Accounting for Post-Crisis Inflation: A Retro Analysis*

Online Appendix — NOT FOR PUBLICATION

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Abstract

Why was there no deflation and what accounts for inflation after 2008? Is the missing deflation puzzle an indictment of Phillips-curve-type analyses, as Hall (2011) has argued, or is all good and well, if one fixes the model with the appropriate features, as Del Negro, Giannoni and Schorfheide (2015) have found? To shed light on this issue and in order to avoid confounding the answer with post-crisis model adaptations, we provide a "retro analysis" and employ the original benchmark Smets and Wouters (2007) model. We show that this model implies that shocks to price and wage markups alone are nearly enough to account for inflation before 2008, and that they do so substantially post 2007 as well. The Phillips curve tradeoff is weak after 2007 according to the model, but also before 2007. We thus argue that the asserted post-crisis model failures were visible pre-crisis already. We extend the retro analysis by a discussion and novel analysis of zero lower bound

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considerations, by allowing for shocks to the inflation target, by allowing for financial frictions and other recent extensions to the original Smets and Wouters (2007) framework, without much altering our key insights.

Appendix A. The model

The model is described in detail in Smets and Wouters (2007) . This is a review, for convenience. Households maximize the sum of the discounted flow of per-period utility with respect to a consumption good, labor, investment, effective capital and capital utilization. The utility function has external habits. Households can transfer resources in the future by investing in physical capital or by buying government bonds. Capital adjustments come at a cost that depends on the investment growth.

Final good producers use a continuum with mass 1 of imperfectly substitutable intermediate goods to produce a final consumption good. They solve a static problem in which they maximize profits subject to a production function and a zero-profit condition. They take the price of the final good and of the intermediate goods as given. Intermediate firms maximize the sum of the discounted flow of profits assuming a Calvo price setting with partial indexation to inflation subject to the demand of intermediate goods by the final good producers. They produce intermediate goods using capital and labor.

Households provide labor to the labor unions. Labor unions sell labor to labor packers that resell the labor to the intermediate firms. Labor packers operate in a competitive market. They buy labor from unions and repackage it according to a Dixit-Stiglitz aggregator. They maximize profits taking as given the intermediate wage and the final wage and subject to a zero profit condition. Labor unions maximize the sum of the discounted flow of profits assuming a Calvo price setting with partial indexation to inflation subject to the demand of labor by the labor packers.

Finally, a Taylor rule and a stochastic process for government expenditure close the model. Following Smets and Wouters, the government expenditure depends on its lag, an exogenous shock and the technological shock.

Appendix A.1. Household

The Euler equation is given by

$$\hat{c}_t = \frac{1}{1+h/\gamma}E_t\hat{c}_{t+1} + \frac{h/\gamma}{1+h/\gamma}\hat{c}_{t-1} - \frac{1-h/\gamma}{\sigma_c(1+h/\gamma)}(\hat{R}_t - E_t\hat{\pi}_{t+1}) - \frac{(\sigma_c-1)(w_*^h L_*/c_*)}{\sigma_c(1+h/\gamma)}(E_t\hat{L}_{t+1} - \hat{L}_t) + b_t^2 \tag{A.1}$$

where $\hat{c}_t$ is consumption, $\hat{L}_t$ is labor supply, $\hat{R}_t$ is the nominal interest rate, $\hat{\pi}_t$ is inflation, and b_t^2 is an exogenous process. Variables are expressed in log deviations from the steady state. The investment is characterized by the following equation

$$\hat{i}_t = \frac{1}{1+\bar{\beta}\gamma}(\hat{i}_{t-1} + \hat{\beta}\gamma E_t\hat{i}_{t+1} + \frac{1}{\gamma^2 S''}\hat{Q}_t) + \hat{\mu}_t \tag{A.2}$$

where μ_t is an exogenous process affecting the rate of transformation between consumption and installed capital. The relationship between the value of capital, Q_t, and the level of investment, i_t, is described by the following equation

$$\hat{Q}_t = \frac{\sigma_c(1+h/\gamma)}{1-h/\gamma}\hat{b}_t^2 - \hat{R}_t + E_t\hat{\pi}_{t+1} + \frac{r_*^k}{r_*^k+1-\delta}E_t\hat{r}_{t+1}^k + \frac{1-\delta}{r_*^k+1-\delta}E_t\hat{Q}_{t+1} \tag{A.3}$$

where r_{t+1}^k is the rental rate of capital.

The household also chooses optimally the level of capital utilization, u_t

$$\hat{u}_t = \frac{r_*^k}{a''(1)}\hat{r}_t^k \tag{A.4}$$

The relationship between the stock of capital, $\bar{k}_t$, and the amount of capital rented out to firms, k_t, is given by

$$\hat{k}_t = \hat{u}_t + \hat{\bar{k}}_{t-1} \tag{A.5}$$

Finally, the evolution of the stock of capital is characterized by the following equation

$$\hat{\bar{k}}_t = (1 - \frac{i_*}{\bar{k}_*})\hat{\bar{k}}_{t-1} + \frac{i_*}{\bar{k}_*}\gamma^2 S''(\gamma)\mu_t + \frac{i_*}{\bar{k}_*}\hat{i}_t \tag{A.6}$$

Appendix A.2. Firms

The production function is given by

$$\hat{y}_t = \Phi \hat{Z}_t + \alpha \Phi \hat{k}_t + (1-\alpha)\Phi \hat{L}_t \tag{A.7}$$

where y_t is the level of output, Φ is a fixed cost in production, Z_t is a stochastic process describing the evolution of technology. From the optimality conditions, firms have the same capital-labor ratio:

$$\hat{k}_t = \hat{w}_t - \hat{r}_t^k + \hat{L}_t \tag{A.8}$$

where w_t is the real wage. Real marginal costs are given by

$$\hat{mc}_t = \alpha \hat{r}_t^k + (1-\alpha)\hat{w}_t - \hat{Z}_t \tag{A.9}$$

Finally, a Phillips curve described the evolution of inflation as a function of marginal costs and a price-markup exogenous process, $\lambda_{p,t}$

$$\hat{\pi}_t = \frac{(1-\zeta_p\bar{\beta}\gamma)(1-\zeta_p)}{(1+\bar{\beta}\gamma\iota_p)\zeta_p}\frac{1}{(\frac{y_*+\Phi}{y_*}-1)*curvp+1}\hat{mc}_t + \hat{\lambda}_{p,t} + \frac{\iota_p}{(1+\bar{\beta}\gamma\iota_p)}\hat{\pi}_{t-1} + \frac{\bar{\beta}\gamma}{(1+\bar{\beta}\gamma\iota_p)}E_t\hat{\pi}_{t+1} \tag{A.10}$$

Appendix A.3. Labor unions

Real wages evolve according to the following equation

$$(1+\bar{\beta}\gamma)\hat{w}_t - \hat{w}_{t-1} - \bar{\beta}\gamma E_t\hat{w}_{t+1} = \tag{A.11}$$

$$= \frac{(1-\zeta_w\bar{\beta}\gamma)(1-\zeta_w)}{\zeta_w}\frac{1}{(\lambda_w-1)*curvw+1}\left[\frac{1}{1-h/\gamma}\hat{c}_t - \frac{h/\gamma}{1-h/\gamma}\hat{c}_{t-1} + \nu_L\hat{L}_t - \hat{w}_t\right] \tag{A.12}$$

$$-(1+\bar{\beta}\gamma\iota_w)\hat{\pi}_t + \iota_w\hat{\pi}_{t-1} + \bar{\beta}\gamma E_t\hat{\pi}_{t+1} + \hat{\lambda}_{w,t} \tag{A.13}$$

where $\lambda_{w,t}$ is a wage-markup exogenous process.

Appendix A.4. Monetary Policy

The monetary policy is described by the following feedback rule

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)(\psi_1 \hat{\pi}_t + \psi_2(\hat{y}_t - \hat{y}_t^f)) + \psi_3(\hat{y}_t - \hat{y}_{t-1} - (\hat{y}_t^f - \hat{y}_{t-1}^f)) + ms_t \tag{A.14}$$

where $\hat{y}_t^f$ is the level of output under flexible prices and ms_t is an exogenous process driving a wedge between the Taylor-implied interest rate and $\hat{R}_t$

Appendix A.5. Aggregate resource constraints

The following equation described the aggregate resource constraint

$$\frac{c_*}{y_*}\hat{c}_t + \frac{i_*}{y_*}\hat{i}_t + \hat{g}_t + \frac{r_*^k k_*}{y_*}\hat{u}_t = \hat{y}_t \tag{A.15}$$

where $\hat{g}_t$ is a stochastic process describing the level of government spending.

Appendix A.6. Natural output level

The following equations describe the economy under flexible prices. The f subscript identifies variables under flexible prices.

Appendix A.6.1. Household under flexible prices

$$\hat{c}_t^f = \frac{1}{1+h/\gamma}E_t\hat{c}_{t+1}^f + \frac{h/\gamma}{1+h/\gamma}\hat{c}_{t-1}^f - \frac{1-h/\gamma}{\sigma_c(1+h/\gamma)}\hat{R}_t^f - \frac{(\sigma_c-1)(w_*^h L_*/c_*)}{\sigma_c(1+h/\gamma)}(E_t\hat{L}_{t+1}^f - \hat{L}_t^f) + b_t^2 \tag{A.16}$$

$$\hat{i}_t^f = \frac{1}{1+\bar{\beta}\gamma}(\hat{i}_{t-1}^f + \hat{\beta}\gamma E_t\hat{i}_{t+1}^f + \frac{1}{\gamma^2 S''}\hat{Q}_t^f) + \hat{\mu}_t \tag{A.17}$$

$$\hat{Q}_t^f = \frac{\sigma_c(1+h/\gamma)}{1-h/\gamma}\hat{b}_t^2 - \hat{R}_t^f + \frac{r_*^k}{r_*^k+1-\delta}E_t\hat{r}_{t+1}^{k,f} + \frac{1-\delta}{r_*^k+1-\delta}E_t\hat{Q}_{t+1}^f \tag{A.18}$$

$$\hat{u}_t^f = \frac{r_*^k}{a''(1)}\hat{r}_t^{k,f} \tag{A.19}$$

$$\hat{k}_t^f = \hat{u}_t^f + \hat{\bar{k}}_{t-1}^f \tag{A.20}$$

$$\hat{\bar{k}}_t^f = (1 - \frac{i_*}{\bar{k}_*})\hat{\bar{k}}_{t-1}^f + \frac{i_*}{\bar{k}_*}\gamma^2 S''(\gamma)\mu_t + \frac{i_*}{\bar{k}_*}\hat{i}_t^f \tag{A.21}$$

Appendix A.6.2. Firms under flexible prices

$$\hat{y}_t^f = \Phi\hat{Z}_t + \alpha\Phi\hat{k}_t^f + (1-\alpha)\Phi\hat{L}_t^f \tag{A.22}$$

$$\hat{k}_t^f = \hat{w}_t{}^f - \hat{r}_t^{k,f} + \hat{L}_t^f \tag{A.23}$$

$$0 = \alpha\hat{r}_t^k + (1-\alpha)\hat{w}_t^f - \hat{Z}_t \tag{A.24}$$

Appendix A.6.3. Labor unions under flexible prices

$$\hat{w}_t^f = \frac{1}{1-h/\gamma}\hat{c}_t{}^f - \frac{h/\gamma}{1-h/\gamma}\hat{c}_{t-1}^f + \nu_L\hat{L}_t^f \tag{A.25}$$

Appendix A.6.4. Aggregate resource constraints under flexible prices

$$\frac{c_*}{y_*}\hat{c}_t^f + \frac{i_*}{y_*}\hat{i}_t^f + \hat{g}_t^f + \frac{r_*^k k_*}{y_*}\hat{u}_t^f = \hat{y}_t^f \tag{A.26}$$

Appendix A.7. Exogenous processes

Finally, the exogenous variables in the model are described by AR(1) processes

$$Z_t = \rho_Z Z_{t-1} + e_Z \tag{A.27}$$

$$b_t^2 = \rho_{b^2} b_{t-1}^2 + e_{b^2} \tag{A.28}$$

$$g_t = \rho_g g_{t-1} + e_g + \rho_{gZ} e_Z \tag{A.29}$$

$$\mu_t = \rho_\mu \mu_{t-1} + e_\mu \tag{A.30}$$

$$\lambda_{p,t} = \rho_p \lambda_{p,t-1} + e_p - \theta_p e_{p,t-1} \tag{A.31}$$

$$\lambda_{w,t} = \rho_w \lambda_{w,t-1} + e_w - \theta_w e_{w,t-1} \tag{A.32}$$

$$ms_t = \rho_{ms} ms_{t-1} + e_{ms} \tag{A.33}$$

Appendix A.8. Measurement equations

The following equations link the data to the variables in the model

$$dy_t = y_t - y_{t-1} + ctrend \tag{A.34}$$

$$dc_t = c_t - c_{t-1} + ctrend \tag{A.35}$$

$$dinve_t = i_t - i_{t-1} + ctrend \tag{A.36}$$

$$dw_t = w_t - w_{t-1} + ctrend \tag{A.37}$$

$$pinfobs_t = \pi_t + const_\pi \tag{A.38}$$

$$robs_t = R_t + const_R \tag{A.39}$$

$$labobs_t = L_t + const_L \tag{A.40}$$

where dy_t and the other variables are constructed as described in the next section.

Appendix B. The data

We list the data used in our estimation:

- **GDPC96**: Real Gross Domestic Product, 3 decimal - Billions of Chained 2009 Dollars, Seasonally Adjusted Annual Rate. Source: U.S. Department of Commerce, Bureau of Economic Analysis
- **GDPDEF**: Gross Domestic Product - Implicit Price Deflator - 2009=100, Seasonally Adjusted. Source: U.S. Department of Commerce, Bureau of Economic Analysis
- **PCEC**: Personal Consumption Expenditures - Billions of Dollars, Seasonally Adjusted Annual Rate. Source: U.S. Department of Commerce, Bureau of Economic Analysis
- **FPI** : Fixed Private Investment - Billions of Dollars, Seasonally Adjusted Annual Rate Source: U.S. Department of Commerce, Bureau of Economic Analysis. We are using the latest vintage date, $FPI\_20130731$ (Source for alternative vintage dates: ALFRED).
- **CE16OV** : Civilian Employment: Sixteen Years & Over, Thousands, Seasonally Adjusted. Source: U.S. Department of Labor: Bureau of Labor Statistics. Start date: 1948Q1.
- **CE16OV index** : CE16OV (2009:1)=1
- **Effective Federal Funds Rate** : Percentage, Averages of Daily Figures – Percent, Quarterly. Not Seasonally Adjusted. Source: Board of Governors of the Federal Reserve System. (Before 1954: 3-Month Treasury Bill Rate, Secondary Market Averages of Business Days, Discount Basis. For this time series, we used the data from FRED, TB3MS, 3-Month Treasury Bill: Secondary Market Rate (TB3MS), Percent, Quarterly, Not Seasonally Adjusted.)

- **LNS10000000** : Labor Force Status : Civilian noninstitutional population - Age : 16 years and over - Seasonally Adjusted - Number in thousands. Source: U.S. Bureau of Labor Statistics. (Before 1976: CNP16OV : Civilian Noninstitutional Population level - 16 Years and Older)

- **LNSindex** : LNS10000000(2009:1)=1

- **PRS85006023** - Nonfarm Business, All Persons, Average Weekly Hours Duration : index, 2009 = 100, Seasonally Adjusted. Source : U.S. Department of Labor.

- **COMPNFB** :Nonfarm Business Sector: Compensation Per Hour, Index 2009=100, Quarterly, Seasonally Adjusted. Source : U.S. Department of Labor

Definition of data variables in the measurement equations:

$$consumption = dc = \Delta LN((PCEC/GDPDEF)/LNSindex) * 100 \quad \text{(B.1)}$$

$$investment = dinve = \Delta LN((FPI/GDPDEF)/LNSindex) * 100 \quad \text{(B.2)}$$

$$output = dy = \Delta LN(GDPC96/LNSindex) * 100 \quad \text{(B.3)}$$

$$hours = labobs = LN((PRS85006023 * CE16OV/100)/LNSindex) * 100 \quad \text{(B.4)}$$

$$inflation = pinfobs = LN(GDPDEF/GDPDEF(-1)) * 100 \quad \text{(B.5)}$$

$$realwage = dw = \Delta LN(COMPNFB/GDPDEF) * 100 \quad \text{(B.6)}$$

$$interestrate = robs = FederalFundsRate/4 \quad \text{(B.7)}$$

Table B.1: Summary statistics.

	1984Q1 - 2007Q4		2007Q4 - 2015Q1	
	mean	std dev	mean	std dev
consumption	0.57	0.50	0.10	0.75
investment	0.46	1.47	-0.32	2.76
output	0.50	0.54	0.05	0.74
labor	1.53	1.99	-6.78	2.51
inflation	0.62	0.23	0.36	0.21
wage rate	0.40	0.67	0.16	1.17
interest rate	1.33	0.59	0.13	0.26

Growth rates of consumption, investment, output and real wage. Consumption, investment, output and hours worked are net of labor force growth, normalized to 1 in 2005Q1. Variables are deflated using GDP deflator.

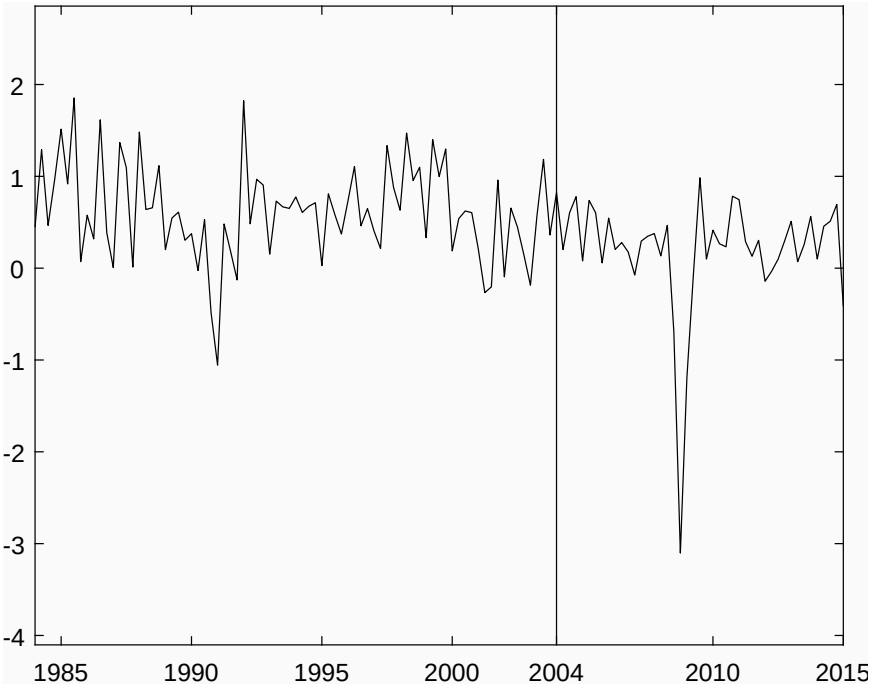

Figure B.1: Consumption (percentage change). The line highlights the data points in addition to Smets, Wouters (2006)

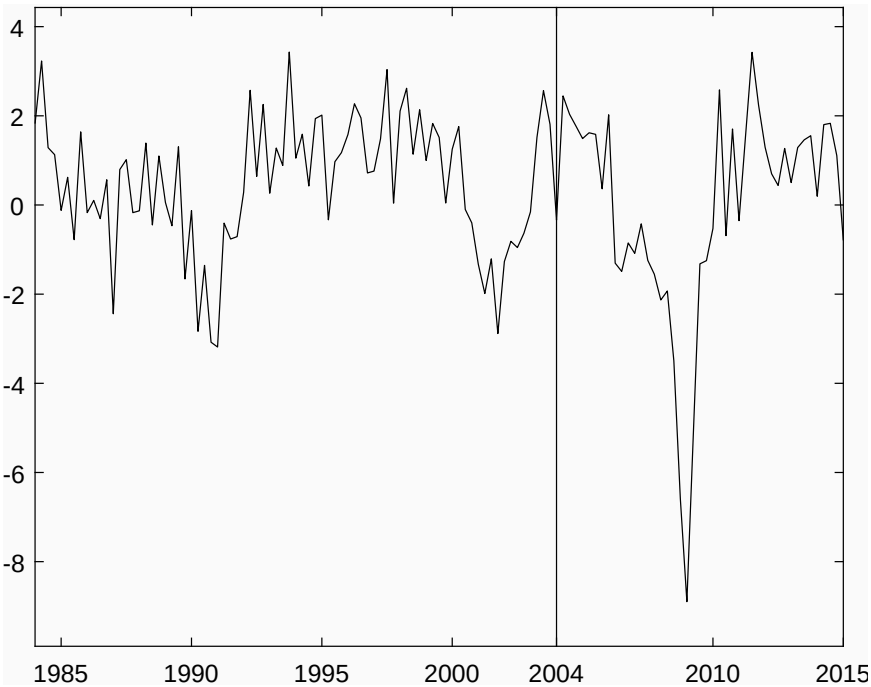

Figure B.2: Investment (percentage change). The line highlights the data points in addition to Smets, Wouters (2006)

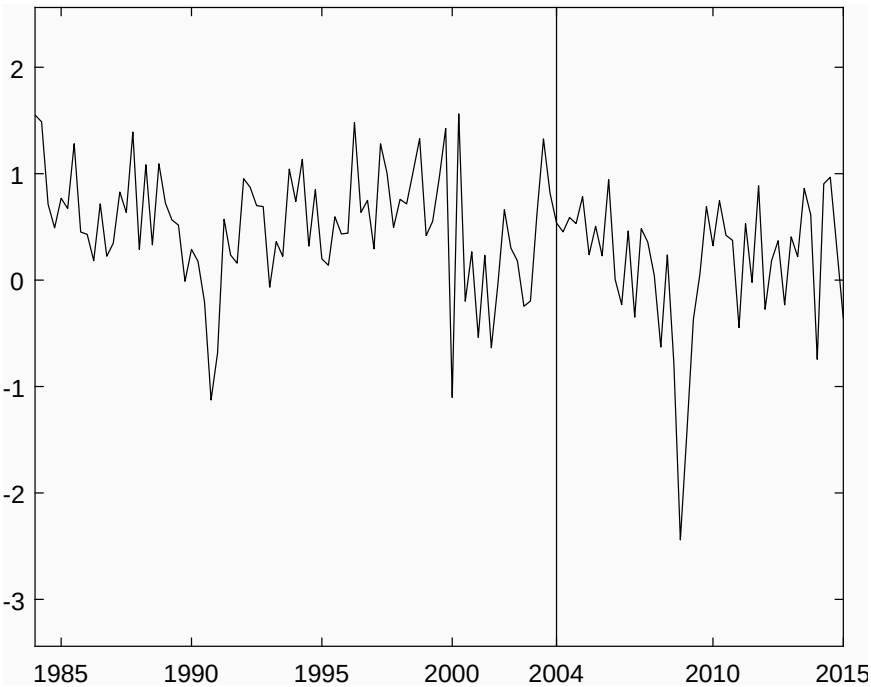

Figure B.3: Output (percentage change). The line highlights the data points in addition to Smets, Wouters (2006)

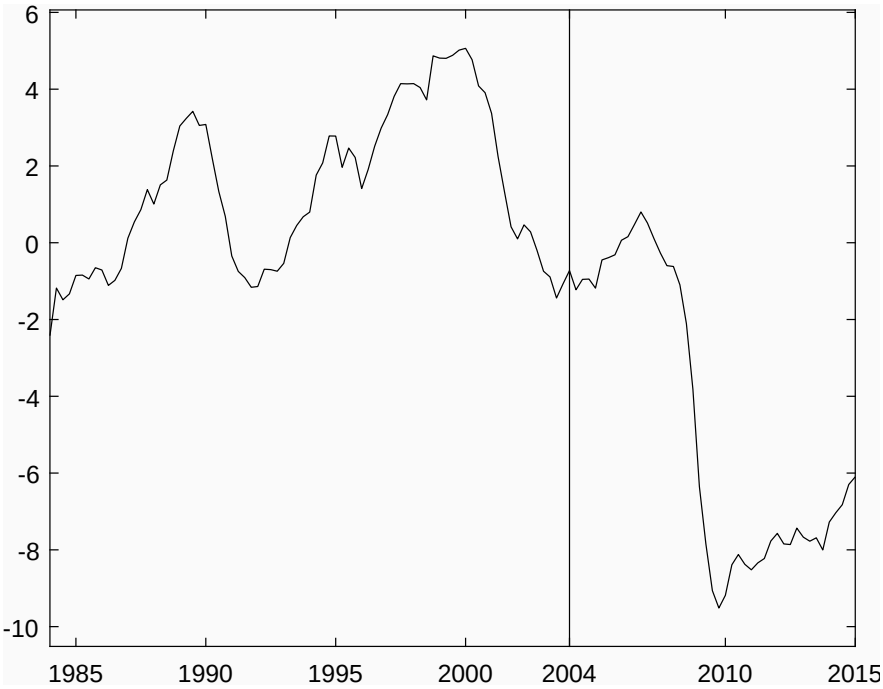

Figure B.4: Labor (index). The line highlights the data points in addition to Smets, Wouters (2006)

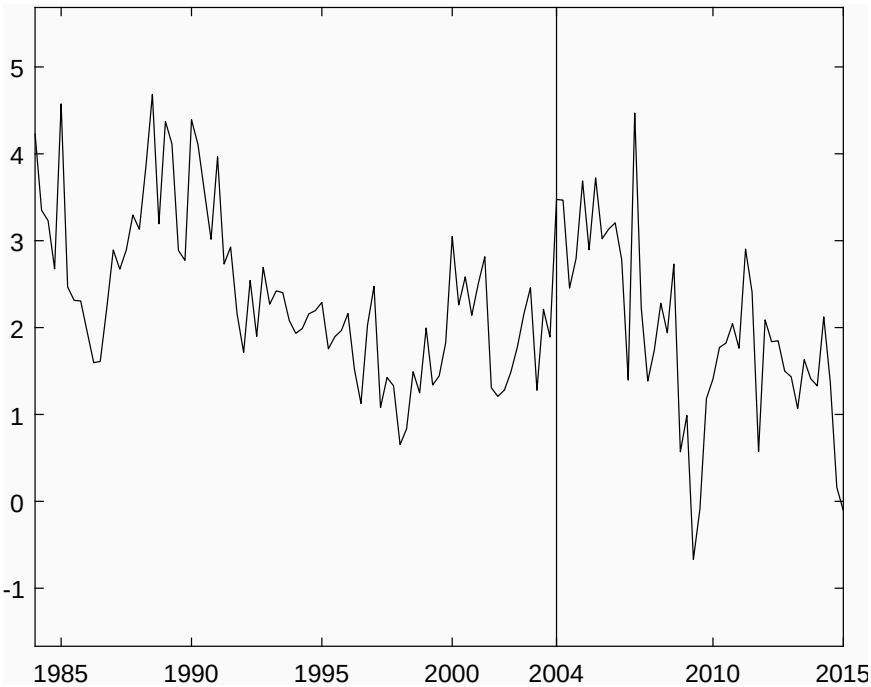

Figure B.5: Inflation. The line highlights the data points in addition to Smets, Wouters (2006)

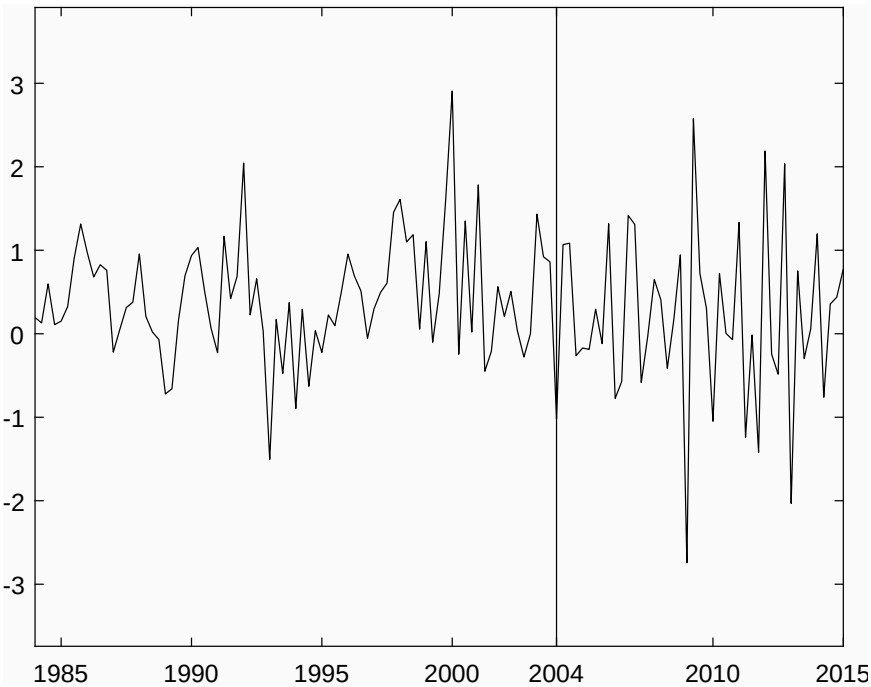

Figure B.6: Wage rate (percentage change). The line highlights the data points in addition to Smets, Wouters (2006)

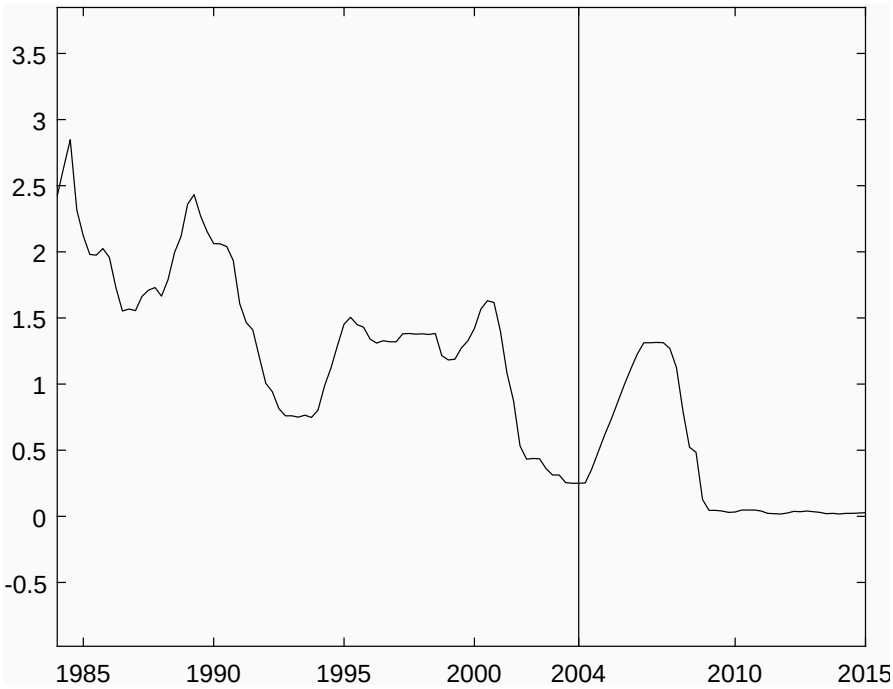

Figure B.7: Interest rate. The line highlights the data points in addition to Smets, Wouters (2006)

Appendix C. Estimation procedure

We use a Metropolis-Hasting algorithm with 250,000 iterations to compute the posterior distributions. We used the same priors as Smets-Wouters.

Appendix C.1. List of estimated posterior distributions

The following are the variables for which we estimate the posterior distribution in the model.

Parameters for the stochastic processes:
$std\ err\ e_Z, std\ err\ e_{b^2}, std\ err\ e_g, std\ err\ e_\mu, std\ err\ e_{ms}, std\ err\ e_p, std\ err\ e_w,$
$\rho_Z, \rho_{b^2}, \rho_g, \rho_{gZ}, \rho_\mu, \rho_{ms}, \rho_p, \rho_w, \theta_p, \theta_w$
Investment adjustment cost: $S''(\gamma)$
Utility function: $\sigma_c, h, \nu_L,$
Capital utilization: $czcap$
Inflation indexation: ι_w, ι_p
Calvo probability of price resetting: ζ_w, ζ_p
Fixed production cost: Φ
Capital share: α
Taylor rule: $\psi_1, \rho_R, \psi_2, \psi_3$
Measurement equations: $const_\pi, constebeta, const_L, ctrend$

Appendix C.2. List of calibrated parameters

The following parameters have been calibrated.
Capital depreciation: $\delta = .025$
Steady state labor markup: $\lambda_{w,*} = 0.5$
Steady state government expenditure: $g_* = 0.18$
Generalization of the Dixit-Stiglitz aggregators for the intermediate good firms and the labor unions: $curvp = curvw = 10$

Appendix C.3. List of derived parameters

The following are function of other parameters:

$$\bar{\beta} = \beta\gamma^{-\sigma_c} \tag{C.1}$$

$$ctrend = 100(\gamma - 1) \tag{C.2}$$

$$\lambda_{p,*} = \Phi - 1 \tag{C.3}$$

$$cr = \frac{cpie}{\beta\gamma^{-\sigma_c}} \tag{C.4}$$

$$r_{k,*} = \beta^{-1}\gamma^{\sigma_c} - (1 - \delta) \tag{C.5}$$

$$w_* = \left(\frac{\alpha^\alpha(1-\alpha)^{1-\alpha}}{\Phi r_{k,*}^\alpha}\right)^{\frac{1}{1-\alpha}} \tag{C.6}$$

$$\frac{i_*}{k_*} = 1 - \frac{1-\delta}{\gamma} \tag{C.7}$$

$$\frac{k_*}{L_*} = \frac{\alpha}{1-\alpha}\frac{w_*}{r_{k,*}} \tag{C.8}$$

$$\frac{k_*}{y_*} = \Phi(\frac{k_*}{L_*})^{1-\alpha} \tag{C.9}$$

$$\frac{i_*}{y_*} = (1 - \frac{1-\delta}{\gamma})\gamma\frac{k_*}{y_*} \tag{C.10}$$

$$\frac{c_*}{y_*} = 1 - g_* - \frac{i_*}{y_*} \tag{C.11}$$

$$\frac{w_*^h L_*}{c_*} = \frac{1}{1+\lambda_{w,*}}\frac{1-\alpha}{\alpha}r_{k,*}\frac{k_*}{c_*} \tag{C.12}$$

$$const_R = (cr - 1) * 100 \tag{C.13}$$

$$const_\pi = (cpie - 1) * 100 \tag{C.14}$$

$$a'(1) = \frac{1 - czcap}{czcap}r_{k,*} \tag{C.15}$$

Appendix D. Re-Estimating the Smets-Wouters model

Following Smets and Wouters, we adopt a Bayesian approach and we estimate the posterior distribution using a MH algorithm with 250,000 sim-

ulations. Priors are the same as the ones assumed in Smets-Wouters. Like them, we use 7 time series to estimate the model: output, consumption, investment, inflation, hours worked, real wages, and the (Federal Fund) interest rate. We compute consumption, investment and hours worked per-capita using a population index normalized to 1 in 1992Q4. We use the GDP deflator as a measure of inflation. Consumption, investment, output and wage are at constant prices. Variables are net of the labor force growth, normalized to 1 in 2005Q1. For the interest rate, we use the Federal Funds Rate.

For the estimation, we use data from U.S. Bureau of Economic Analysis and U.S. Bureau of Labor Statistics for the period 1984Q1-2007Q4.

Table D.2: Posterior distributions (Metropolis Hasting 250000 simulations). 1984Q1 - 2007Q4

		mean
$\sigma(e_Z)$	TFP	0.352
$\sigma(e_{b^2})$	risk premium	0.188
$\sigma(e_g)$	gov't exp	0.410
$\sigma(e_\mu)$		0.372
$\sigma(e_{ms})$	monetary shock	0.095
$\sigma(e_p)$	price shock	0.083
$\sigma(e_w)$	wage shock	0.292
ρ_Z		0.909
ρ_{b^2}		0.180
ρ_g		0.955
ρ_μ		0.641
ρ_{ms}		0.401
ρ_p		0.795
ρ_w		0.820

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Table D.2 – continued from previous page

		mean
θ_p	price MA	0.614
θ_w	wage MA	0.577
$S''(\gamma)$	inv. adj cost	6.842
σ_c	intertemp elast	1.734
h	habits	0.615
ζ_w	wage stickiness	0.646
ν_L	labor	2.116
ζ_p	price stickiness	0.794
ι_w	wage index	0.472
ι_p	price index	0.366
$czcap$	capital utiliz.	0.687
Φ	fixed cost	1.565
ψ_1	monetary p.	1.868
ρ_R	monetary p.	0.854
ψ_2	monetary p.	0.108
ψ_3	monetary p.	0.128
$const_\pi$	measurem eq	0.594
$constebeta$	measurem eq	0.247
$const_L$	measurem eq	1.025
$ctrend$	growth rate	0.476
ρ_{gZ}	gov't exp	0.456
α	$\frac{k_*}{y_*}$	0.268

Appendix E. Additional results for the baseline model

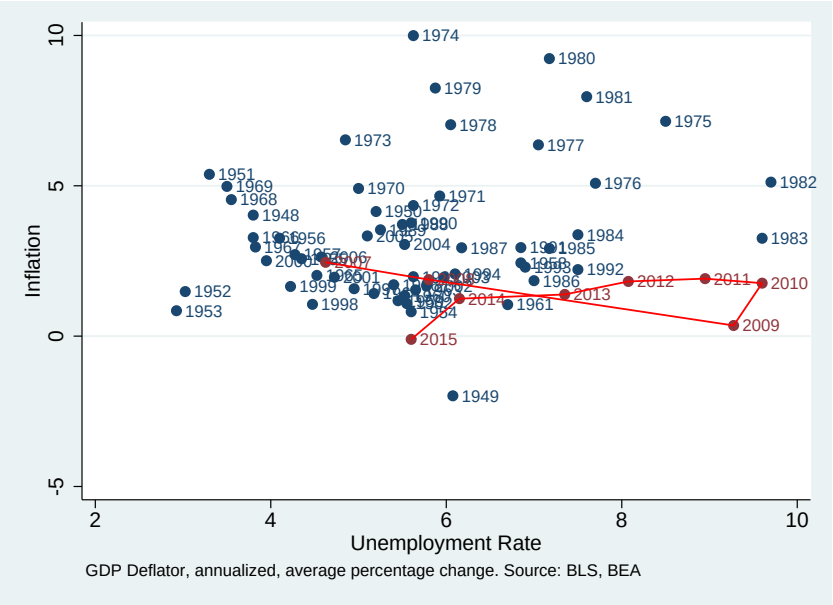

Figure E.8: Phillips Curve using unemployment rate as a measure of slackness.

Table E.3: Asymptotic Variance Decomposition of Inflation

	1948-2015	1948-2007	1984-2007	2008-2015
Technology	1.80	1.73	2.47	3.30
Price Markup	68.75	70.78	54.03	41.52
Wage Markup	10.58	8.44	24.93	43.80
Preferences	0.51	0.50	0.30	0.68
Inv.Spec.Tech.	4.51	4.19	6.00	3.68
Gov't Exp	1.74	1.74	2.20	1.76
Monetary Policy	12.10	12.61	10.07	5.27

The asymptotic variance is approximated by the 200-periods ahead variance.

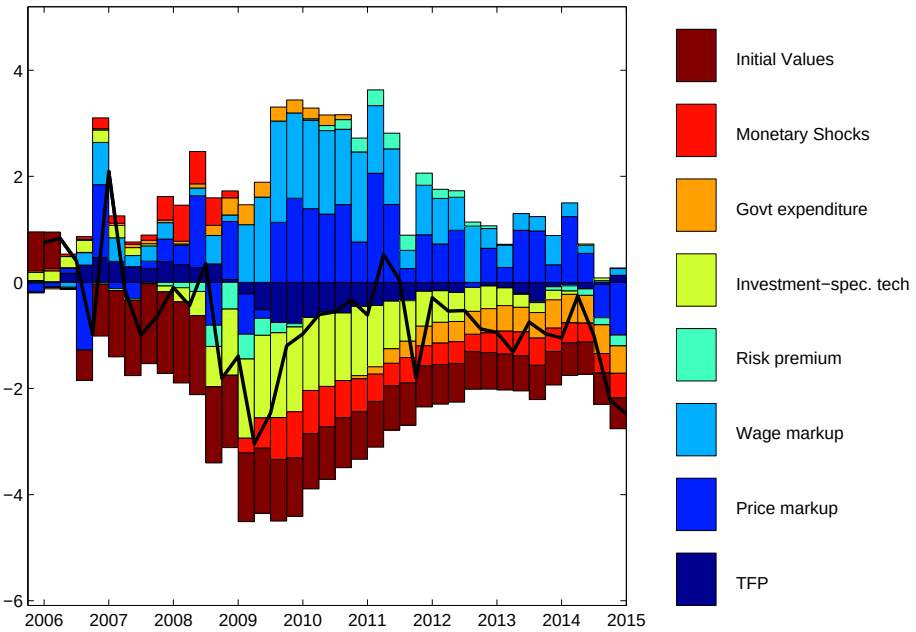

Figure E.9: Historical shock decomposition of inflation since 2006. Solid line is actual inflation.

Table E.4: Asymptotic Variance Decomposition of Employment

	1948-2015	1948-2007	1984-2007	2008-2015
Technology	5.78	5.70	6.81	9.13
Price Markup	16.82	17.82	11.38	8.76
Wage Markup	9.59	7.88	19.45	34.24
Risk Premium	9.70	9.84	4.87	11.08
Inv.Spec.Tech.	25.28	24.14	28.95	17.79
Gov't Exp	13.52	13.92	14.70	11.74
Monetary Policy	19.32	20.71	13.84	7.25

Asymptotic Variance approximated by the 200-periods ahead variance.

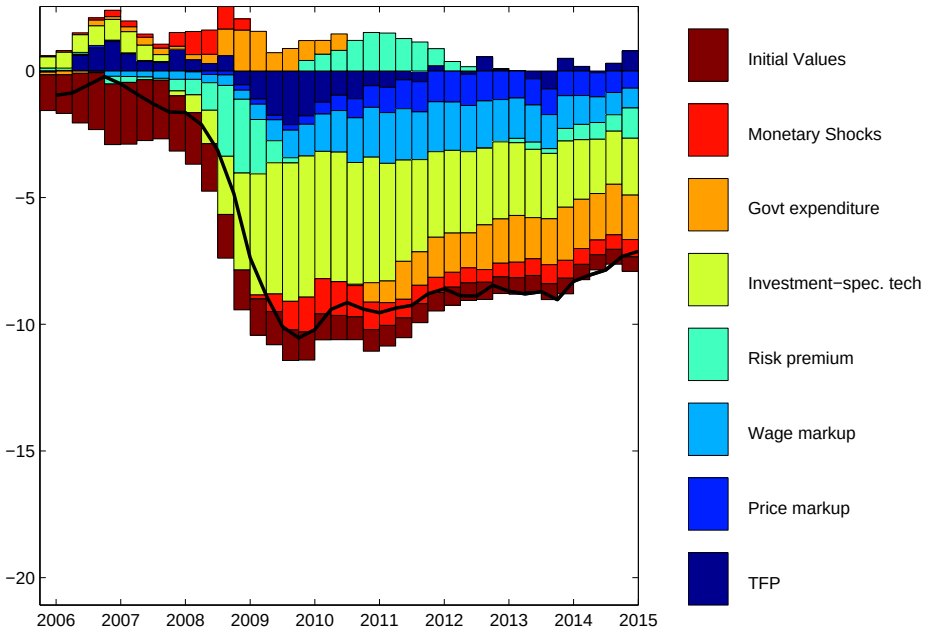

Figure E.10: Historical shock decomposition of the employment since 2006.

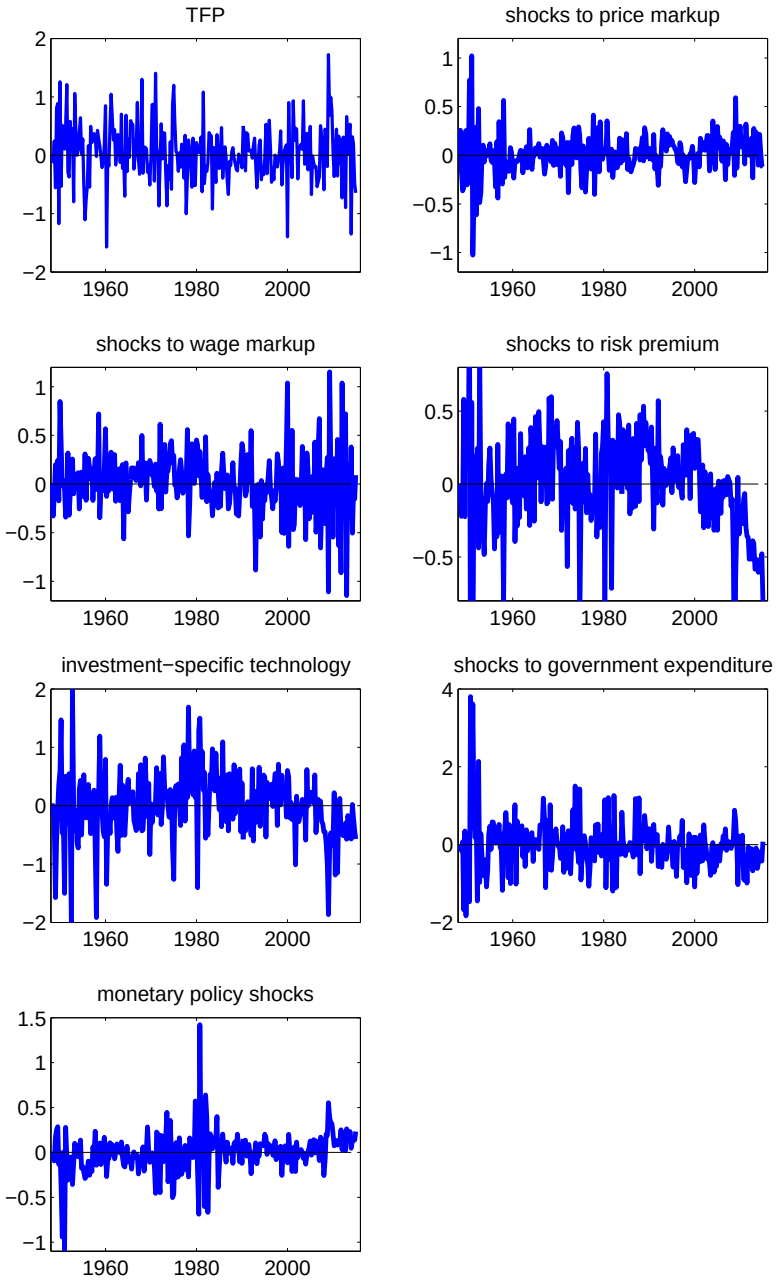

Figure E.11: Time series of the estimated shocks

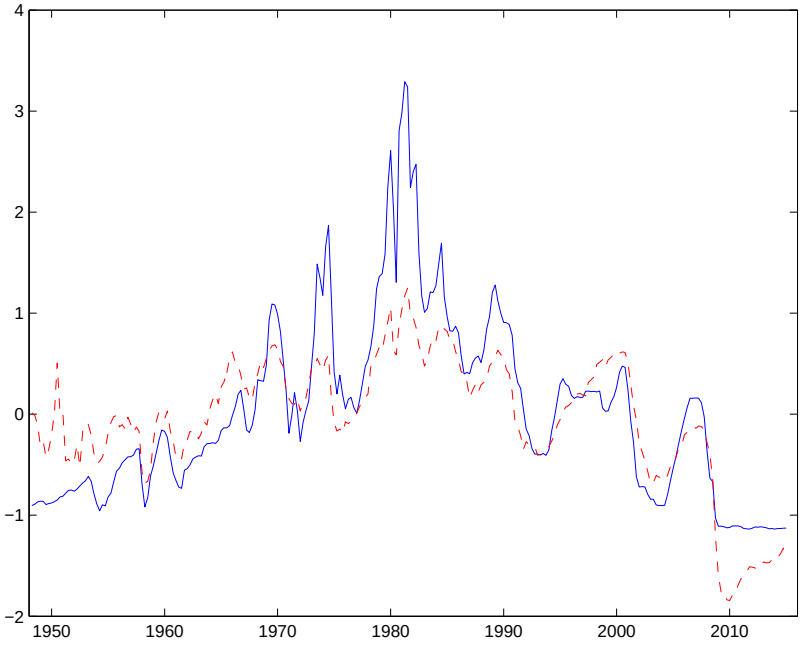

Figure E.12: Historical shock decomposition of the interest rate (relative to long-run constant). The solid line is actual interest rate. The dashed line is interest rate generated by a combination of the estimated shocks to the risk premium and to investment adjustment cost.

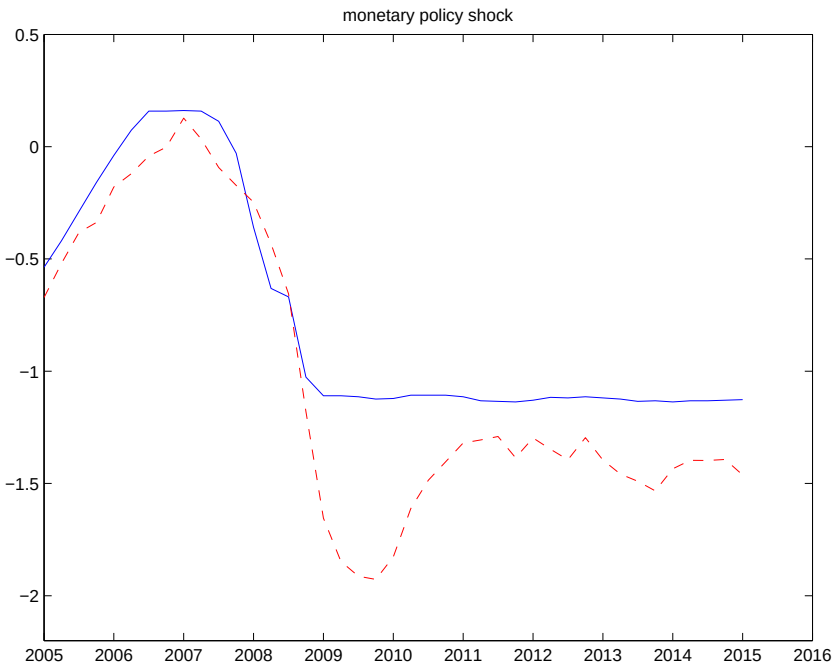

Figure E.13: Historical shock decomposition of the interest rate (relative to long-run constant). The solid line is actual interest rate. The dashed line is the predicted interest rate if there were no monetary policy shocks.

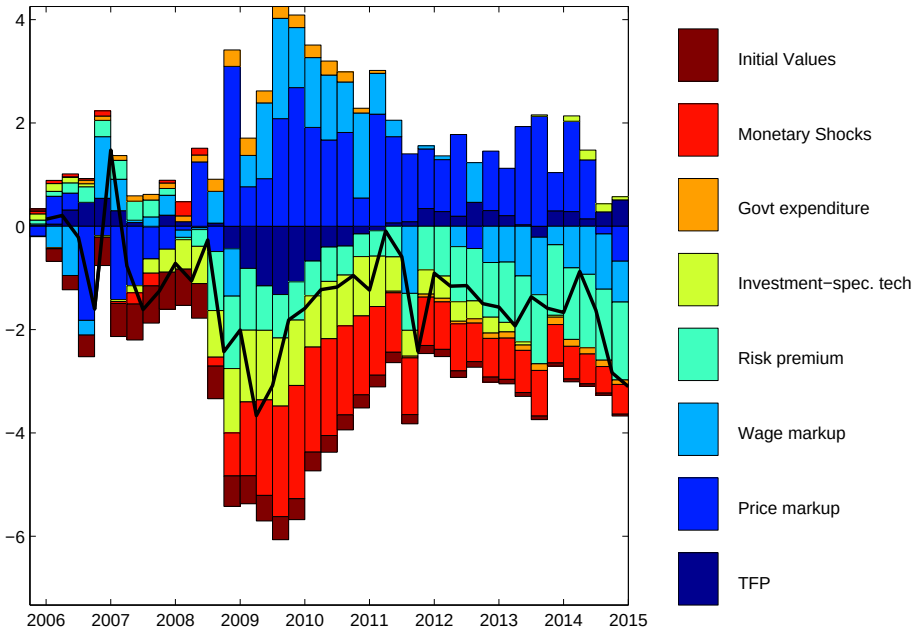

Figure E.14: Historical shock decomposition of inflation

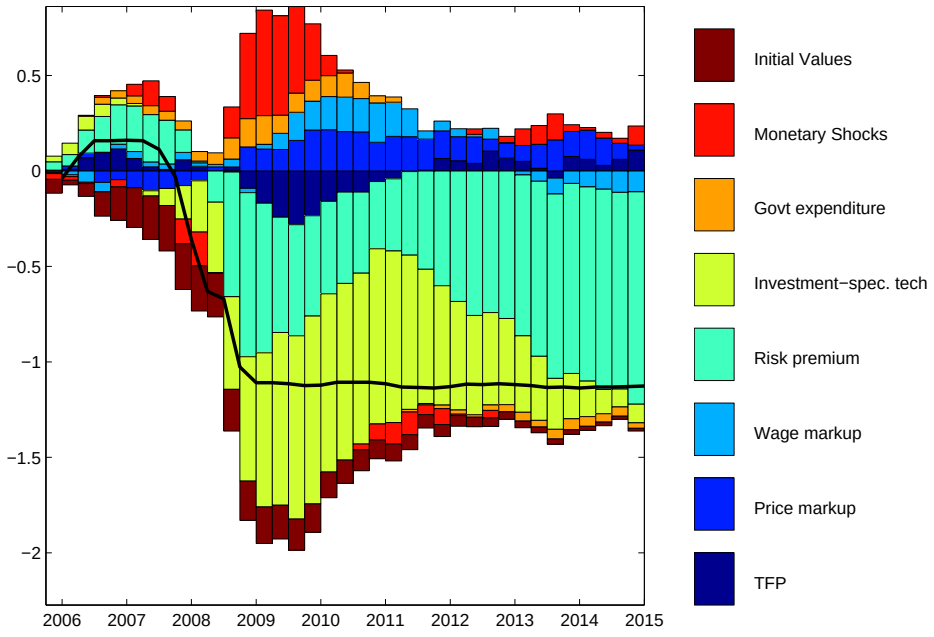

Figure E.15: Historical shock decomposition of the interest rate

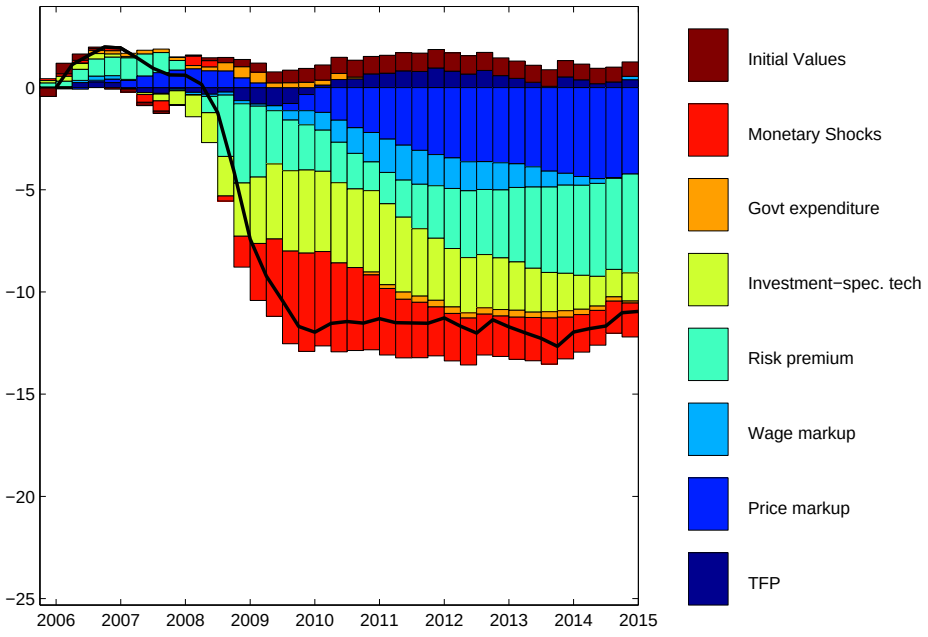

Figure E.16: Historical shock decomposition of the output gap

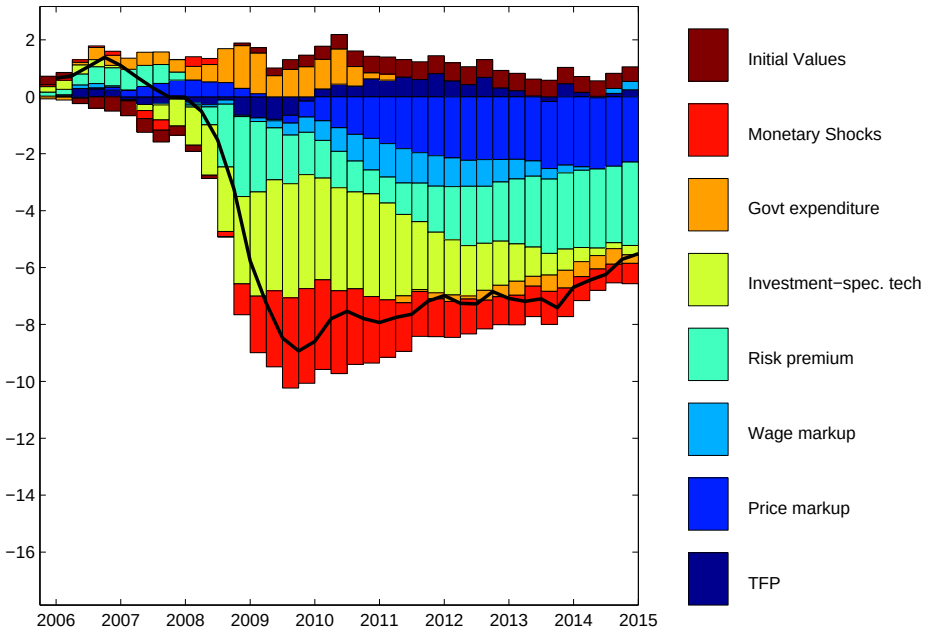

Figure E.17: Historical shock decomposition of the labor

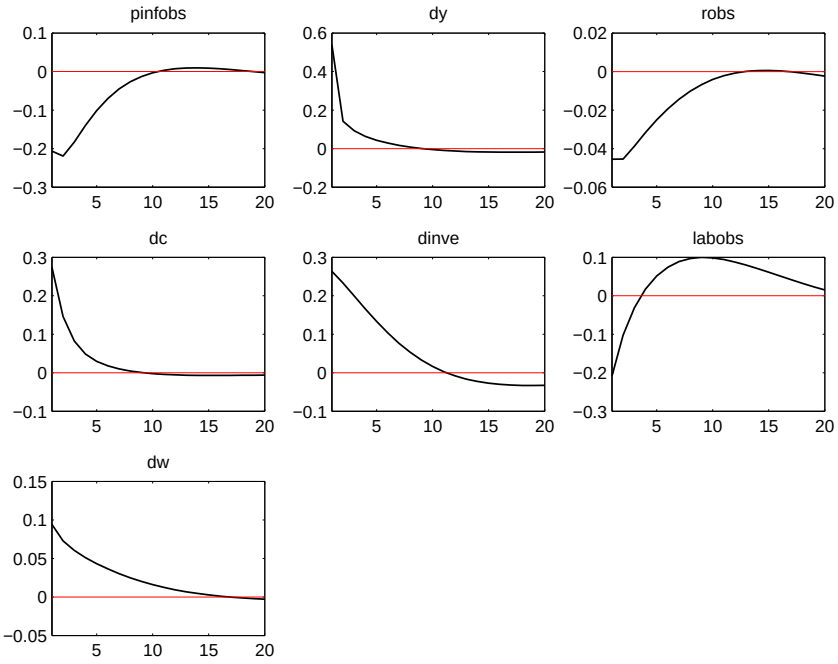

Figure E.18: Impulse Response Functions to a shock to TFP

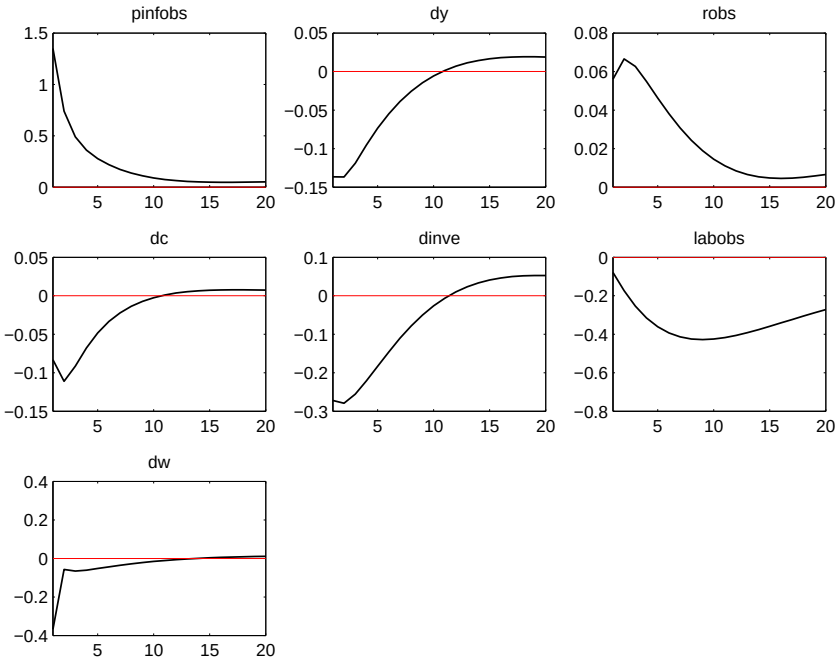

Figure E.19: Impulse Response Functions to a shock to price markup

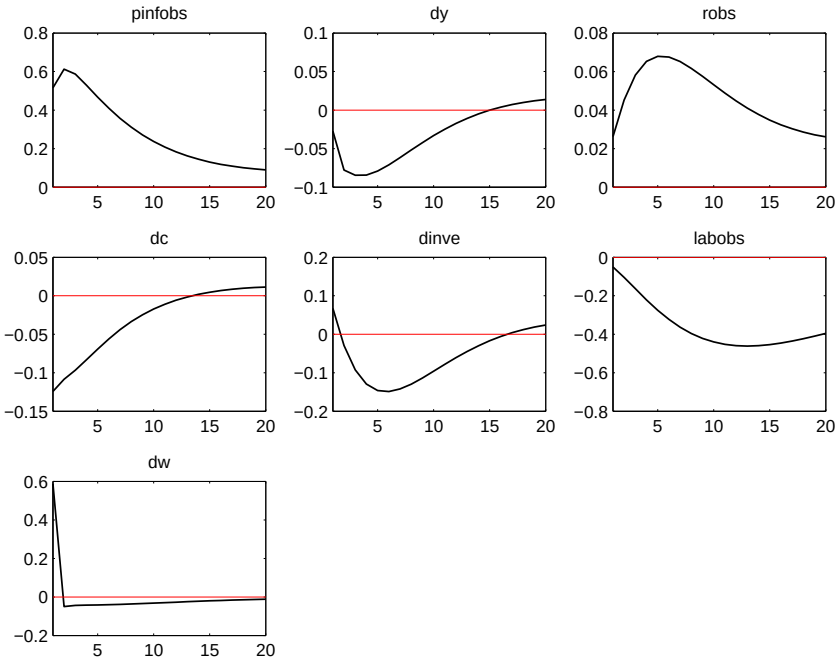

Figure E.20: Impulse Response Functions to a shock to wage markup

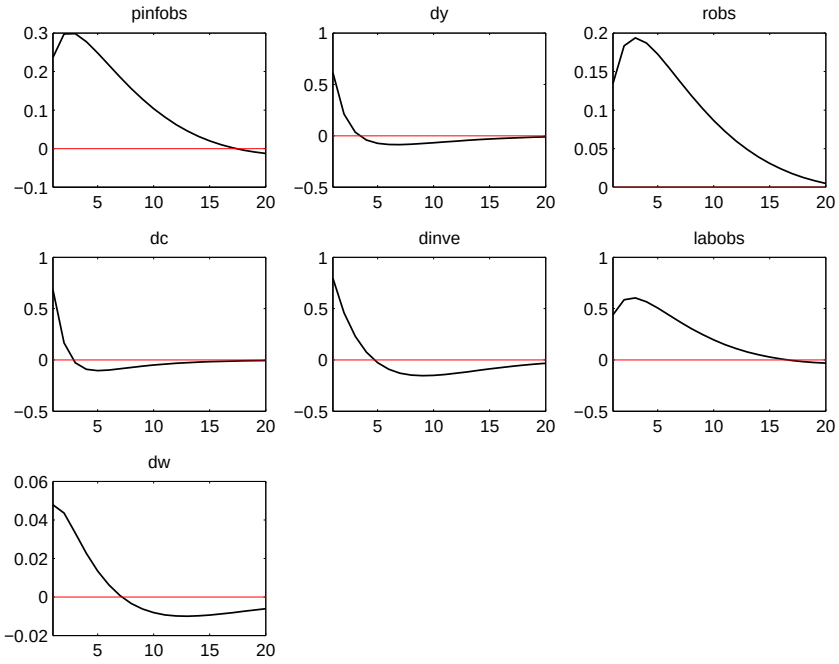

Figure E.21: Impulse Response Functions to a shock to the risk premium

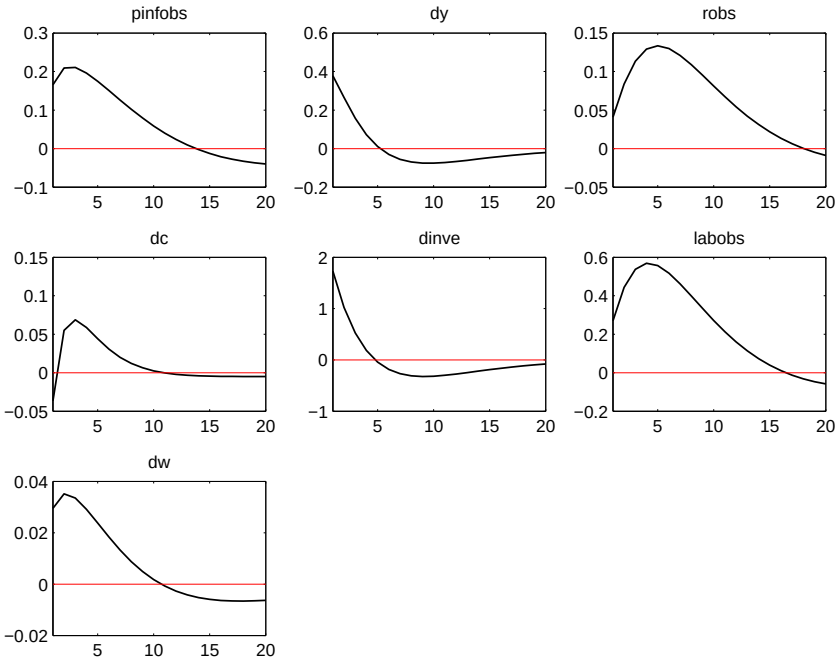

Figure E.22: Impulse Response Functions to a shock to investment-specific technology

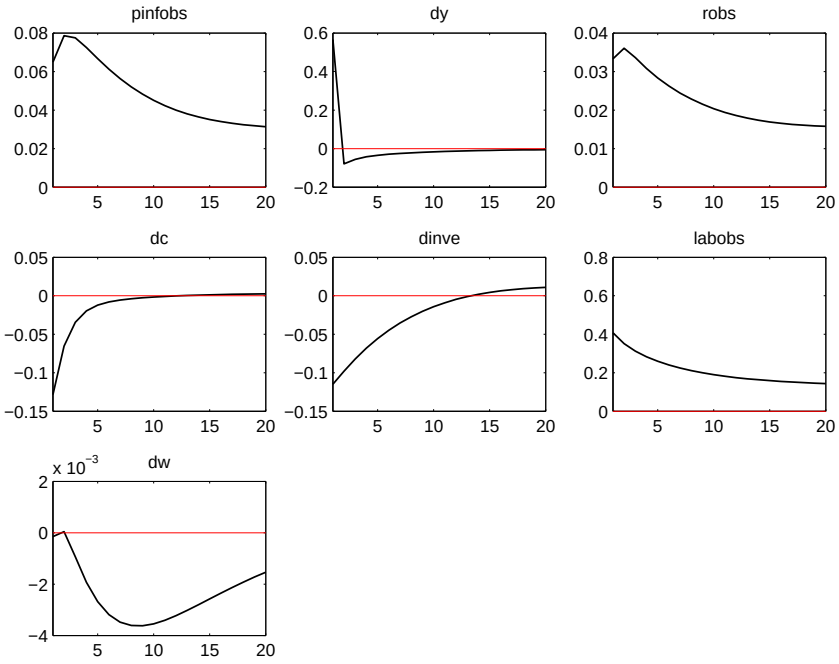

Figure E.23: Impulse Response Functions to a shock to government expenditure

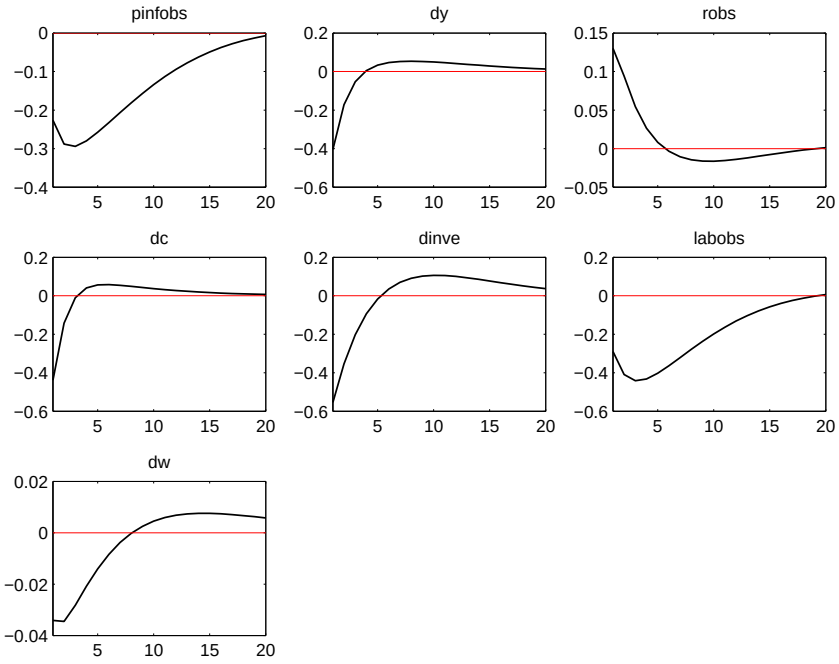

Figure E.24: Impulse Response Functions to a monetary policy shock

Appendix F. Robustness checks

Table F.5: Posterior distributions using alternative samples (Metropolis Hasting 250000 simulations)

		1948Q1 - 2007Q4	1984Q1 - 2015Q1
		mean	mean
$\sigma(e_Z)$	TFP	0.477	0.413
$\sigma(e_{b^2})$	risk premium	0.317	0.063
$\sigma(e_g)$	gov't exp	0.662	0.407
$\sigma(e_\mu)$		0.541	0.309
$\sigma(e_{ms})$	monetary shock	0.228	0.098
$\sigma(e_p)$	price shock	0.203	0.107
$\sigma(e_w)$	wage shock	0.265	0.435
ρ_Z		0.981	0.977
ρ_{b^2}		0.221	0.899
ρ_g		0.963	0.957
ρ_μ		0.630	0.749
ρ_{ms}		0.201	0.474
ρ_p		0.98	0.762
ρ_w		0.953	0.690
θ_p	price MA	0.892	0.648
θ_w	wage MA	0.885	0.649
$S''(\gamma)$	inv. adj cost	5.930	5.632
σ_c	intertemp elast	1.762	1.267
h	habits	0.662	0.504
ζ_w	wage stickiness	0.774	0.788
ν_L	labor	2.175	1.489

Continued on next page

Table F.5 – continued from previous page

		1948Q1 - 2007Q4	1984Q1 - 2015Q1
		mean	mean
ζ_p	price stickiness	0.667	0.861
ι_w	wage index	0.494	0.438
ι_p	price index	0.301	0.245
$czcap$	capital utiliz.	0.417	0.899
Φ	fixed cost	1.714	1.45
ψ_1	monetary p.	1.939	1.682
ρ_R	monetary p.	0.875	0.879
ψ_2	monetary p.	0.124	0.108
ψ_3	monetary p.	0.143	0.152
$const_\pi$	measurem eq	0.626	0.625
$constebeta$	measurem eq	0.254	0.247
$const_L$	measurem eq	1.829	0.340
$ctrend$	growth rate	0.501	0.405
ρ_{gZ}	gov't exp	0.653	0.492
α	$\frac{k_*}{y_*}$	0.277	0.213

Appendix G. Robustness checks 1: Estimation results using sample 1948-2007

Table G.6: 4-quarters ahead Variance Decomposition of Inflation

	1948-2015	1948-2007	2008-2015
Technology	3.09	3.15	3.12
Price Markup	53.52	59.24	26.18
Wage Markup	36.29	29.94	68.60
Risk premium	0.40	0.37	0.16
Inv.Adj.Cost	1.57	1.64	0.56
Gov't Exp	0.48	0.56	0.15
Monetary Policy	4.66	5.12	1.24

Table G.7: Asymptotic Variance Decomposition of Inflation

	1948-2015	1948-2007	2008-2015
Technology	2.65	2.75	2.42
Price Markup	46.72	52.80	20.69
Wage Markup	43.86	36.95	75.08
Risk premium	0.25	0.24	0.09
Inv.Adj.Cost	1.46	1.55	0.47
Gov't Exp	0.69	0.82	0.19
Monetary Policy	4.36	4.89	1.05

The asymptotic variance is approximated by the 200-periods ahead variance.

Table G.8: Standard Deviation of the Estimated Shocks

	1948-2006	2005-2015
Technology	0.47	0.63
Price Markup	0.20	0.18
Wage Markup	0.27	0.55
Risk Premium	0.31	0.28
Inv.Spec.Tech.	0.54	0.42
Gov't Exp	0.65	0.45
Monetary Policy	0.22	0.15

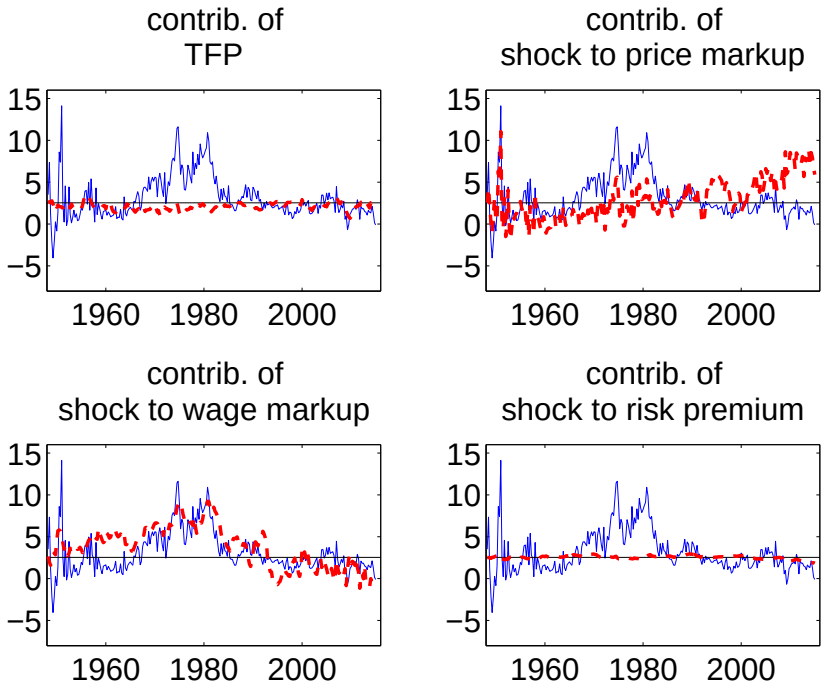

Figure G.25: Historical shocks decomposition of inflation (relative to long-run constant) for the period 1948Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

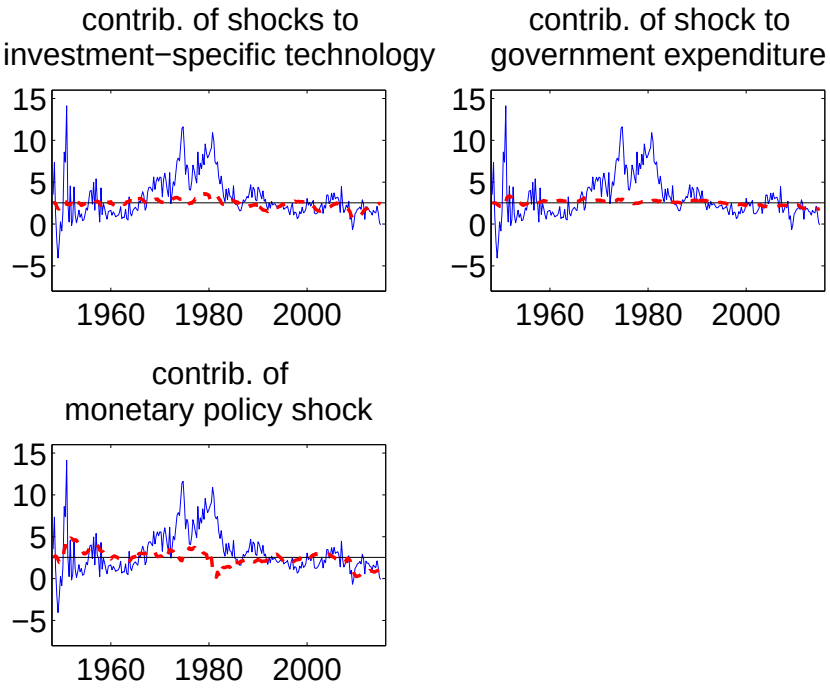

Figure G.26: Historical shocks decomposition of inflation (relative to long-run constant) for the period 1948Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

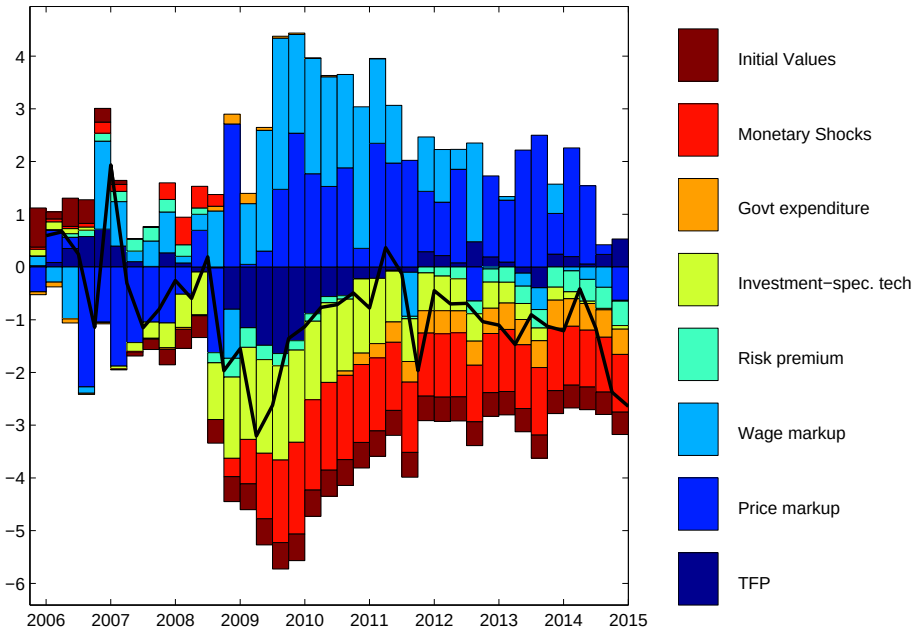

Figure G.27: Historical shock decomposition of inflation since 2006

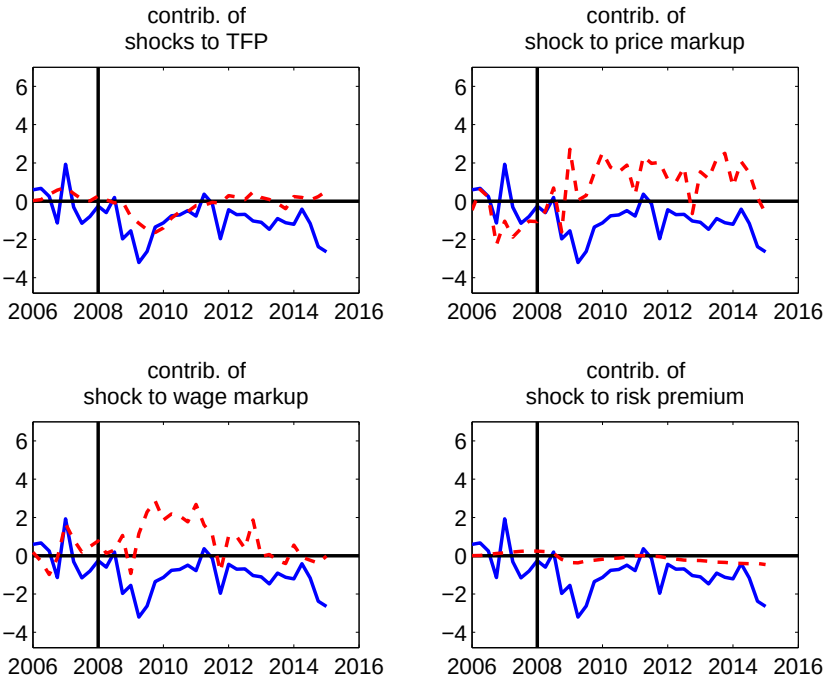

Figure G.28: Historical shock decomposition of inflation (relative to long-run constant) for the period 2006Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

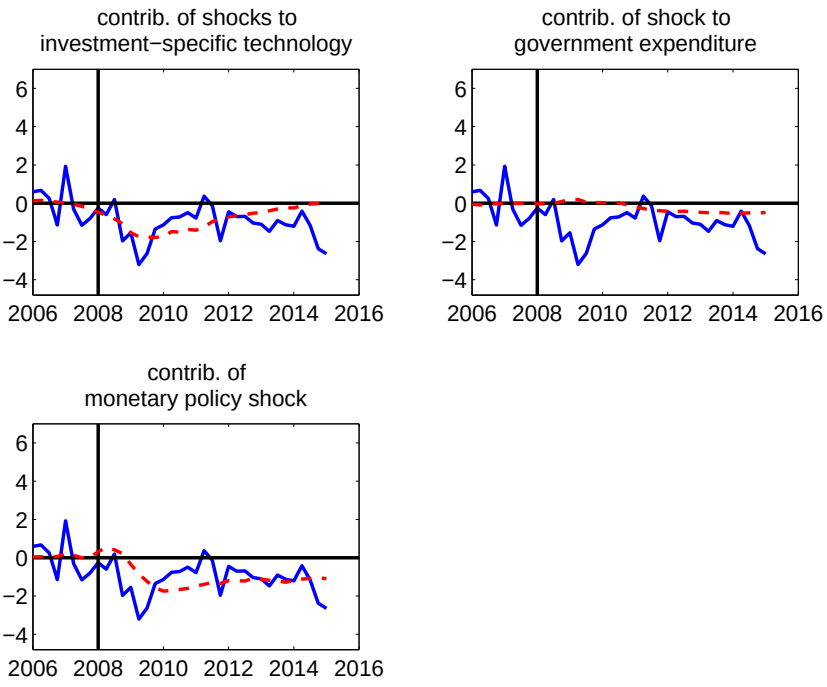

Figure G.29: Historical shock decomposition of inflation (relative to long-run constant) for the period 2006Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

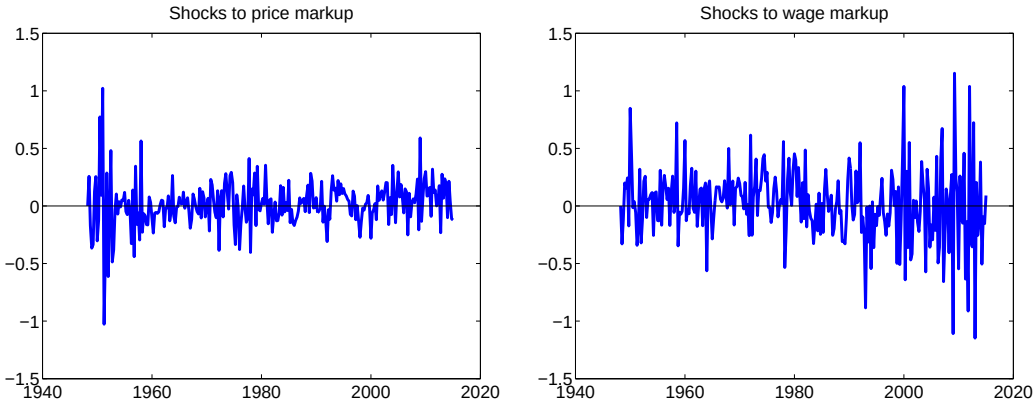

Figure G.30: Price and wage markup shocks estimated from the model.

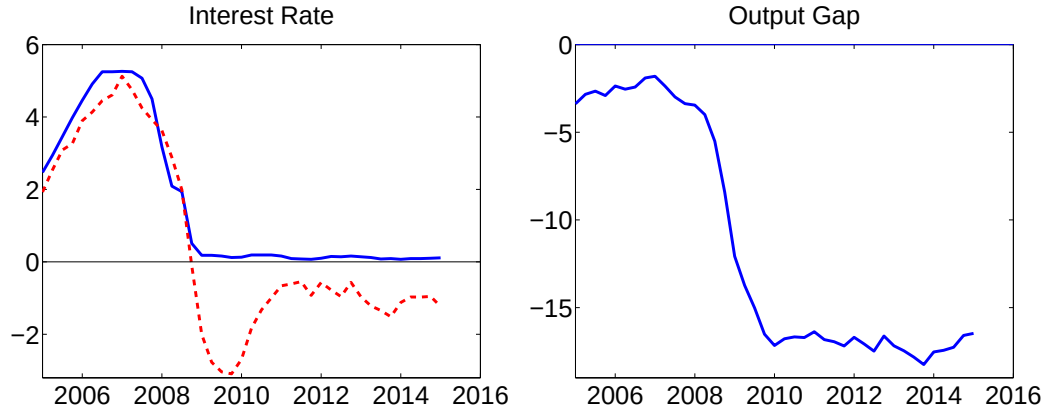

Figure G.31: A comparison between interest rate and the output gap. The left panel shows the real interest rate (solid blue line) and the estimated interest rate in absence of monetary shocks (dashed red line) The right panel shows the output gap, which remains considerably below zero, long after 2008.

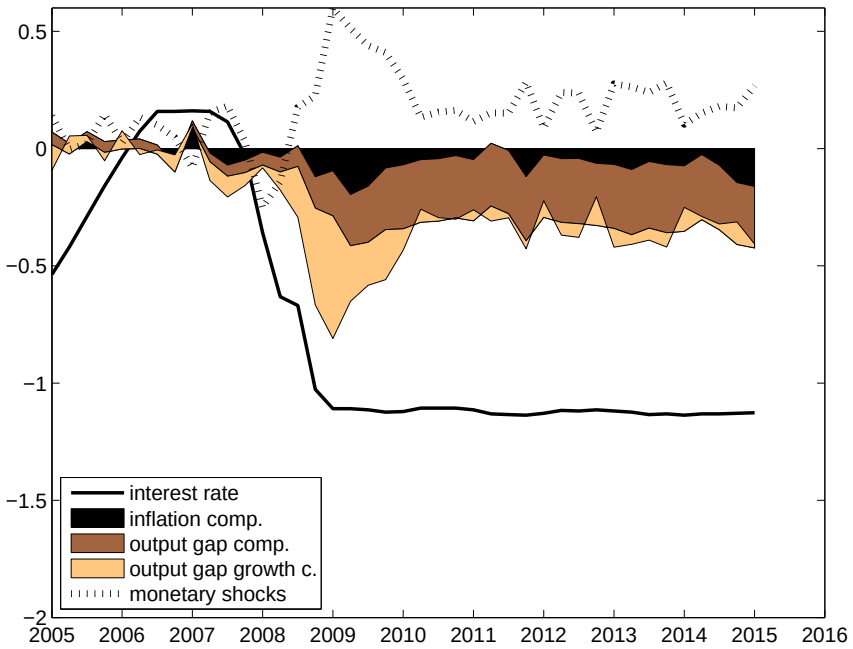

Figure G.32: Decomposition of the nominal interest rate according to the Taylor rule from the model. Nominal interest rate expressed in deviations from the long-run average.

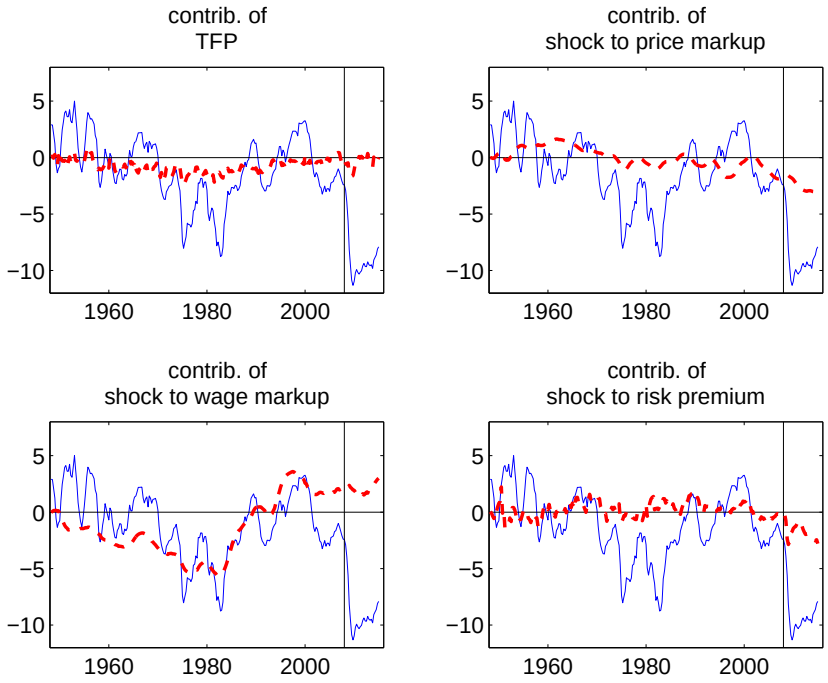

Figure G.33: Historical shock decomposition of employment for the period 1948-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

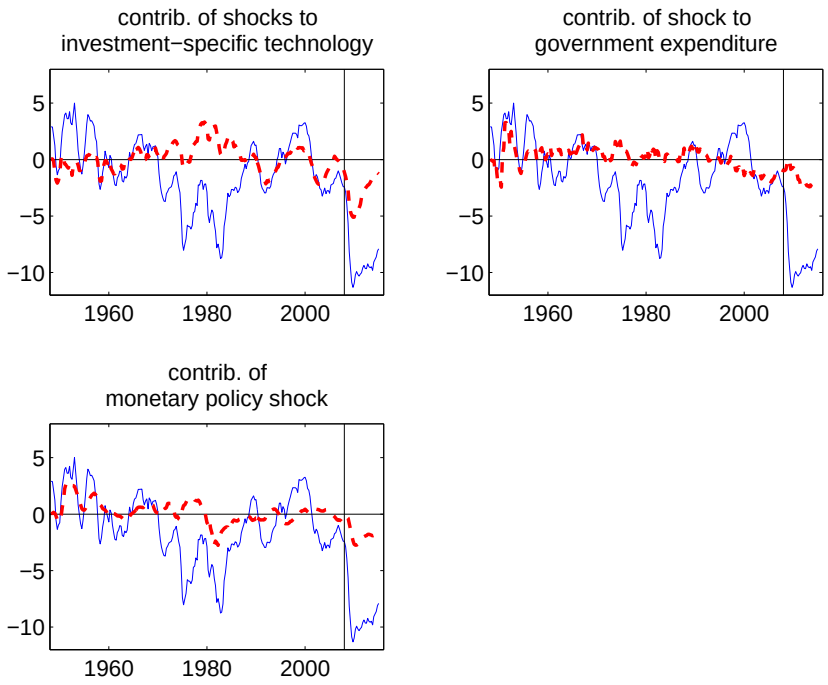

Figure G.34: Historical shock decomposition of employment for the period 1948-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

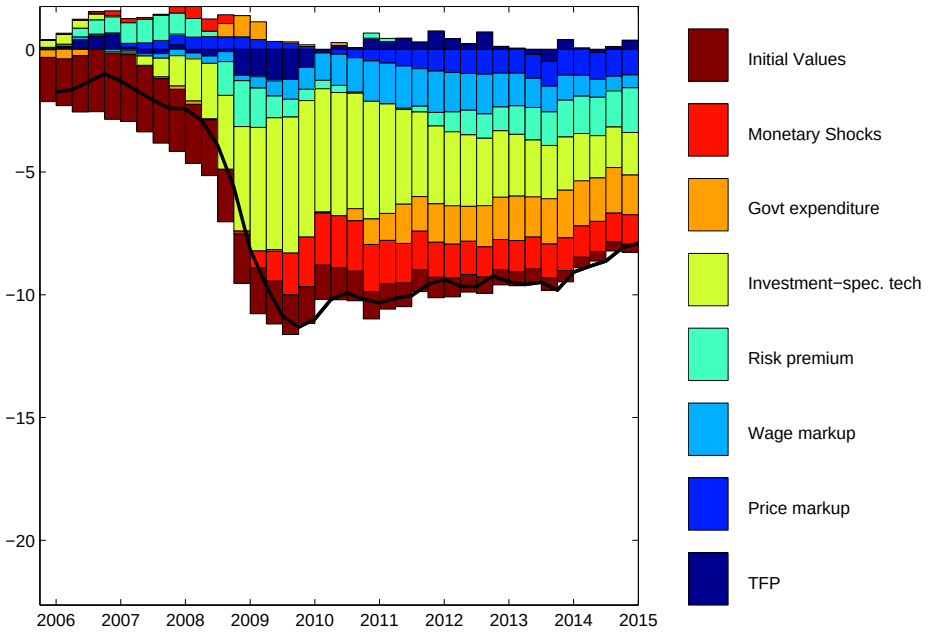

Figure G.35: Historical shock decomposition of the employment

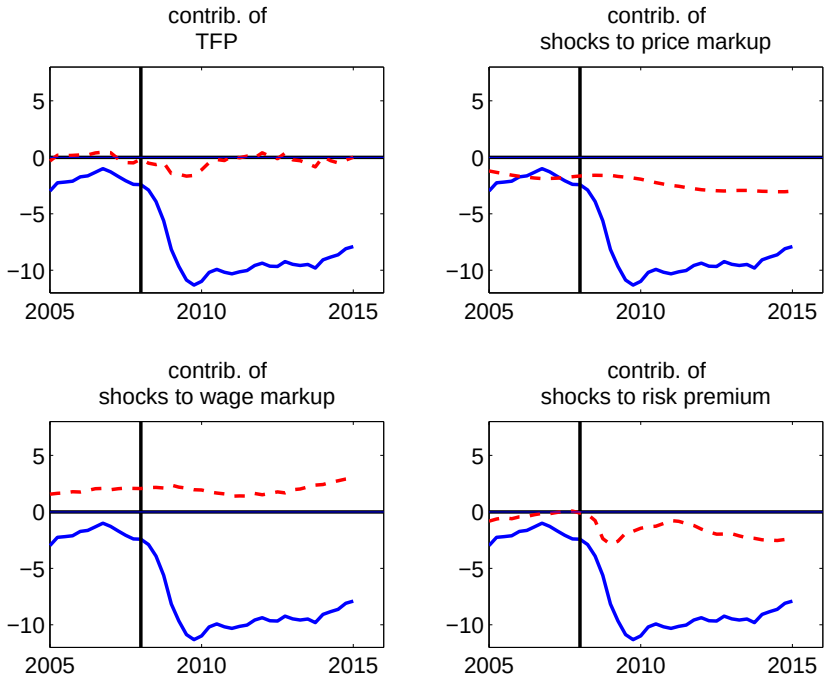

Figure G.36: Historical shock decomposition of employment for the period 2005-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

Table G.9: 4-periods ahead Variance Decomposition of Employment

	1948-2015	1948-2007	2008-2015
Technology	6.09	5.98	13.33
Price Markup	1.82	1.94	1.93
Wage Markup	5.16	4.11	21.13
Preferences	20.31	18.03	17.52
Inv.Spec.Tech.	31.48	31.55	24.07
Gov't Exp	21.33	23.75	14.05
Monetary Policy	13.81	14.63	7.97

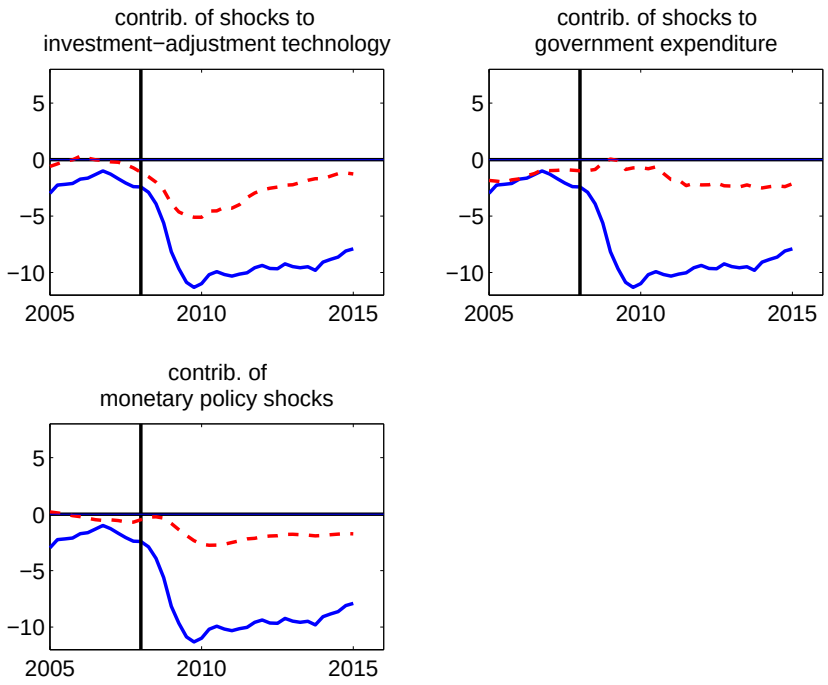

Figure G.37: Historical shock decomposition of employment for the period 2005-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

Table G.10: Asymptotic Variance Decomposition of Employment

	1948-2015	1948-2007	2008-2015
Technology	6.35	6.79	5.65
Price Markup	10.97	12.75	4.72
Wage Markup	47.80	41.42	79.54
Preferences	5.11	4.94	1.79
Inv.Spec.Tech.	13.08	14.27	4.06
Gov't Exp	9.51	11.54	2.55
Monetary Policy	7.19	8.29	1.69

Asymptotic Variance approximated by the 200-periods ahead variance.

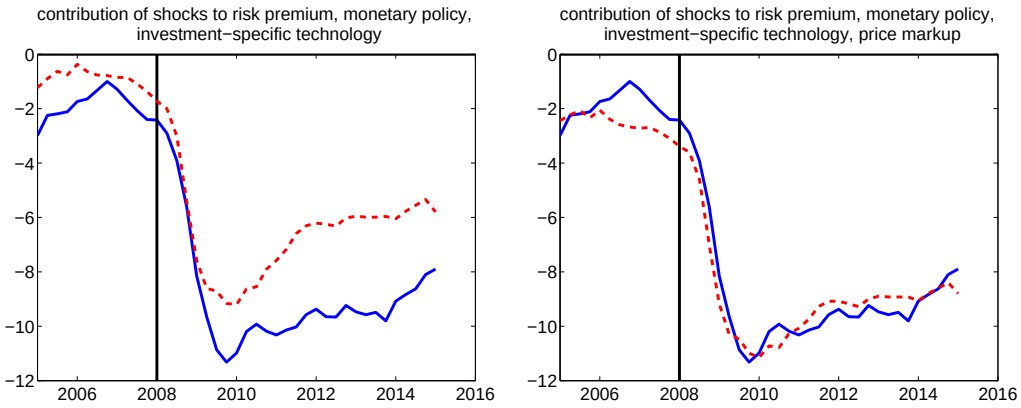

Figure G.38: Historical shock decomposition of employment for the period 2005-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

Appendix H. Robustness Checks 2: Estimation results using sample 1984-2015

Table H.11: 4-quarters ahead Variance Decomposition of Inflation

	1948-2015	1948-2007	2008-2015
Technology	3.90	3.99	3.72
Price Markup	51.09	54.34	26.92
Wage Markup	27.04	22.09	61.72
Preferences	7.65	8.32	2.80
Inv.Spec.Tech.	3.54	3.88	1.65
Gov't Exp	0.43	0.48	0.16
Monetary Policy	6.33	6.88	3.01

Table H.12: Asymptotic Variance Decomposition of Inflation

	1948-2015	1948-2007	2008-2014
Technology	4.15	4.29	3.67
Price Markup	38.65	41.53	18.88
Wage Markup	31.92	26.34	67.52
Risk Premium	9.73	10.69	3.30
Inv.Adj.Cost	4.70	5.20	2.03
Gov't Exp	1.86	2.09	0.64
Monetary Policy	8.97	9.85	3.95

The asymptotic variance is approximated by the 200-periods ahead variance.

Table H.13: Standard Deviation of the Estimated Shocks

	1948-2007	2008-2015
Technology	0.47	0.64
Price Markup	0.21	0.18
Wage Markup	0.27	0.55
Risk Premium	0.32	0.30
Inv.Spec.Tech.	0.56	0.43
Gov't Exp	0.65	0.45
Monetary Policy	0.22	0.15

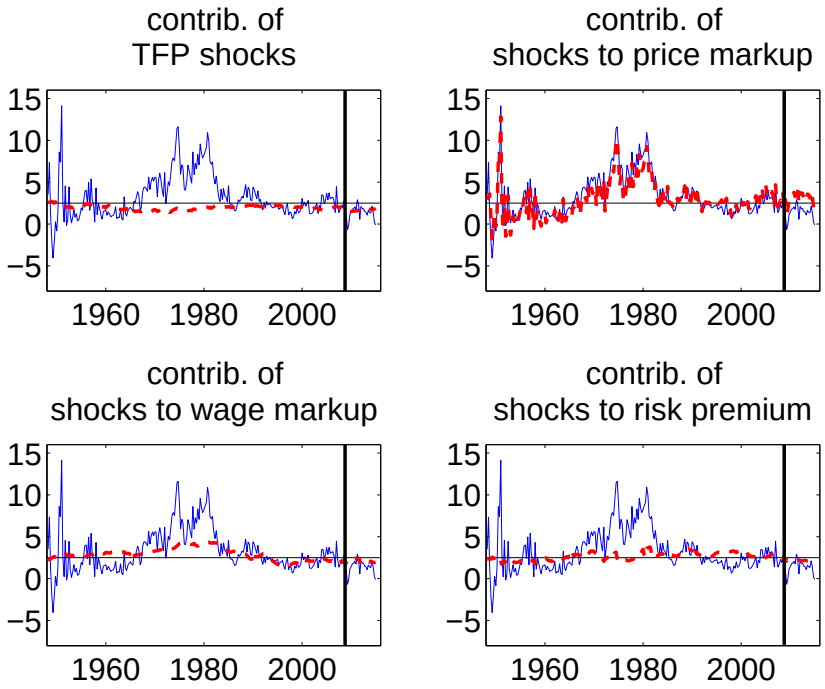

Figure H.39: Historical shocks decomposition of inflation (relative to long-run constant) for the period 1948Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

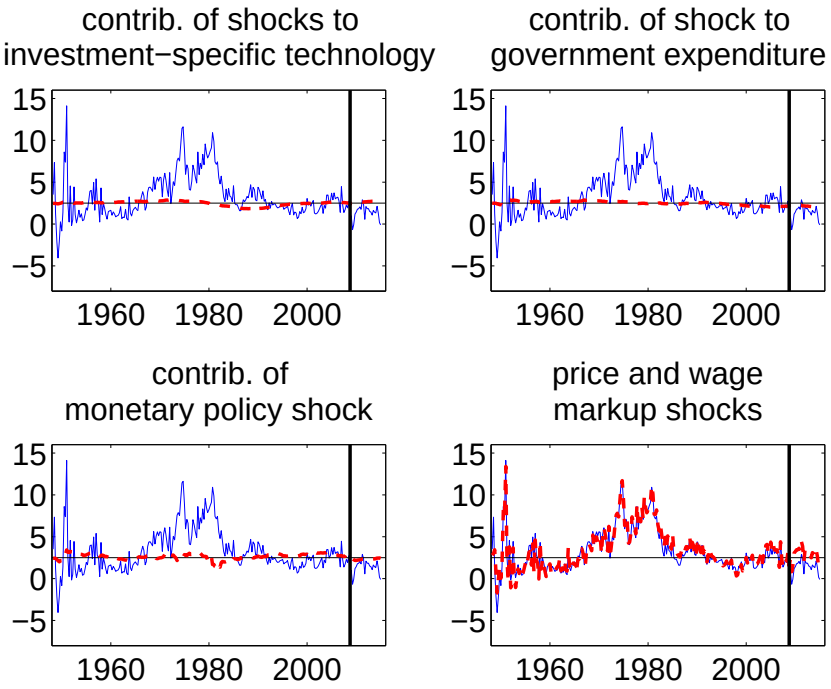

Figure H.40: Historical shocks decomposition of inflation (relative to long-run constant) for the period 1948Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

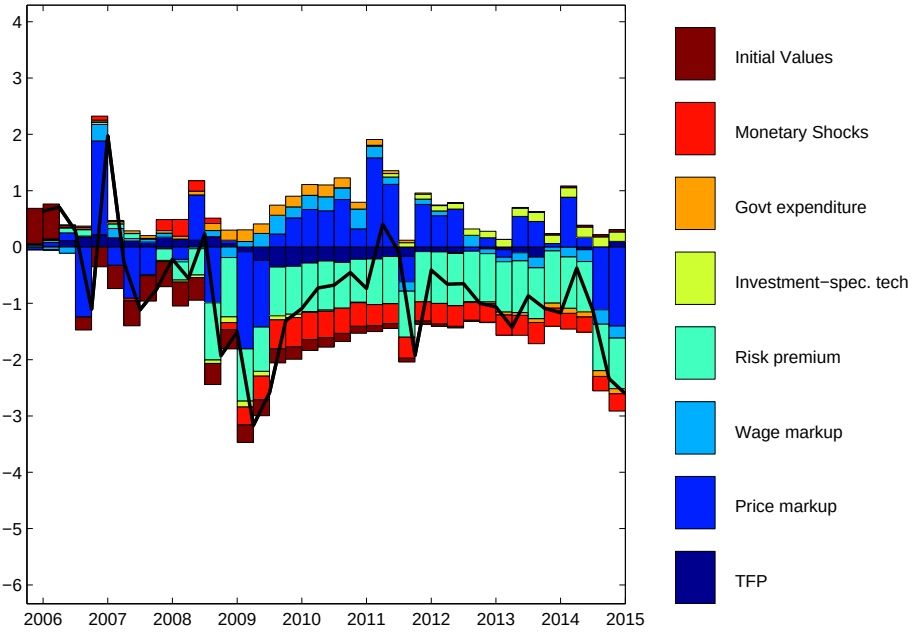

Figure H.41: Historical shock decomposition of inflation since 2006 Solid line is actual inflation.

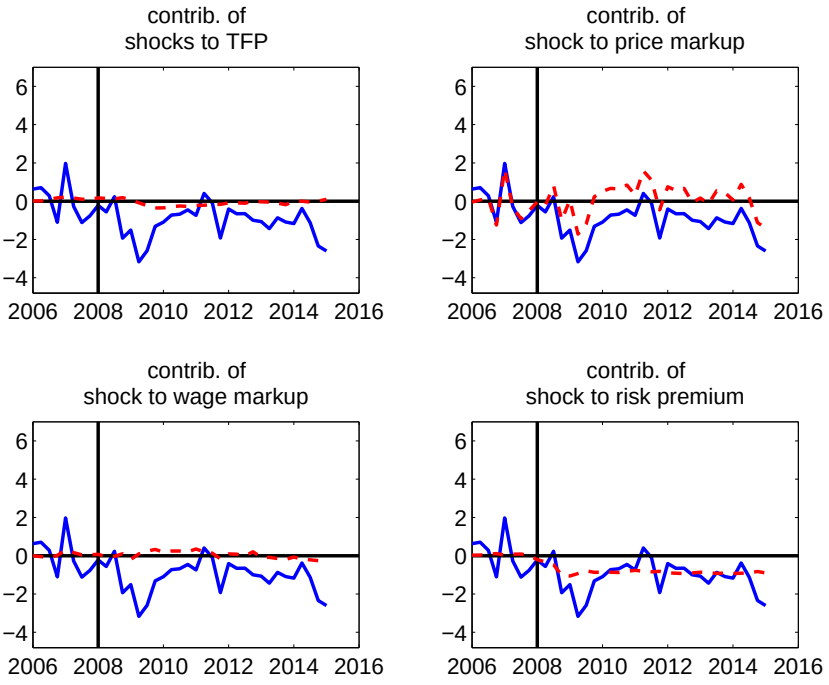

Figure H.42: Historical shock decomposition of inflation (relative to long-run constant) for the period 2006Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

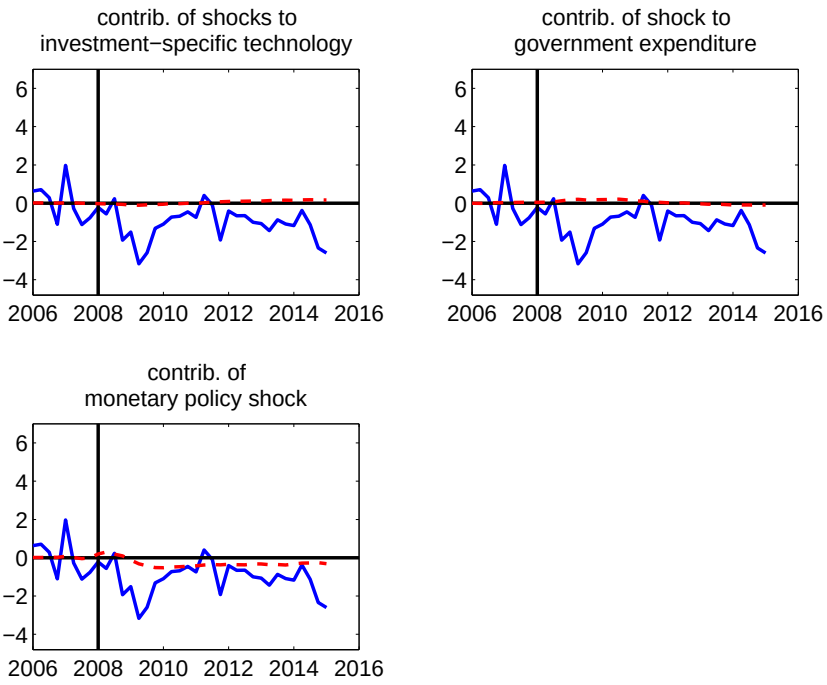

Figure H.43: Historical shock decomposition of inflation (relative to long-run constant) for the period 2006Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

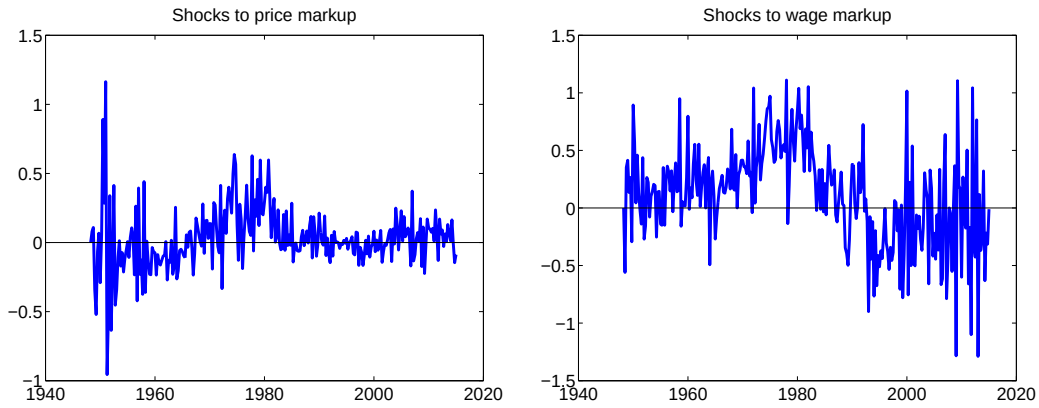

Figure H.44: Price and wage markup shocks estimated from the model.

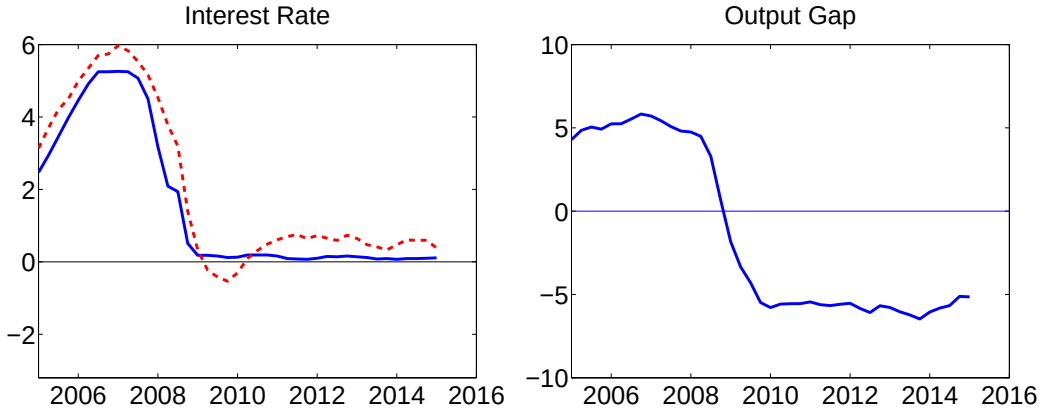

Figure H.45: A comparison between interest rate and the output gap. The left panel shows the actual interest rate (solid blue line) and the estimated interest rate in absence of monetary shocks (dashed red line) The right panel shows the output gap, which remains considerably below zero, long after 2008.

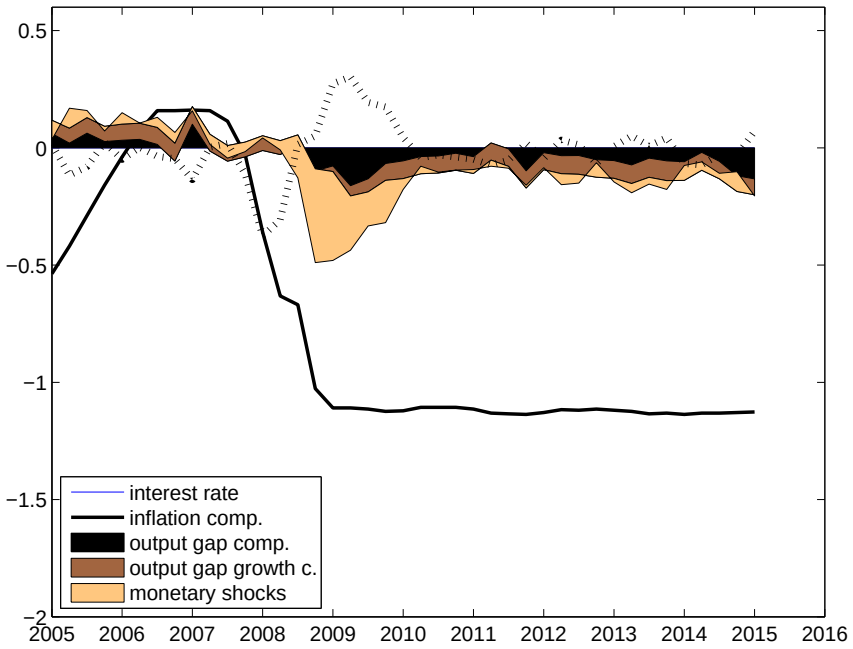

Figure H.46: Decomposition of the nominal interest rate according to the Taylor rule from the model. The solid black line is the time series for the nominal interest rate in deviations from its long-run average. The black shaded area is the component of the nominal interest rate (in deviation from its long-run average) due to inflation. The brown shaded area is the output gap component. The beige shaded area represents the output gap growth component. The monetary shocks are represented by the dotted line.

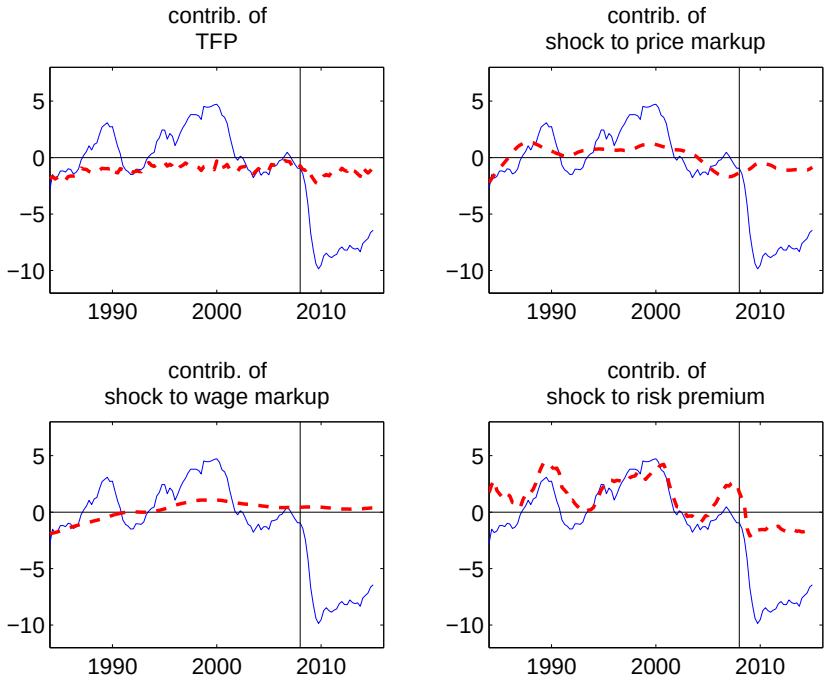

Figure H.47: Historical shock decomposition of employment for the period 1984-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

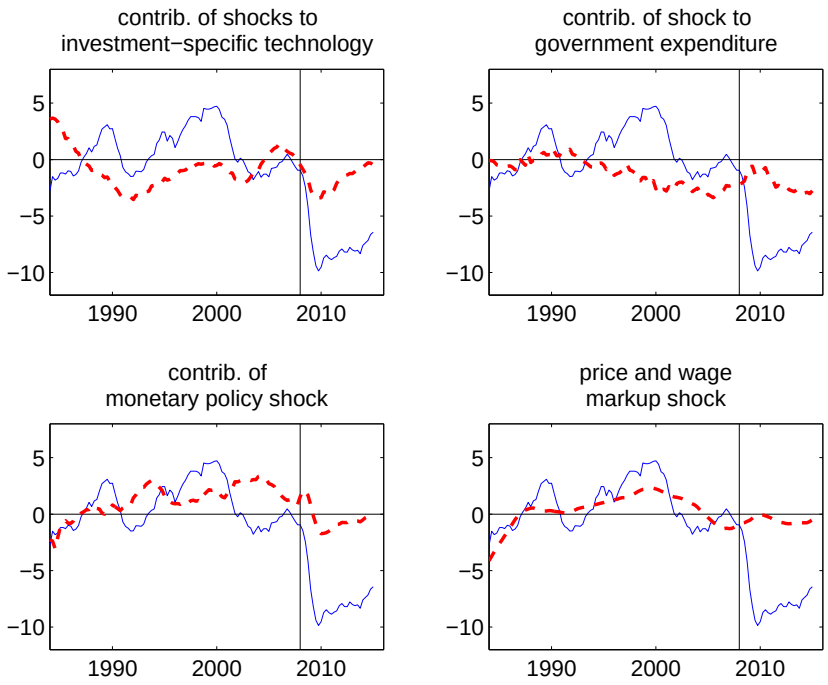

Figure H.48: Historical shock decomposition of employment for the period 1984-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

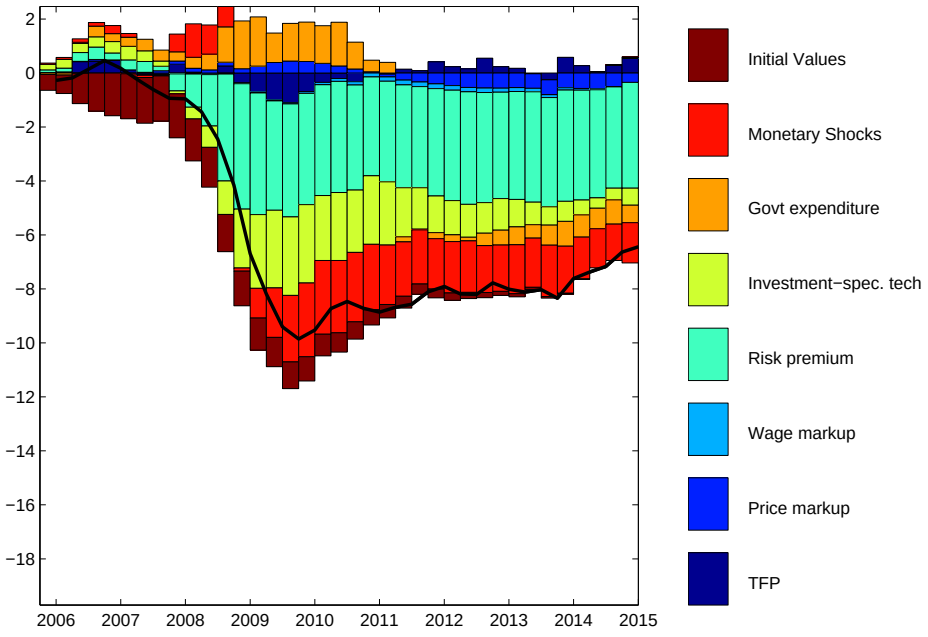

Figure H.49: Historical shock decomposition of the employment

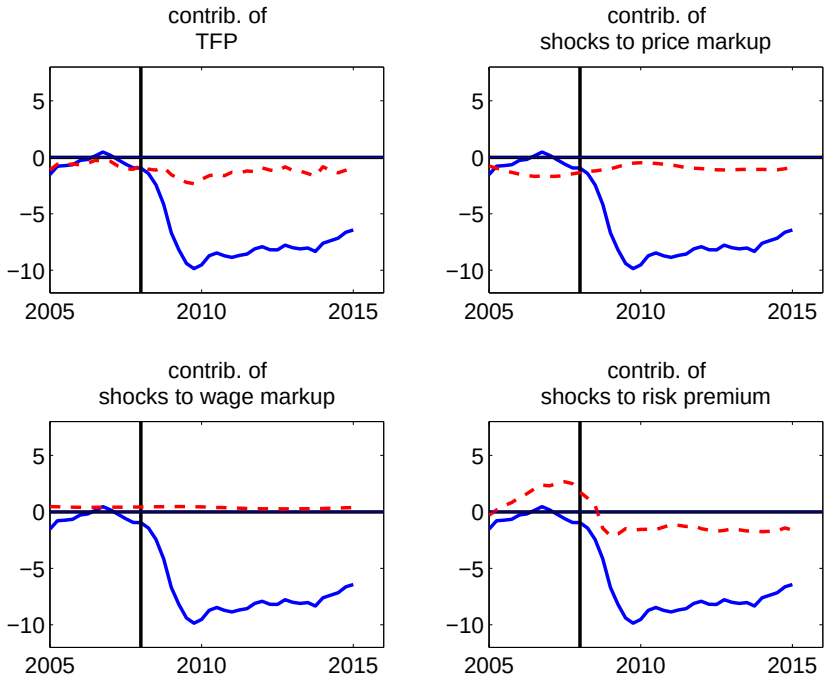

Figure H.50: Historical shock decomposition of employment for the period 2005-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

Table H.14: 4-periods ahead Variance Decomposition of Employment

	1948-2015	1948-2007	2008-2015
Technology	1.40	1.32	2.94
Price Markup	4.18	4.09	4.86
Wage Markup	1.36	1.02	6.83
Preferences	37.51	37.53	30.27
Inv.Spec.Tech.	24.64	24.87	25.35
Gov't Exp	11.68	11.95	9.57
Monetary Policy	19.23	19.22	20.17

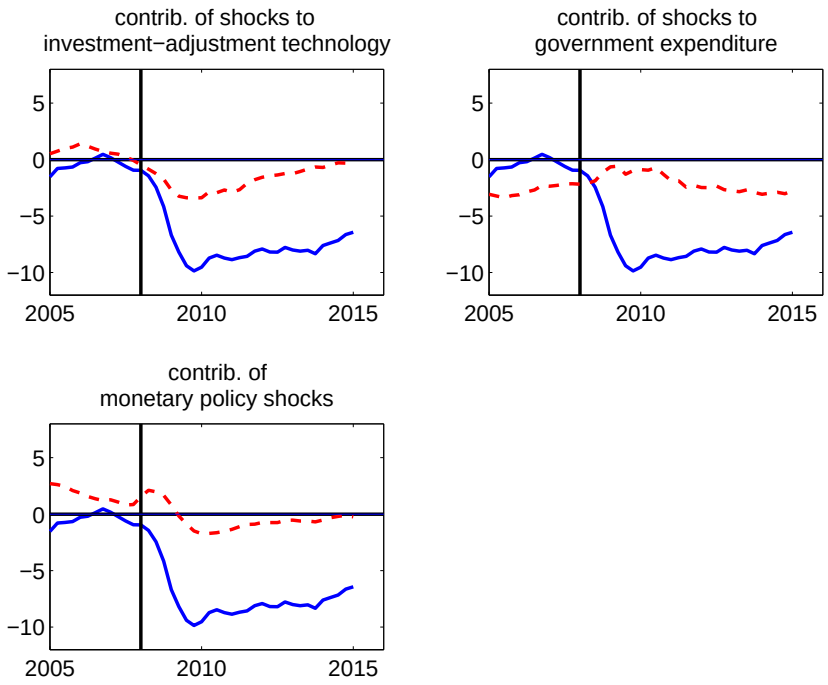

Figure H.51: Historical shock decomposition of employment for the period 2005-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

Table H.15: Asymptotic Variance Decomposition of Employment

	1948-2015	1948-2007	2008-2015
Technology	3.36	3.36	3.63
Price Markup	16.07	16.70	9.59
Wage Markup	23.09	18.43	59.70
Risk Premium	17.10	18.16	7.09
Inv.Adj.Cost	16.67	17.86	8.82
Gov't Exp	13.47	14.65	5.67
Monetary Policy	10.20	10.82	5.49

Asymptotic Variance approximated by the 200-periods ahead variance.

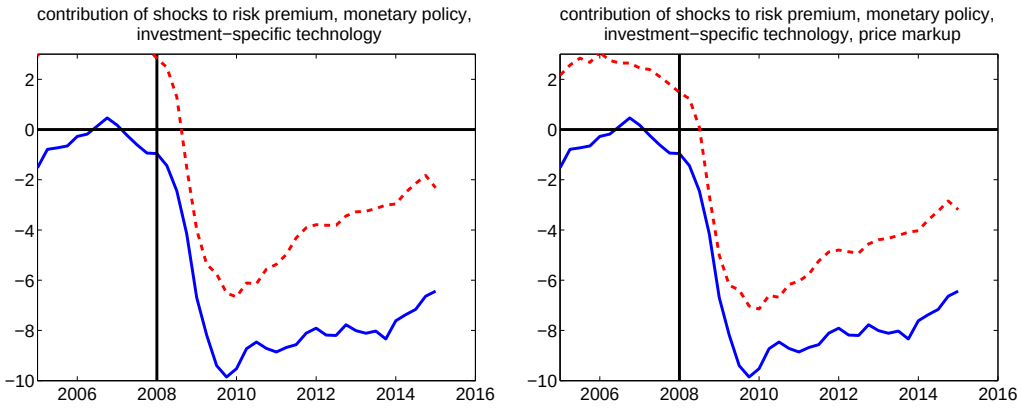

Figure H.52: Historical shock decomposition of employment for the period 2005-2015. Solid line is actual employment. The dashed line is employment predicted by each shock individually.

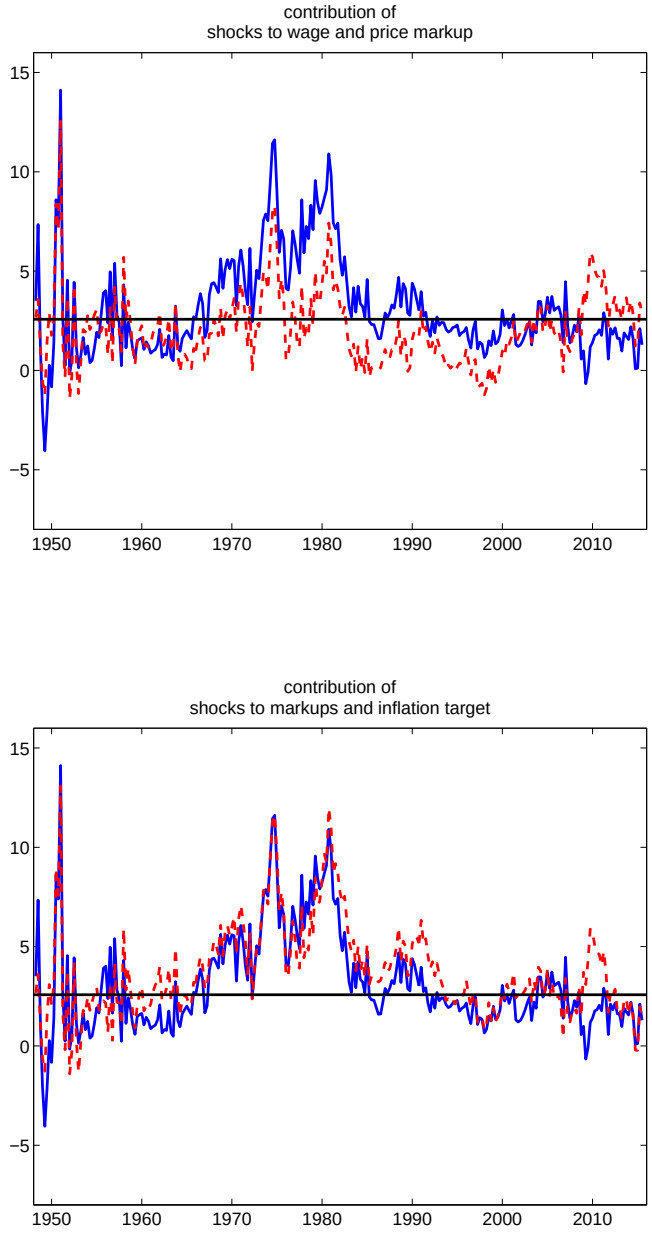

Figure H.53: Accounting for inflation in a model with time-varying inflation target, using the calibrated value of 0.99 for the inflation target autoregression coefficient.

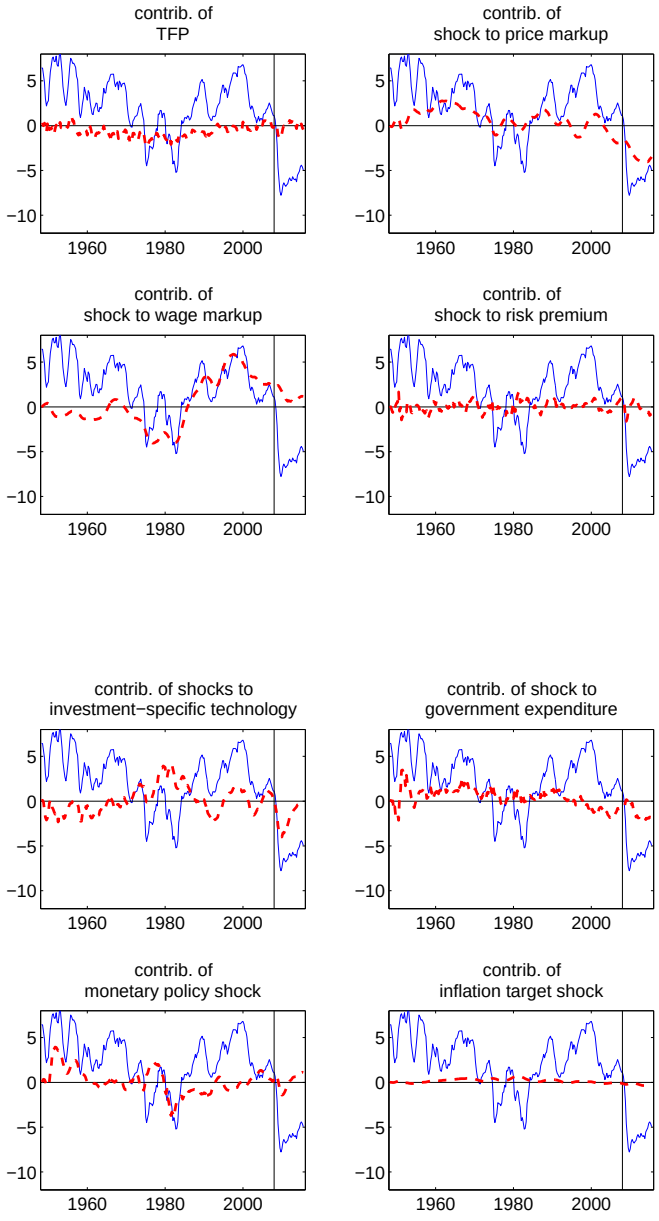

Figure H.54: Accounting for the movements in employment, when the inflation target autoregression is set to 0.99.

Appendix I. Extensions to the model

Appendix I.1. Estimation results

Table I.16: Extensions to the model - Posterior distributions

		Inflation Target		Financial Frictions
		mode(1)	mode(2)	
$\sigma(e_Z)$	TFP	0.0145	0.0163	0.496
$\sigma(e_{b^2})$	risk premium	0.0090	0.0258	0.038
$\sigma(e_g)$	gov't exp	0.0244	0.0265	2.908
$\sigma(e_\mu)$		0.0356	0.0225	0.503
$\sigma(e_{ms})$	monetary shock	0.0098	0.0078	0.292
$\sigma(e_p)$	price shock	0.0193	0.0132	0.154
$\sigma(e_w)$	wage shock	0.0157	0.0137	0.257
ρ_Z		0.9818	0.9786	0.956
ρ_{b^2}		0.1539	0.107	0.944
ρ_g		0.9604	0.9688	0.979
ρ_μ		0.6469	0.593	0.644
ρ_{ms}		0.1798	0.205	0.067
ρ_p		0.9824	0.9854	0.794
ρ_w		0.9532	0.9663	0.661
θ_p	price MA	0.8987	0.9083	NA
θ_w	wage MA	0.8886	0.9172	NA
$S''(\gamma)$	inv. adj cost	5.8576	5.4273	3.044
σ_c	intertemp elast	1.8582	1.641	1.316
h	habits	0.6536	0.665	0.244

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Table I.16 – continued from previous page

		Inflation Target		Financial Frictions
		mean(1)	mean(2)	Del Negro et al. (2015)
ζ_w	wage stickiness	0.7605	0.7847	0.888
ν_L	labor	1.9525	1.8053	2.673
ζ_p	price stickiness	0.6752	0.666	0.868
ι_w	wage index	0.4726	0.4031	0.419
ι_p	price index	0.2453	0.2972	0.226
$czcap$	capital utiliz.	0.3931	0.3945	0.188
Φ	fixed cost	1.7419	1.7339	1.526
ψ_1	monetary p.	2.0338	1.8805	1.374
ρ_R	monetary p.	0.8832	0.8665	0.675
ψ_2	monetary p.	0.1296	0.0679	0.018
ψ_3	monetary p.	0.148	0.1468	0.240
$const_\pi$	measurem eq	0.67	0.6153	0.766
$constebeta$	measurem eq	0.2562	0.2179	0.401
$const_L$	measurem eq	1.35	0.4973	0.4973
$const\_SP$	measurem eq	NA	NA	1.908
$ctrend$	growth rate	0.5146	0.4881	0.401
ρ_{gZ}	gov't exp	0.6107	0.6752	0.874
α	$\frac{k_*}{y_*}$	0.2846	0.2795	0.179
ρ_{π^*}	infl. target shock	0.5141	0.990*	0.990
σ_{π^*}	infl. target shock	0.0040	0.0053	0.030
ρ_n	fin. frict.	NA	NA	0.990
σ_n	fin. frict.	NA	NA	0.057
ζ_{spb}	fin. frict.	NA	NA	0.044

Mean(2): AR parameter for inflation target stochastic process parametrized to 0.99.

In addition to the ones listed above, the evolution law of the entrepreneurs' net worth in DGS's model has the following parameter values

Table I.17: Parameters in the evolution law for the entrepreneurs' net worth in DGS's model

α_1	1.6938
α_2	0.693
α_3	0.0021
α_4	0.9987
α_5	-0.1252

Appendix I.2. Additional results from the alternative specifications of the model

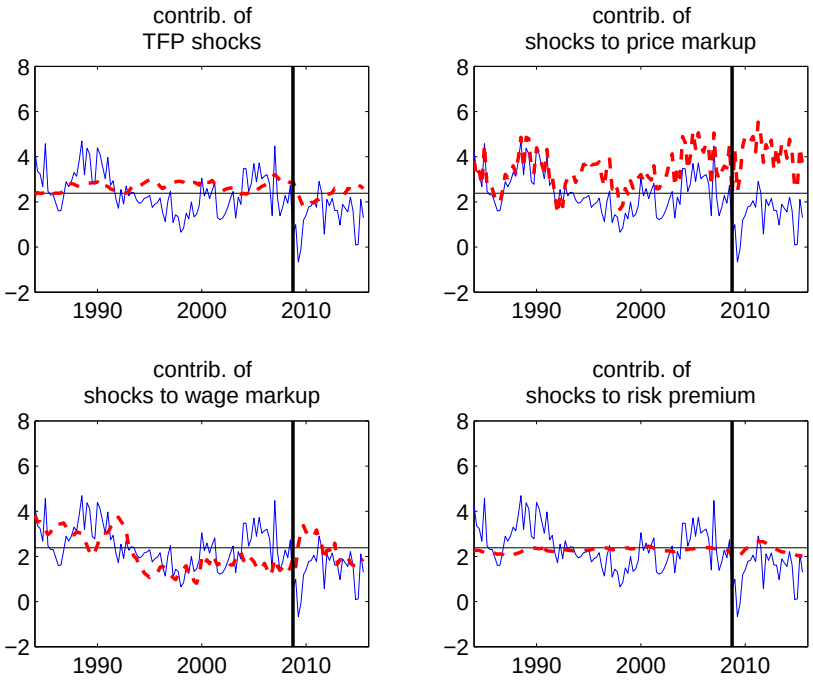

Figure I.55: Model with time-varying inflation target. Historical shocks decomposition of inflation (relative to long-run constant) for the period 1984Q1-2015Q1. Posterior distributions according to mean 1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

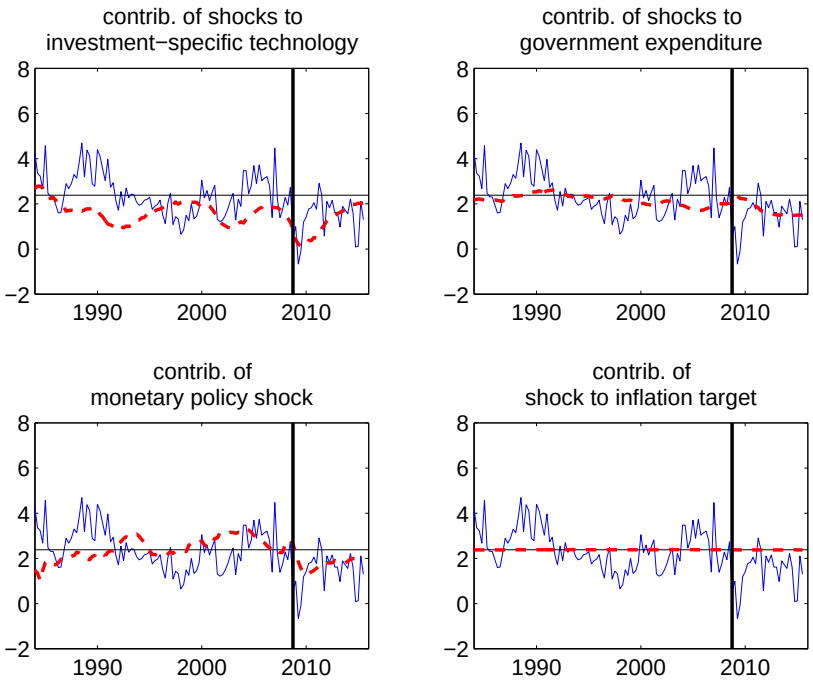

Figure I.56: Model with time-varying inflation target. Historical shocks decomposition of inflation (relative to long-run constant) for the period 1984Q1-2015Q1. Posterior distributions according to mean 1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

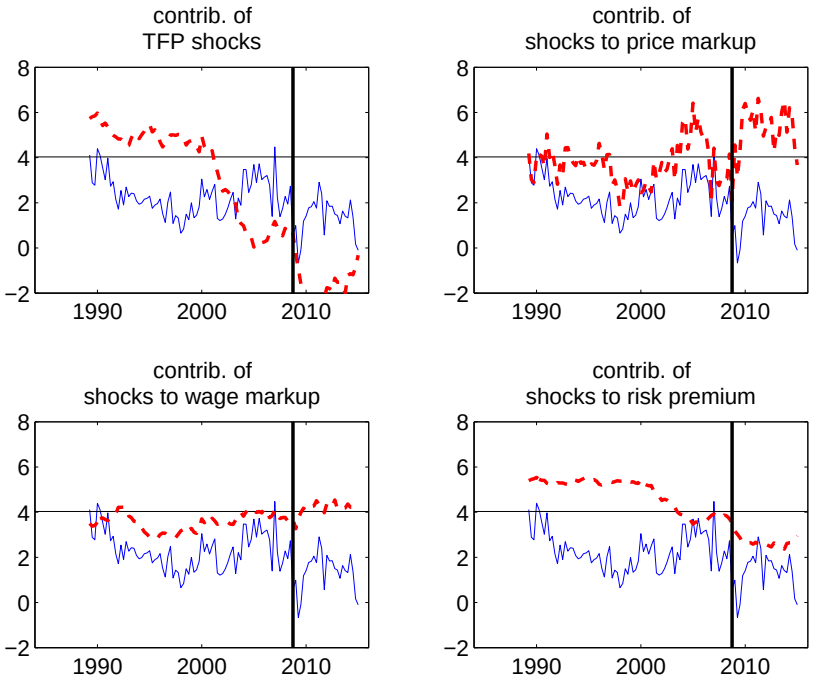

Figure I.57: Del Negro, Giannoni and Schorfheide (2015) . Historical shocks decomposition of inflation (relative to long-run constant) for the period 1984Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

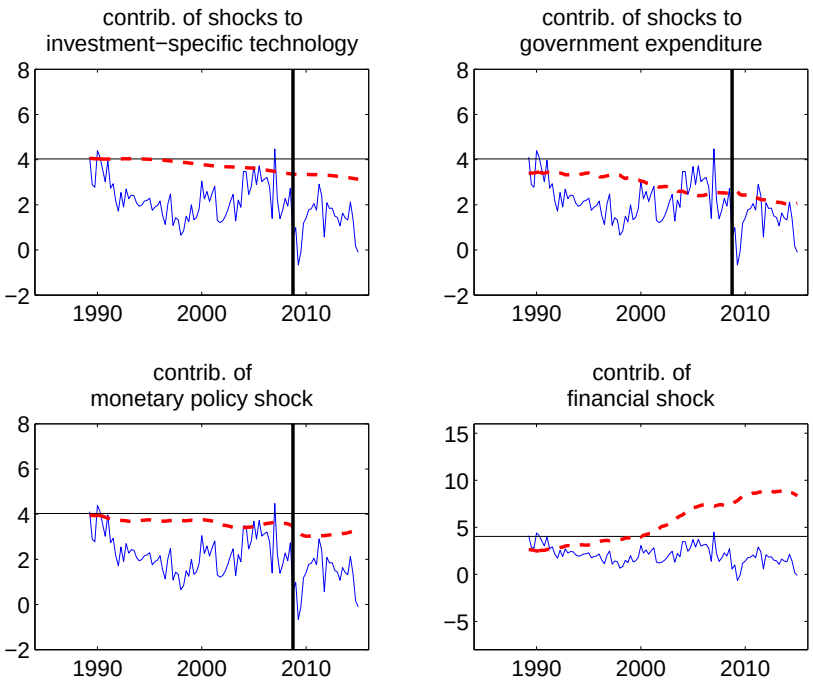

Figure I.58: Del Negro, Giannoni and Schorfheide (2015) . Historical shocks decomposition of inflation (relative to long-run constant) for the period 1984Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

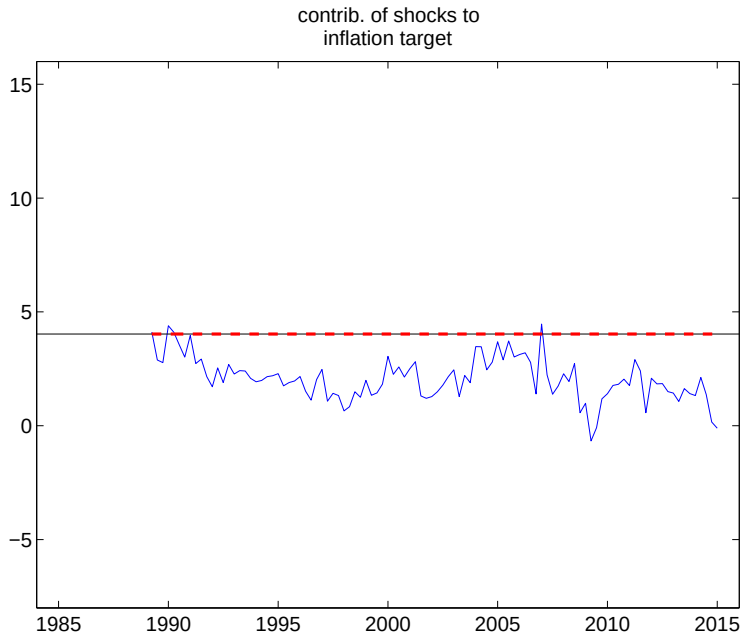

Figure I.59: Del Negro, Giannoni and Schorfheide (2015) . Historical shocks decomposition of inflation (relative to long-run constant) for the period 1984Q1-2015Q1. Solid line is actual inflation. The dashed line is inflation predicted by each shock individually.

References

Del Negro, Marco, Marco P. Giannoni, and Frank Schorfheide. 2015. "Inflation in the Great Recession and New Keynesian Models." *American Economic Journal: Macroeconomics*, 7(1): 168–196.

Hall, Robert. 2011. "The Long Slump." *American Economic Review*, 101(2): 431–469.

Smets, Frank, and Raf Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *The American Economic Review*, 97(3): 586–606.