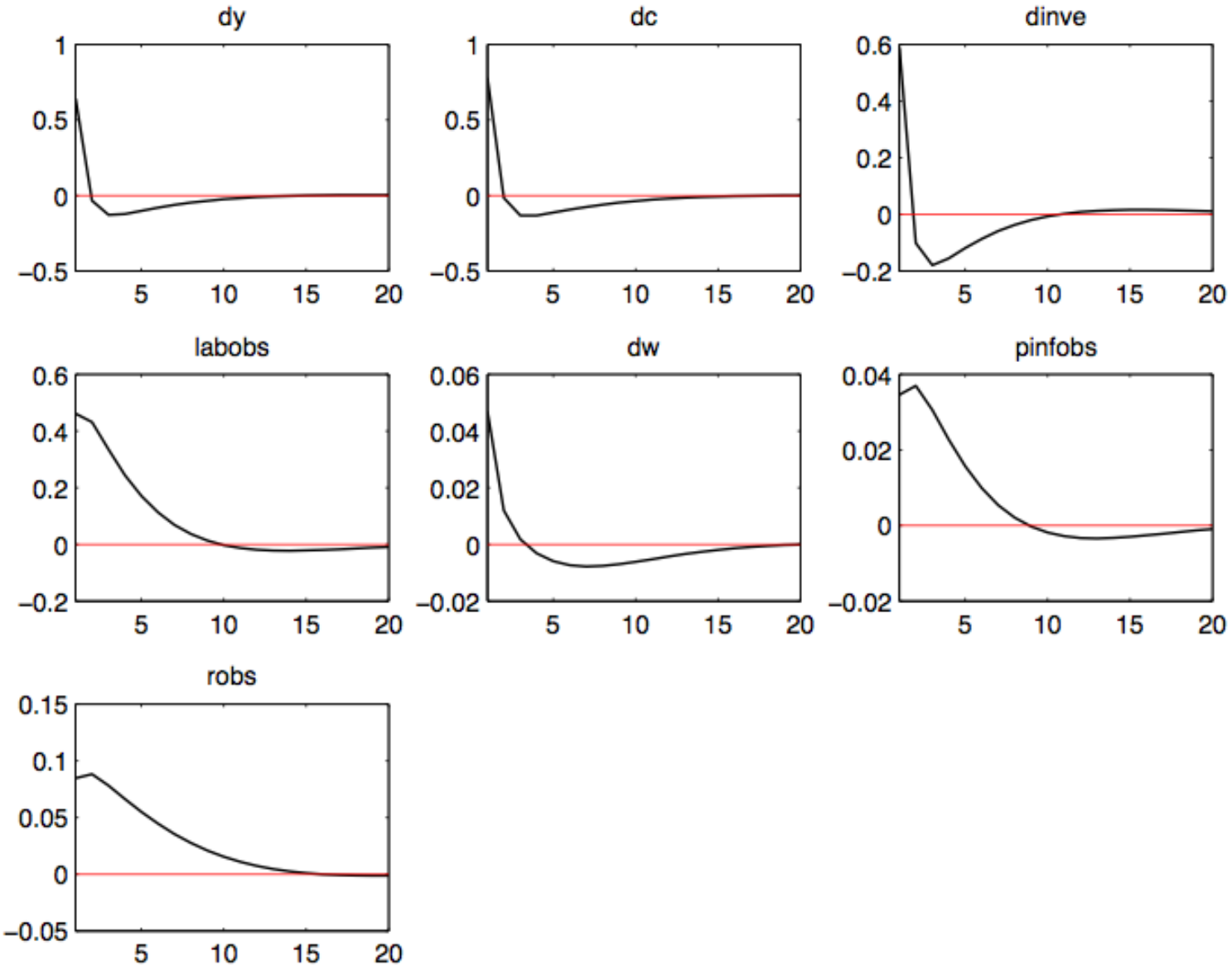
Historical Shock Decomposition: Investment



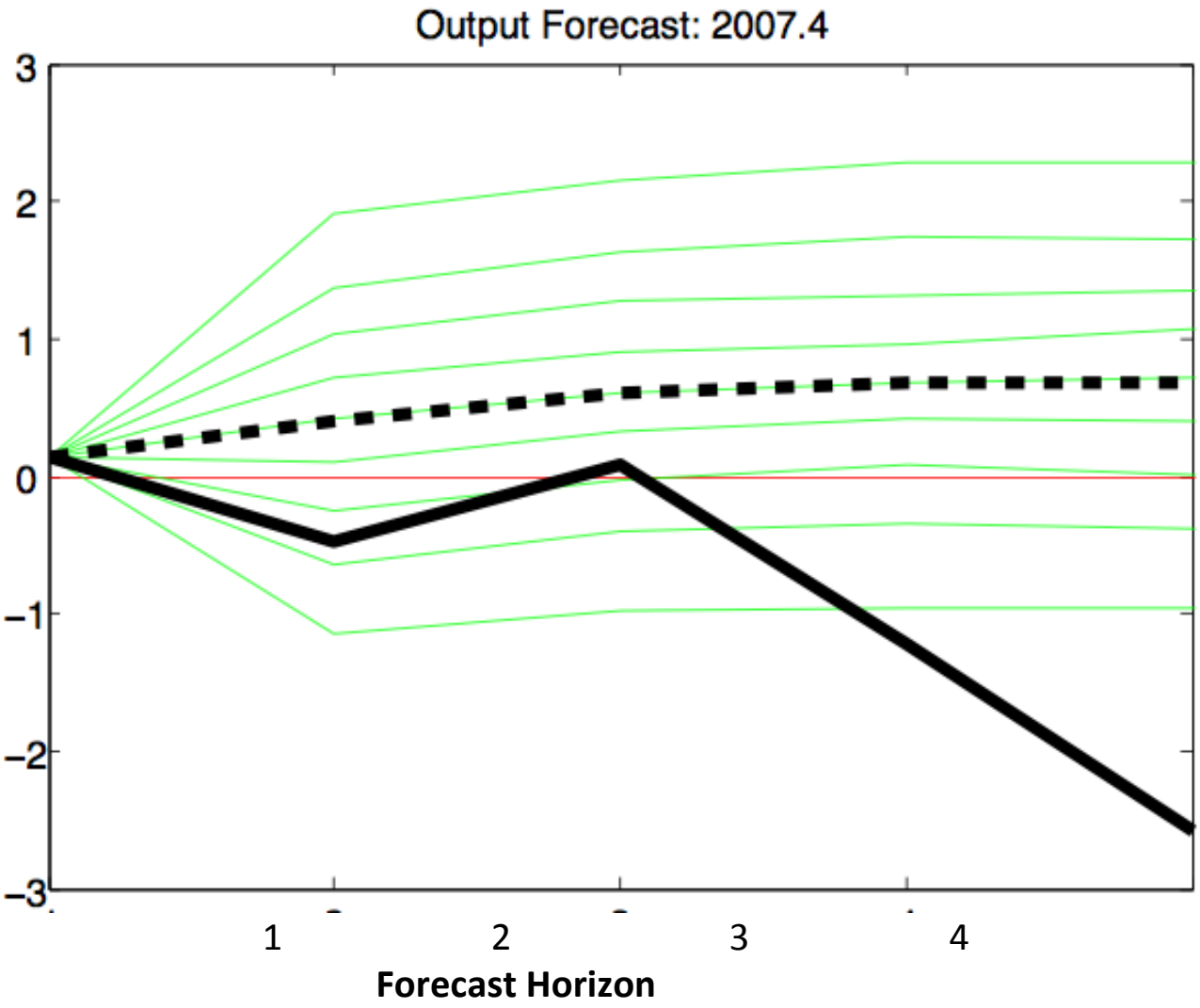
Impulse Response Functions: Monetary Policy Shock



Impulse Response Functions: Risk Premium Shock

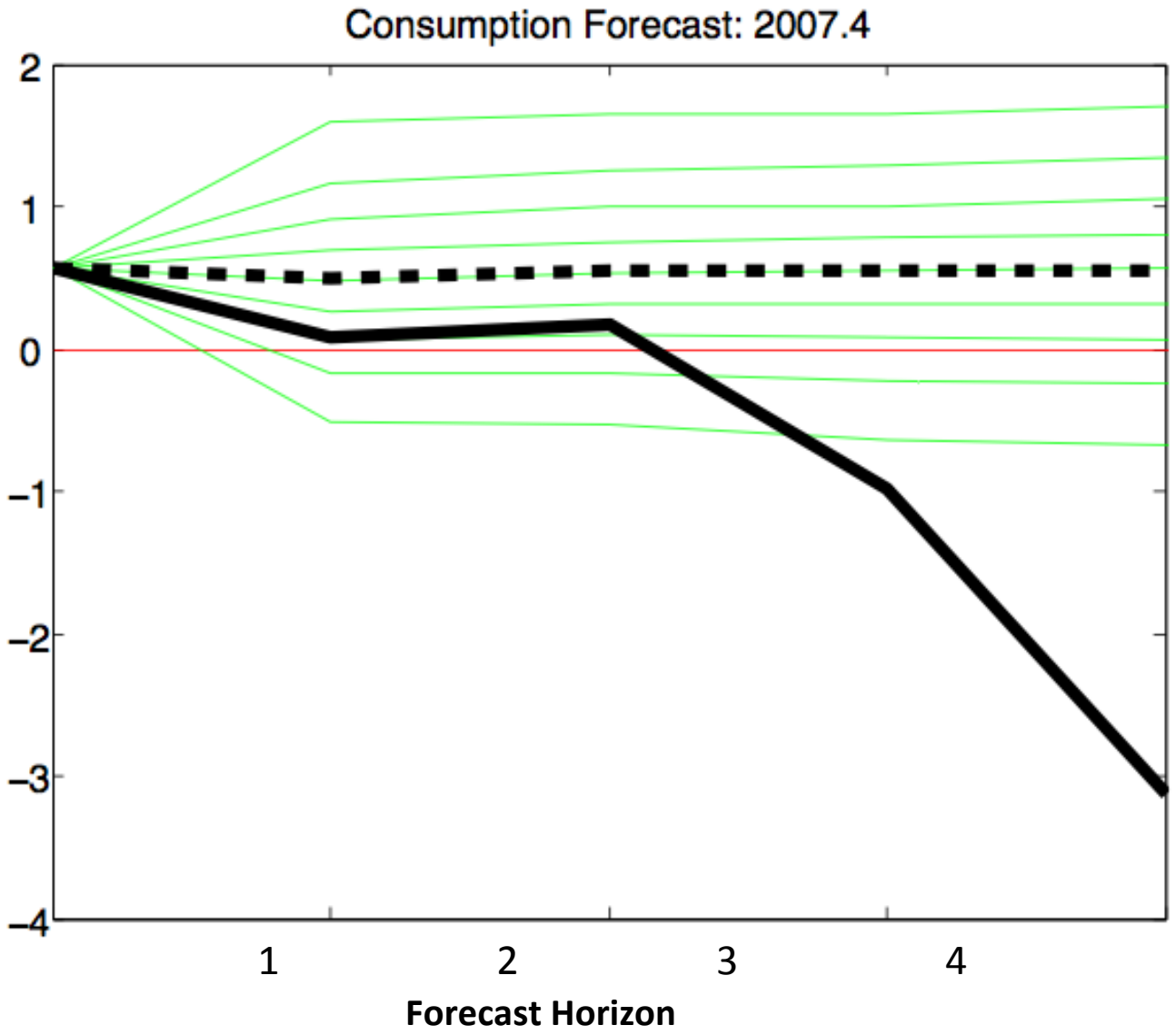


Forecasting performance: Output



The *solid* line represents the actual time series observed and the *dashed* line represents the DSGE model forecast. The *green* lines represent the 90% confidence intervals

Forecasting performance: Consumption



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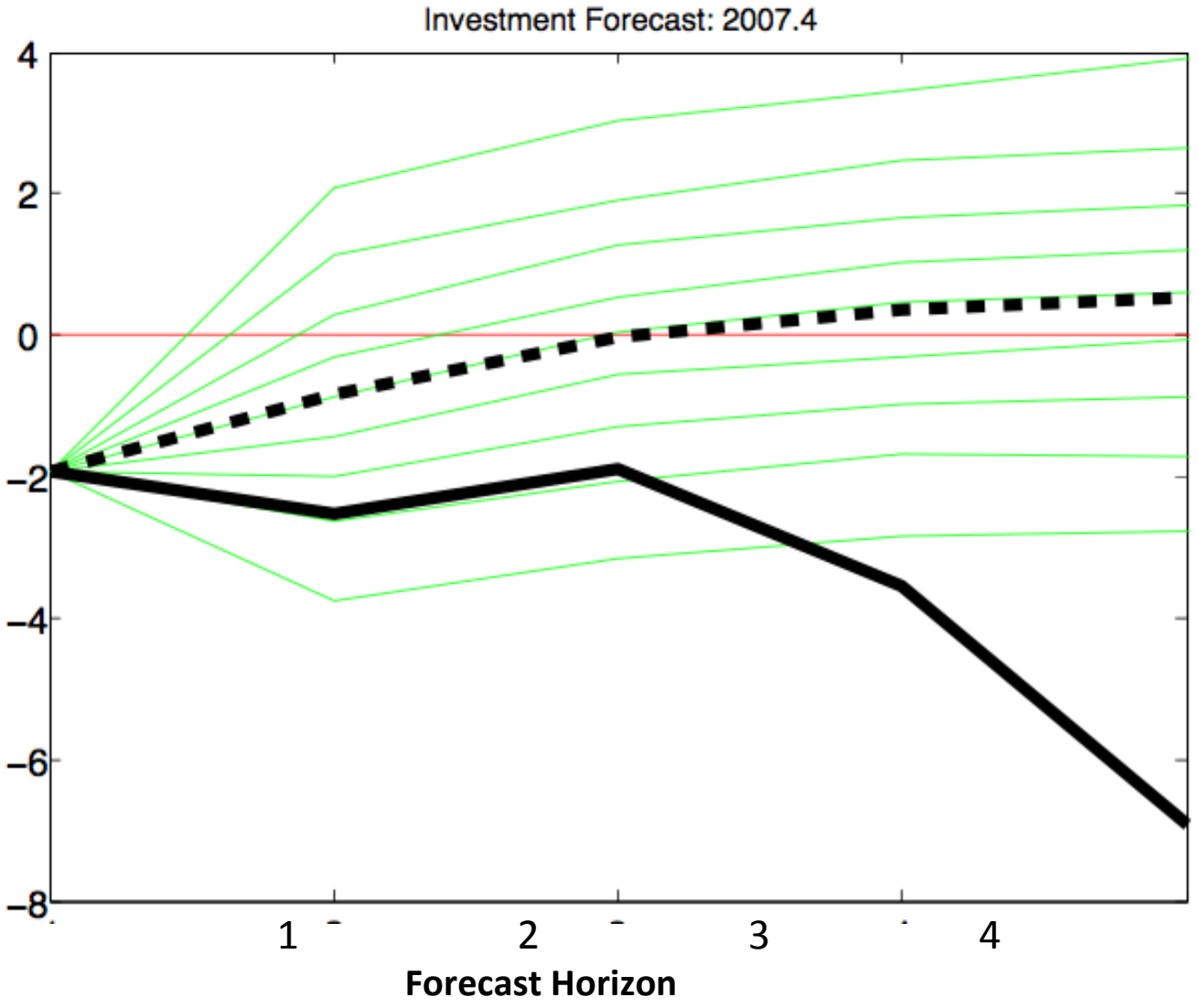
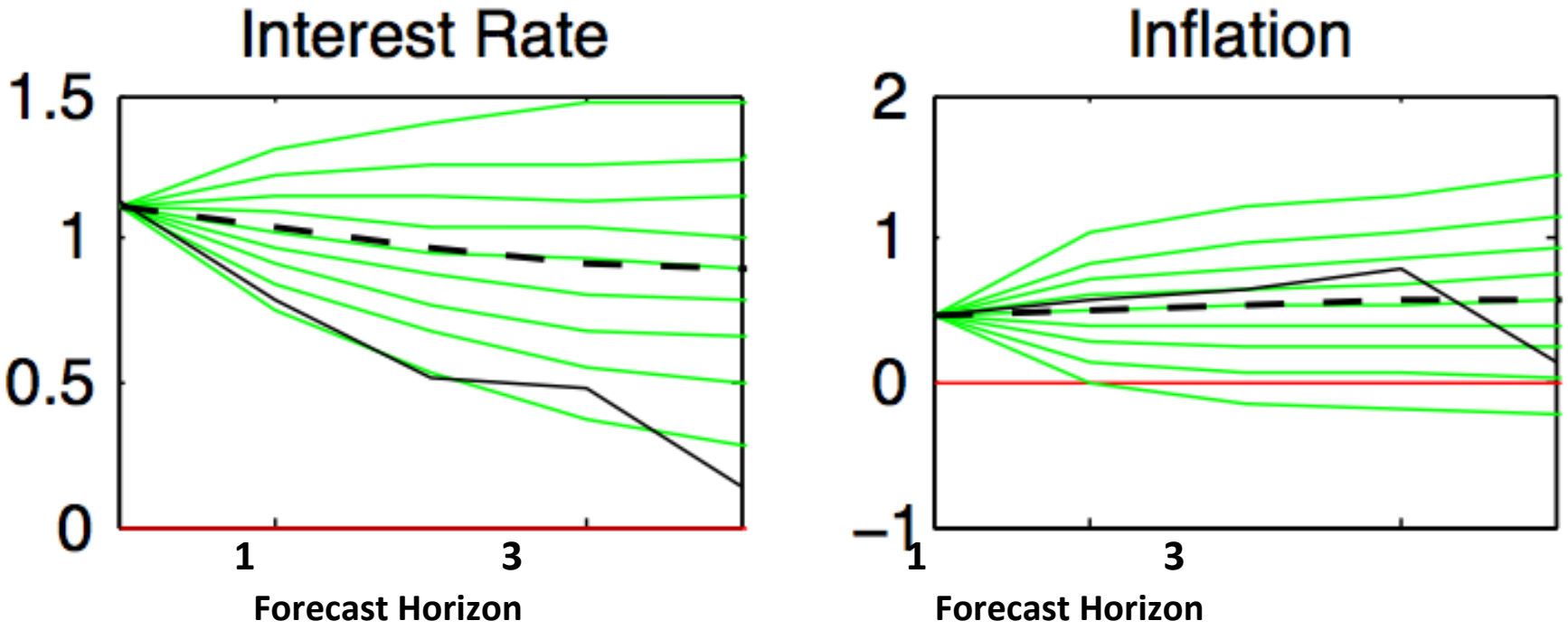
Forecasting performance: Investment



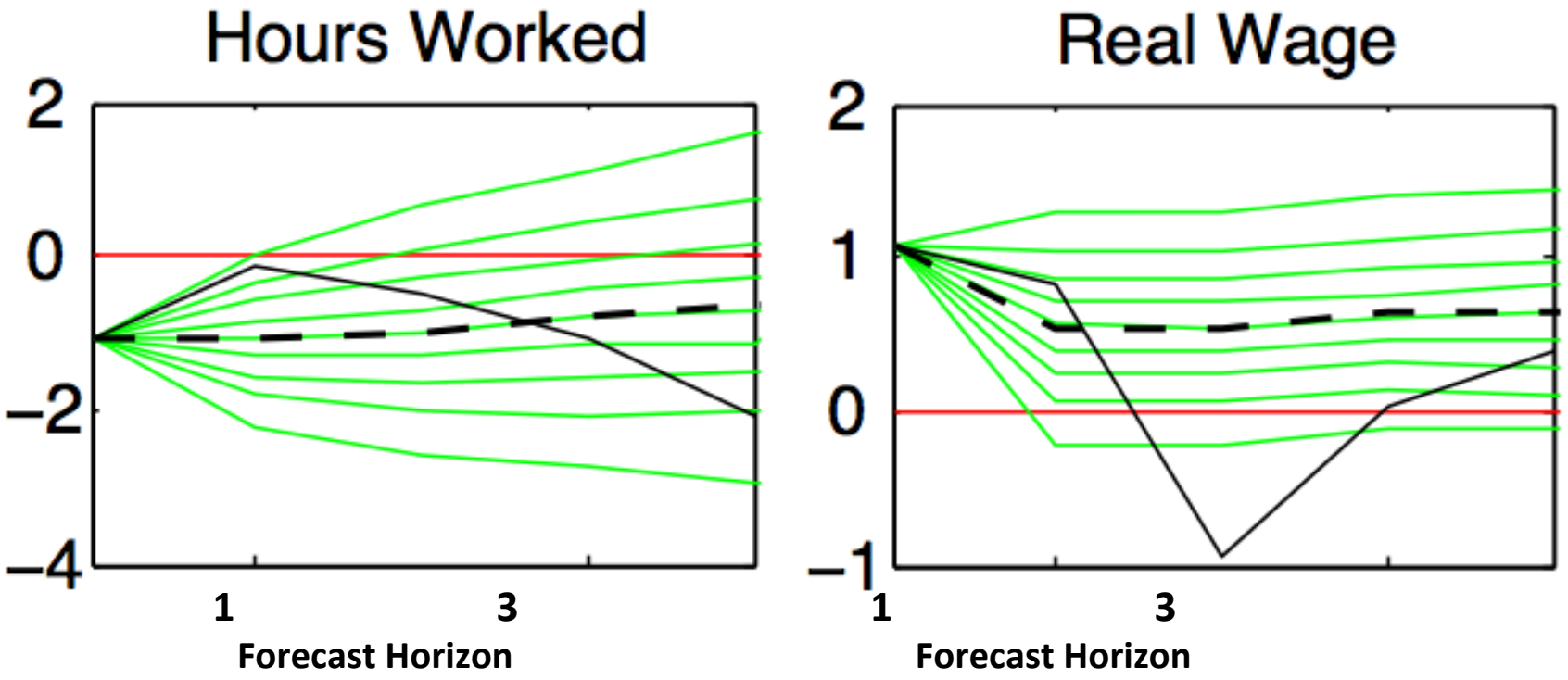
The *solid* line represents the actual time series observed and the *dashed* line represents the DSGE model forecast. The *green* lines represent the 90% confidence intervals

Forecasting performance: Interest Rate & Inflation



The *solid* line represents the actual time series observed and the *dashed* line represents the DSGE model forecast. The *green* lines represent the 90% confidence intervals

Forecasting Performance: Hours Worked & Real Wage



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Model Conclusions

- This research examined whether the Smets and Wouters benchmark DSGE model was able to capture the financial crisis in the US

- Forecasts by DSGE models failed to acknowledge that a recession was imminent and gave no indication of any form that a crisis would ensue.

- Exogenous shock process do not give us sufficient information regarding the specific causes and sources of shocks.

- It can be argued the assumptions made by DSGE models are too simplistic (homogenous agents, complete financial markets, ignoring nonlinearities etc.)

Therefore, the challenge is to explicitly model the economy's financial instability as residing in its financial structure, rather than in exogenous shocks in the real sector coupled with price rigidites, as in Smets & Wouters 2007.

Augmenting the DSGE Model

The current paradigm is missing key elements:

1. Housing Market
2. Banking Sector

Going forward, the inclusion of the above elements will be an essential component in understanding fluctuations in the macroeconomy.

Goodhart et al. (2009) is going a step further & is attempting to include the possibility of default within the model frameworld.

Bezemer (2009) "*Why some economists could see the crisis coming"*, undertook a study of the models used by economists who did foresee the crisis.

Central to their thinking was a 'flow-of-funds' model where there was accounting of:

- Financial flows (credit, interests, profits & wages)
- Stocks (debt & wealth)
- Sharp distinction between the real economy and the financial sector

Thank you for your time!

Questions & Suggestions...