How Bad was Lehman Shock?:

Estimating a DSGE model with Firm and Bank Balance Sheets in a Data-Rich Environment*

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* The views expressed in this presentation are those of the presenter and does not necessarily reflect those of ESRI or Cabinet Office, Government of Japan.

Motivation of this paper

- Recent financial crisis in U.S. which was precipitated by so-called 'Lehman Shock' has exemplified that deterioration of balance sheet condition, especially that of financial sector, can cause a deep and long-lasting recession.

- As Alan Greenspan puts, "**We are in the midst of a once-in-a century credit tsunami**." (Testimony made at the House of Representatives, Oct. 23, 2008)

- Since two years have past since Lehman Shock, time seems to be ripe in assessing the impact of the shock.

Objective of this paper

- In this paper, we quantify and assess the impact of Lehman Shock.
- We ask two questions:
  - How large was the magnitude of Lehman Shock?
  - How large was the effect of Lehman Shock to the economy?
- Strategy: We identify Lehman Shock by banking sector net worth shock.

Contributions of this paper

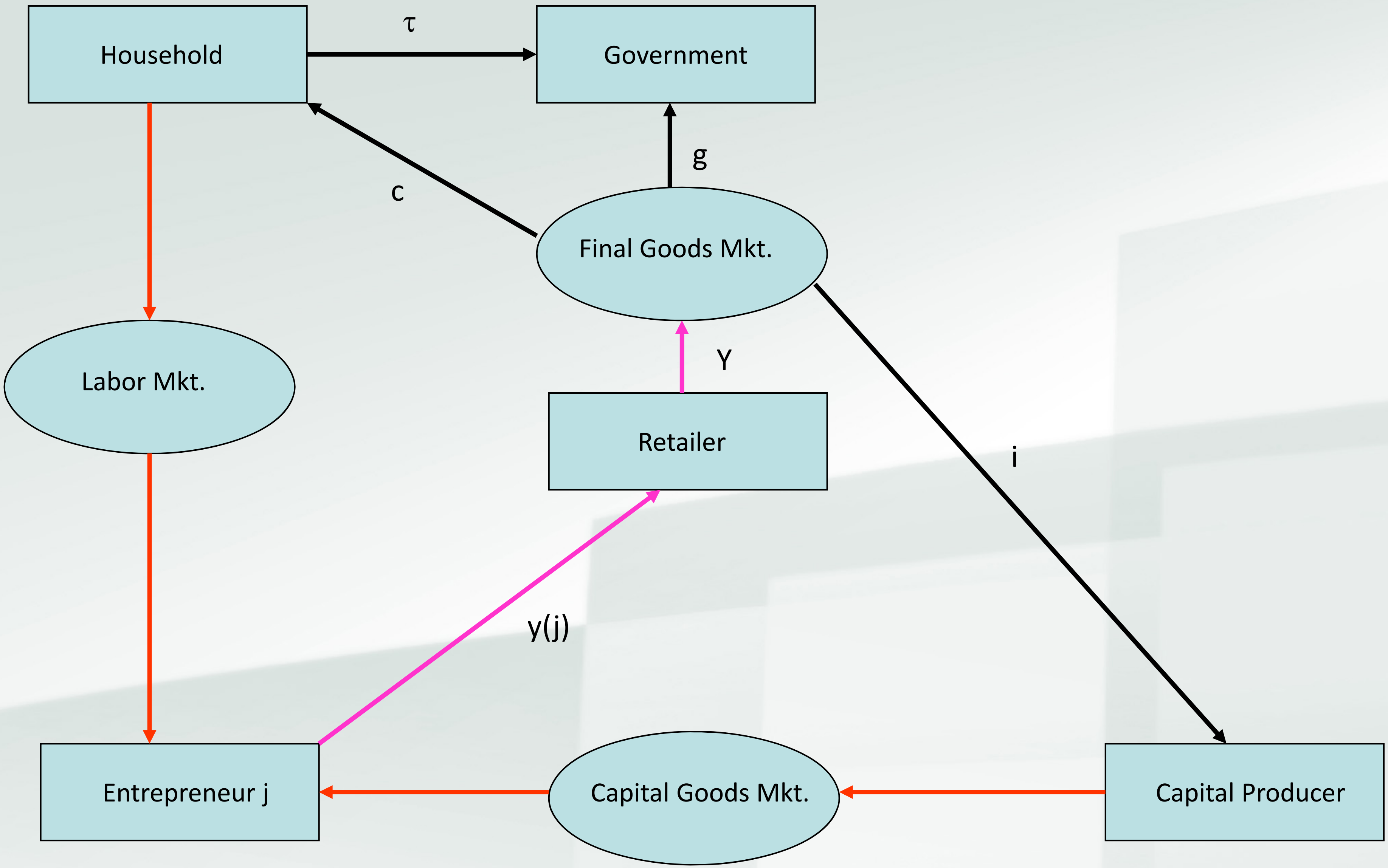
- We combine two canonical financial friction models.
  - For corporate balance sheet, we adopt BGG (1999)
  - For bank balance sheet, we adopt Gertler and Kiyotaki (2010) and Gertler and Karadi (2010)
  - We need to model two balance sheets to identify Lehman Shock
  - Related work is Hirakata, Sudo, and Ueda (2010)

- We adopt Data-Rich method proposed by Boivin and Giannoni (2006)
  - By utilizing multiple time series information for each observable, we can expect an improved efficiency in estimating parameters and structural shocks.

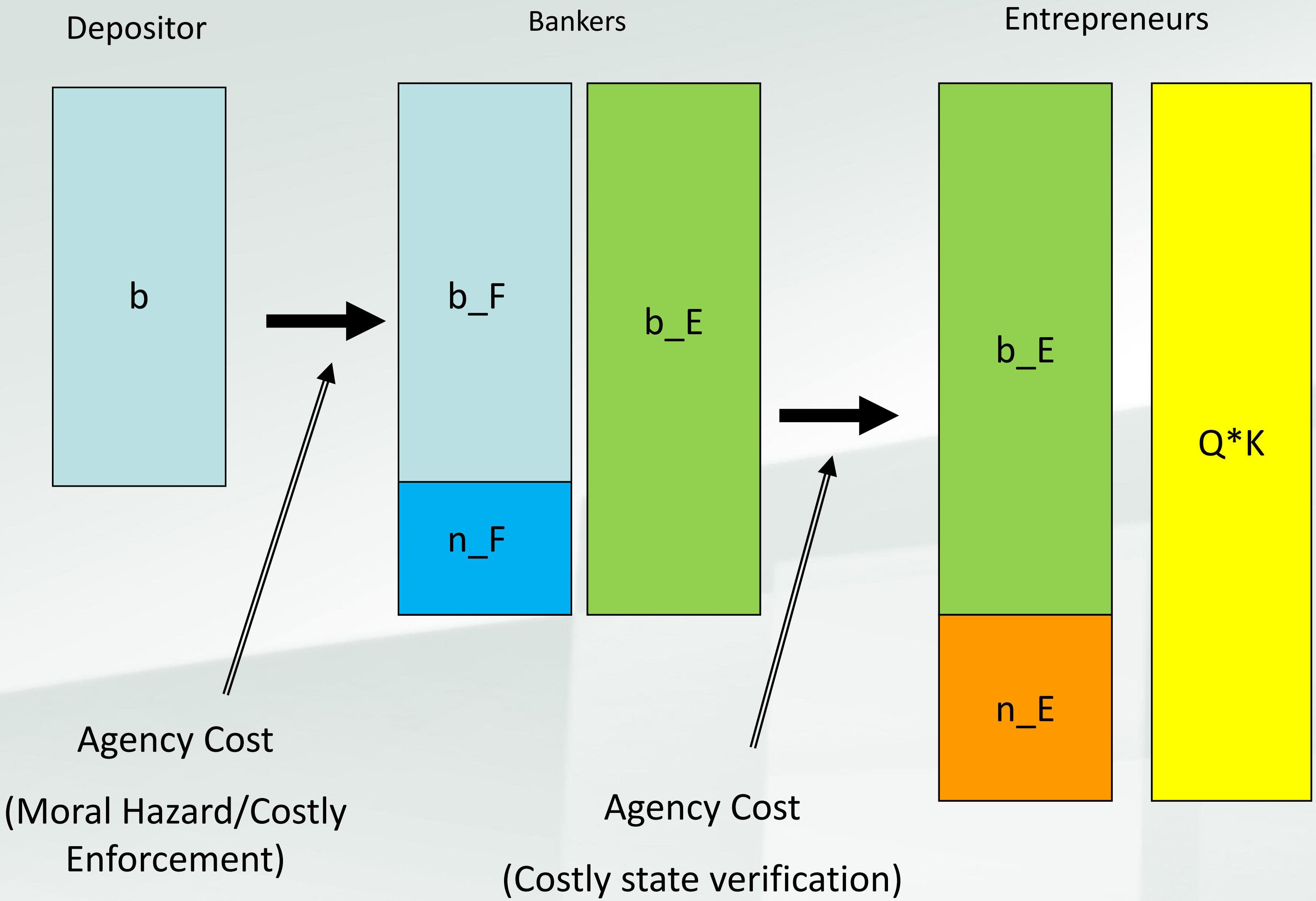
Model Description

- The idea is to embed corporate balance sheet and bank balance sheet to the stylized DSGE model.
- Includes standard features: habit formation, sticky price, sticky wage, investment-adjustment cost, Taylor rule, etc.
- There are 8 structural shocks: TFP shock, preference shock, labor supply shock, investment-specific technology shock, govt. expenditure shock, monetary policy shock, **entrepreneur net worth shock**, and **bank net worth shock**

Goods and Factor Inputs Flow Chart



Financial Flow Chart



Model Description

- Representative Household with continuum of members which measures to 1.
- Fraction of f^E become entrepreneurs
- Fraction of f^F become financial intermediaries (or bankers)
- Fraction of $1 - f^E - f^F$ become workers

Model Description

- Representative Household's Problem

$$\mathrm{E}_t \sum_{i=0}^{\infty} \beta^i \chi_{t+i}^c \left[\frac{(c_{t+i} - hc_{t+i-1})^{1-\sigma^c}}{1-\sigma^c} - \chi_{t+i}^L \frac{(l_{t+i})^{1+\sigma^L}}{1+\sigma^L} \right]$$

$$\underbrace{c_t}_{\text{consumption}} + \underbrace{\mathrm{b}_t}_{\text{deposit}} = \frac{\mathrm{R}_{t-1}}{\pi_t} \mathrm{b}_{t-1} - \tau_t + \underbrace{w_t}_{\text{labor income}} + \underbrace{\Xi_t^{\mathrm{div}}}_{\text{dividend}} + \underbrace{\Xi_t^{\mathrm{E}}}_{\text{net transfer from entrepreneur}} + \underbrace{\Xi_t^{\mathrm{F}}}_{\text{net transfer from bankers}}$$

Model Description: Entrepreneur's Problem

- Faces stochastic survival rate, γ^E_{t+1}
- Each entering entrepreneur receives 'start-up' transfer from the household. Total 'start-up' transfer is $\xi^E n^E_t$
- For exiting 1- γ^E_{t+1} entrepreneurs, they transfer their existing net worth back to household.
- So, the net transfer that household receive is

  $(1- \gamma^E_{t+1} - \xi^E) n^E_t$

Model Description: Entrepreneur's Problem

- Production Function: $y_t(j) = \underbrace{\omega_t(j)}_{\text{idiosyncratic Shock}} \underbrace{A_t}_{\text{TFP Shock}} k_t(j)^{\alpha} l_t(j)^{1-\alpha}$

- Balance sheet equation is given by

$$\underbrace{q_t k_{t+1}(j)}_{\text{Asset}} = \underbrace{b_t^E(j)}_{\text{Liability}} + \underbrace{n_t^E(j)}_{\text{Net Worth}}$$

- Income statement equation is given by

$$n_t^E(j) = \underbrace{p_t^{mc}(j) y_t(j)}_{\text{revenue}} - \underbrace{w_t l_t}_{\text{labor cost}} - \underbrace{\frac{R_{t-1}^E(j)}{\pi_t} b_{t-1}^E(j)}_{\text{borrowing cost}} + \underbrace{q_t (1-\delta) k_t(j)}_{\text{resale value of capital}}$$

Model Description: Entrepreneur's Problem

- Capital demand equation is given by

$$\underbrace{E_t\left[\frac{R_t^E(j)}{\pi_{t+1}}\right]}_{\substack{\text{expected corporate}\\ \text{real borrowing rate}}} = \underbrace{E_t\left[\frac{p_{t+1}^{mc}(j)mpk_{t+1}(j)+(1-\delta)q_{t+1}}{q_t}\right]}_{\text{expected marginal return of capital investment}}$$

- Debt contract between entrepreneur and banker
  - Exist information asymmetry: costly state verification

$$\underbrace{s_t(j)}_{\substack{\text{external finance}\\ \text{premium}}} = s\underbrace{\left(\frac{q_t k_{t+1}(j)}{n_t^E(j)}\right)}_{\text{leverage ratio}} \qquad \underbrace{E_t R_{t+1}^F(m)}_{\substack{\text{risk-adjusted}\\ \text{lending rate}}} = \frac{R_t^E(j)}{s_t(j)}$$

Model Description: Entrepreneur's Problem

- Aggregation
  - Thanks to constant-return-to-scale production technology and risk-neutrality of entrepreneur, marginal cost, MPL, MPK, and leverage ratio are the same across entrepreneurs.

- Aggregate net worth transition

$$n_{t+1}^{E} = \gamma_{t+1}^{E}[\underbrace{r_{t+1}^{k} q_t k_{t+1}}_{\text{realized gross return from capital}} - \underbrace{\frac{R_t^E}{\pi_{t+1}} b_t^E}_{\text{debt repayment}}] + \underbrace{\xi^E n_t^E}_{\text{start-up transfer from household}}$$

- Notice that stochastic survival rate act like an aggregate net worth shock in corporate sector

Model Description: Banker's Problem

- Faces stochastic survival rate, γ^F_{t+1}
- Each entering banker receives 'start-up' transfer from the household. Total 'start-up' transfer is $\xi^F n^F_t$
- For exiting 1- γ^F_{t+1} bankers, they transfer their existing net worth back to the household.
- So, the net transfer that household receive is

  $(1- \gamma^F_{t+1} - \xi^F) n^F_t$

Model Description: Banker's Problem

- Balance sheet equation is given by

$$\underbrace{b_t^E(m)}_{\text{banker's asset}} = \underbrace{b_t^F(m)}_{\text{banker's liability}} + \underbrace{n_t^F(m)}_{\text{banker's net worth}}$$

  - Notice that banker's asset becomes entrepreneur's liability

- Income statement equation is given by

$$n_{t+1}^F(m) = \underbrace{\frac{R_{t+1}^F(m)}{\pi_{t+1}} b_t^E(m)}_{\text{gross return from lending}} - \underbrace{\frac{R_t}{\pi_{t+1}} b_t^F(m)}_{\text{debt repayment}}$$

Model Description: Banker's Problem

- Banker's objective function is given by

$$V_t^F(m) = \underbrace{E_t \sum_{i=0}^{\infty} \beta^i (1-\gamma_{t+1}^F)\gamma_{t+1,\,t+1+i}^F n_{t+1+i}^F}_{\text{net present value of banking business}}$$

- Moral hazard / costly enforcement problem
  - Banker has a technology to divert fraction λ of his asset
  - Incentive constraint for a banker to remain in business becomes

$$V_t^F(m) \geq \underbrace{\lambda b_t^E(m)}_{\substack{\text{reservation value}\\\text{retained by banker}}}$$

Model Description: Banker's Problem

- Imposing this constraint, Gertler and Kiyotaki (2010) shows the NPV of banking business to be

$$V_t^F(m) = \nu_t b_t^E(m) + \eta_t n_t^F(m)$$

- Also, they show bank leverage ratio to be constrained by

$$\underbrace{\frac{b_t^E(m)}{n_t^F(m)}}_{\text{bank leverage ratio}} \leq \phi_t \equiv \frac{\eta_t}{\lambda - \nu_t}$$

- Notice the similarity with Basel Regulation

Model Description: Banker's Problem

- Aggregation
  - Gertler and Kiyotaki (2010) shows that ν_t, η_t, and ϕ_t to be equal across bankers which makes the aggregation very simple.
  - Also given that $E_t R^F_t(m)$ is equal across m, we can obtain the following aggregate transition of banking sector net worth.

- Aggregate net worth transition of banking sector

$$n^F_{t+1} = \gamma^F_{t+1}[\underbrace{\frac{\overline{R}^F_{t+1}}{\pi_{t+1}} b^E_t}_{\text{aggregate gross return from lending}} - \underbrace{\frac{R_t}{\pi_{t+1}} b^F_t}_{\text{aggregate gross debt repayment}}] + \underbrace{\xi^F n^F_t}_{\text{start-up transfer from household}}$$

- Notice that stochastic survival rate act like an aggregate net worth shock in banking sector.

Model Description: Recap of Interest Rates

- There are two types of interest rate spreads in this model
  - External finance premium
  - Profit margin of bank lending rate

$$\underbrace{R_t^E \geq}_{\text{external finance premium}} \overline{R}_t^F \underbrace{\geq}_{\text{profit margin of bank lending rate}} R_t$$

Stemming from agency problem between entrepreneur and banker:

Costly state verification

Stemming from agency problem between banker and depositor:

Moral hazard / costly enforcement

Data-Rich Estimation

- The idea of Boivin and Giannoni's (2006) Data-Rich method is to extract a common factor from multiple time series data and to match that with each observable variable in the model.
  - One-to-one matching (standard Bayesian estimation)
  - One-to-many matching (Data-Rich estimation)

- A merit of this approach is that we can expect improved efficiency in estimating parameters and structural shocks.

- Why Data-Rich estimation in this paper?
  - Since our focus is to obtain a reliable estimate of the impact of Lehman Shock, Data-Rich estimation is vital.

Data-Rich Estimation

- DSGE model in state-space form…

$$\underbrace{\mathbf{s_t}}_{(N\times 1)} = \underbrace{\Phi}_{(N\times N)} \underbrace{\mathbf{s_{t-1}}}_{(N\times 1)} + \underbrace{\Gamma}_{(N\times J)} \underbrace{\mathbf{u_t}}_{(J\times 1)} \quad \text{(optimal state transition eq.)}$$

$$\underbrace{\mathbf{x_t}}_{(M\times 1)} = \underbrace{\Lambda}_{(M\times N)} \underbrace{\mathbf{s_t}}_{(N\times 1)} + \underbrace{\mathbf{e_t}}_{(M\times 1)} \quad \text{(measurement equation)}$$

- The idea is to increase the dimension of $\mathbf{X}_t$ (i.e., larger M) by supplying multiple time series, while keeping the dimension of Φ, Γ, $\mathbf{s_t}$, and $\mathbf{u_t}$ constant.

  $\Rightarrow$ Can expect efficiency gain in estimating structural parameters, smoothing states and structural shocks.

Data-Rich Estimation: Measurement Eq.

- Case A set-up: (Standard Bayesian estimation)

$$\begin{bmatrix} \text{output data \#1} \\ \text{inflation data \#1} \\ \vdots \end{bmatrix} = \begin{bmatrix} 1 & 0 & \cdots \\ 0 & 1 & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix} \cdot \mathbf{s_t} + \mathbf{e_t}$$

- Case B set-up: (Data-Rich estimation)

$$\begin{bmatrix} \text{output data \#1} \\ \text{output data \#2} \\ \vdots \\ \text{output data \#}\,\mathrm{n_y} \\ \text{inflation data \#1} \\ \text{inflation data \#2} \\ \vdots \\ \text{inflation data \#}\,\mathrm{n}_\pi \\ \vdots \end{bmatrix} = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \lambda_{y2} & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ \lambda_{yn} & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ 0 & \lambda_{\pi 2} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \lambda_{\pi n} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \end{bmatrix} \cdot \mathbf{s_t} + \mathbf{e_t}$$

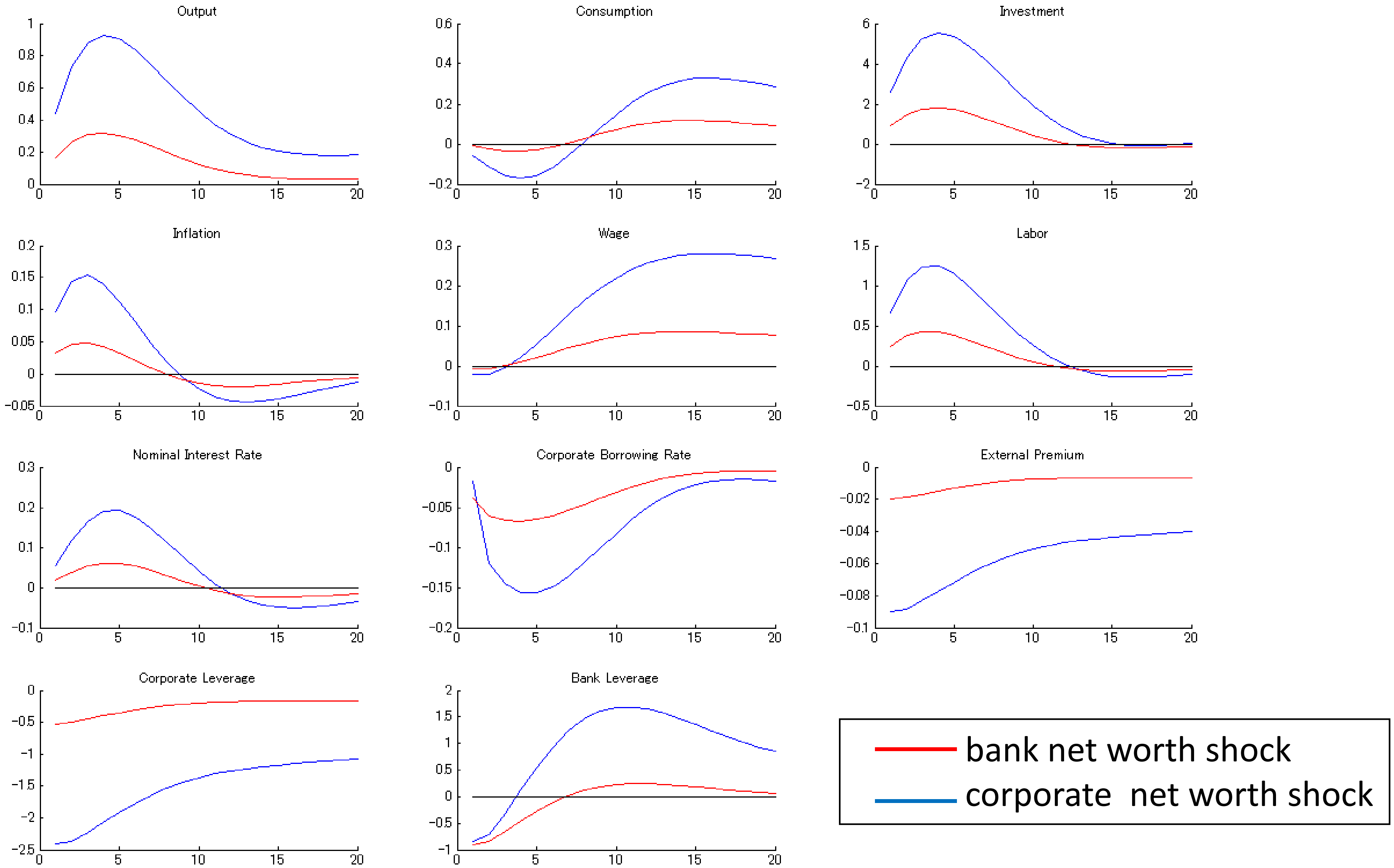
Data Set

- Sample Period: 1985Q2 to 2010Q2

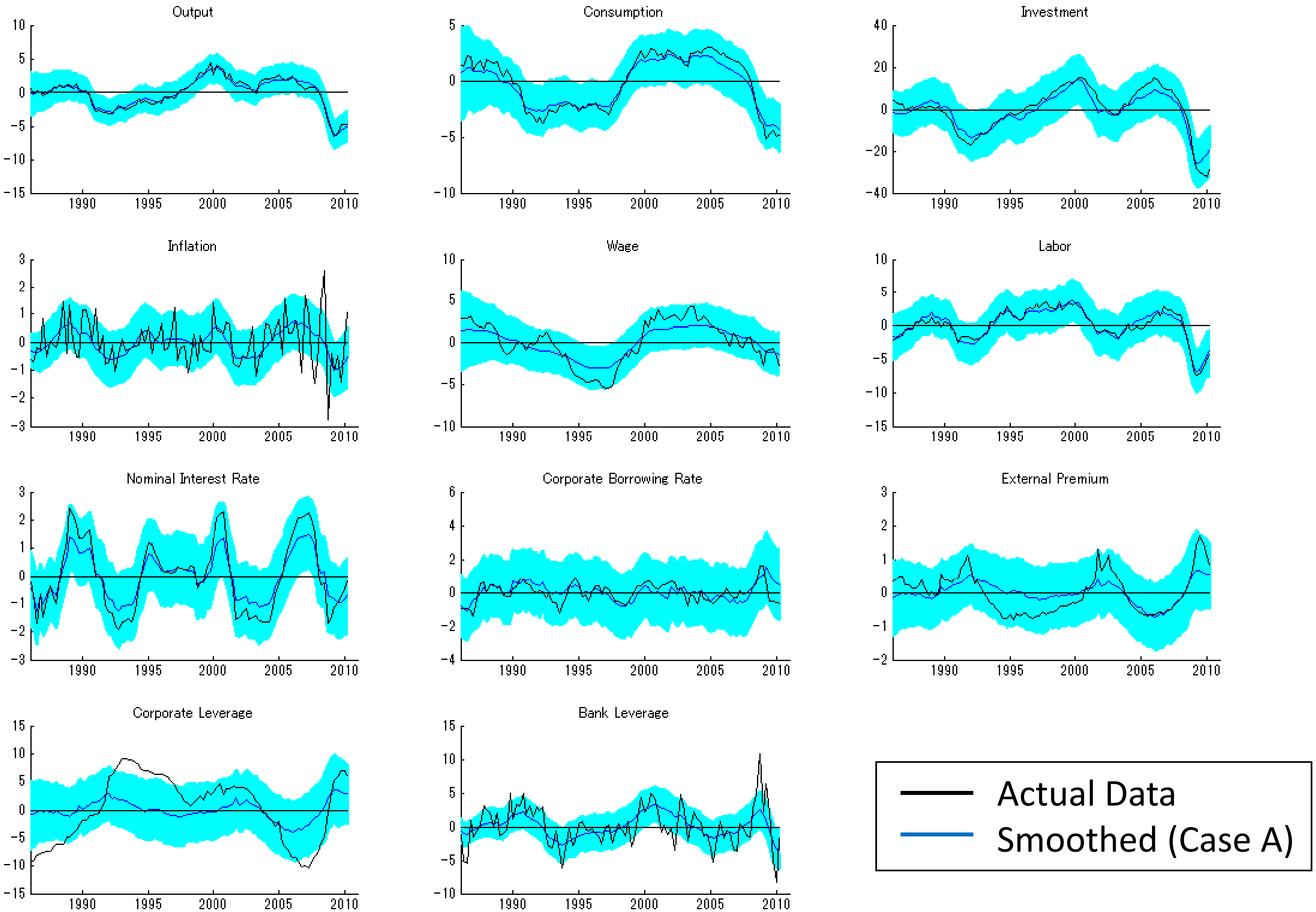
- Case A Data Set (11 data series)
  - 1. real GDP, 2. personal consumption expenditure, 3. business fixed investment, 4. GDP deflator, 5. real wage, 6. hours worked, 7. Fed Funds rate, 8. Moody's Baa corporate bond index, 9. business leverage ratio, 10. commercial bank leverage ratio, 11. charge-off rates (all financial institution)

- Case B Data Set (21 data series)
  - In addition to Case A data set…
  - 12. Personal consumption expenditure (non-durable), 13. Private domestic investment, 14. Price deflator (PCE), 15. Core CPI (ex. food and energy), 16. Civilian labor force, 17. Employees (total non-farm), 18. Core capital leverage ratio, 19. Domestically chartered commercial banks leverage ratio, 20. Charge-off rate (all loans and leases), 21. Charge-off rate (all loans)

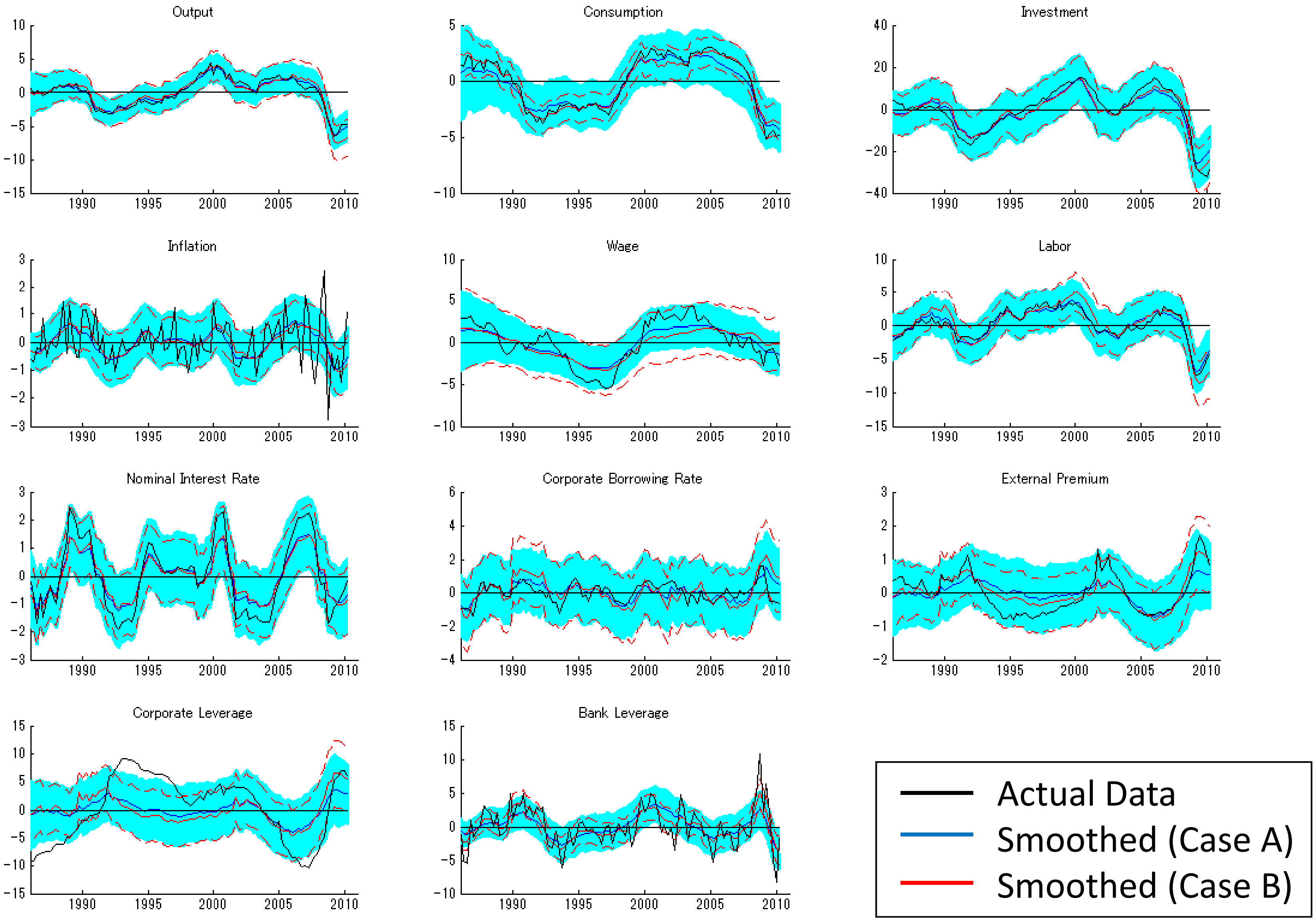
Estimation Results: Estimated IRF



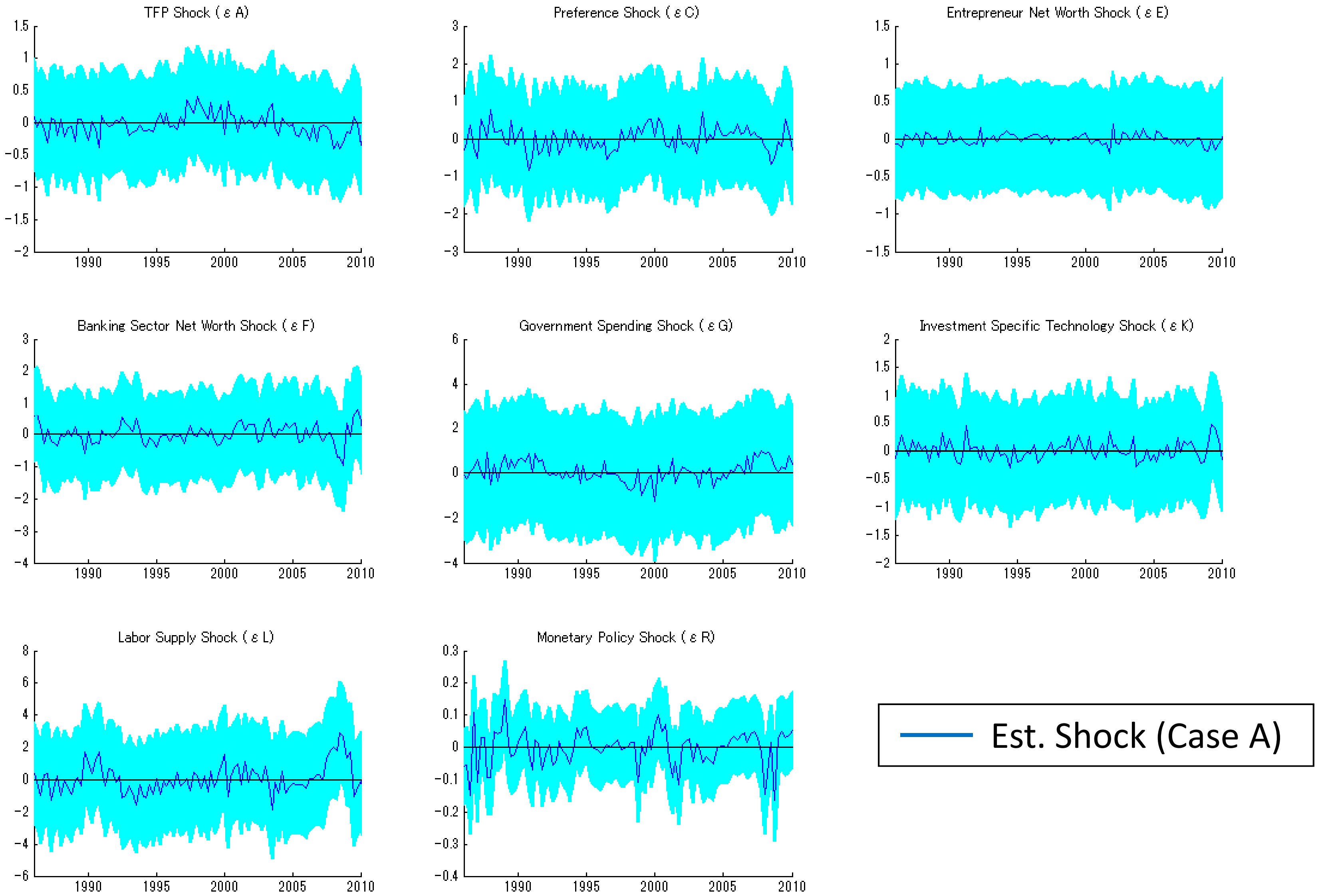
Estimation Results: Smoothed Observables



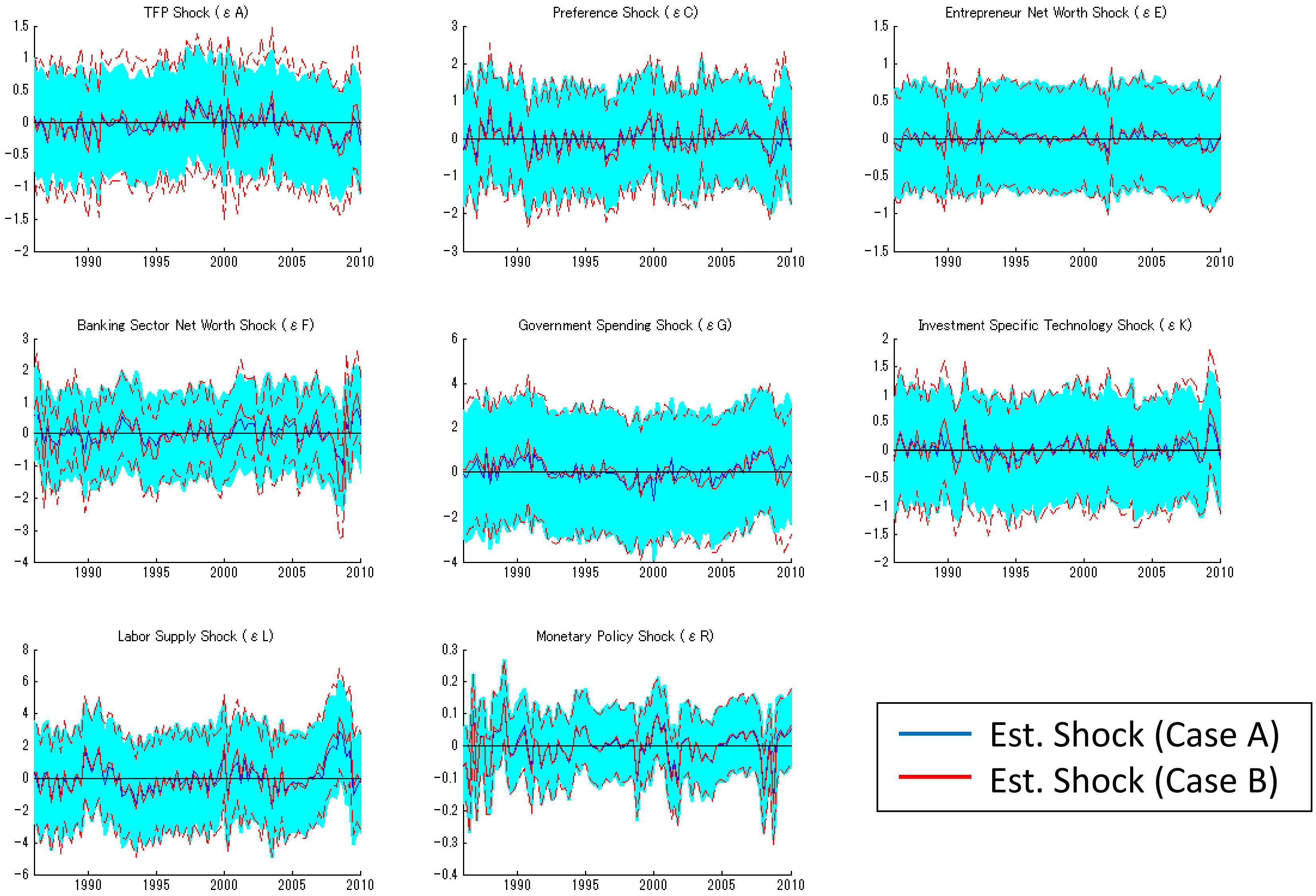
Estimation Results: Smoothed Observables



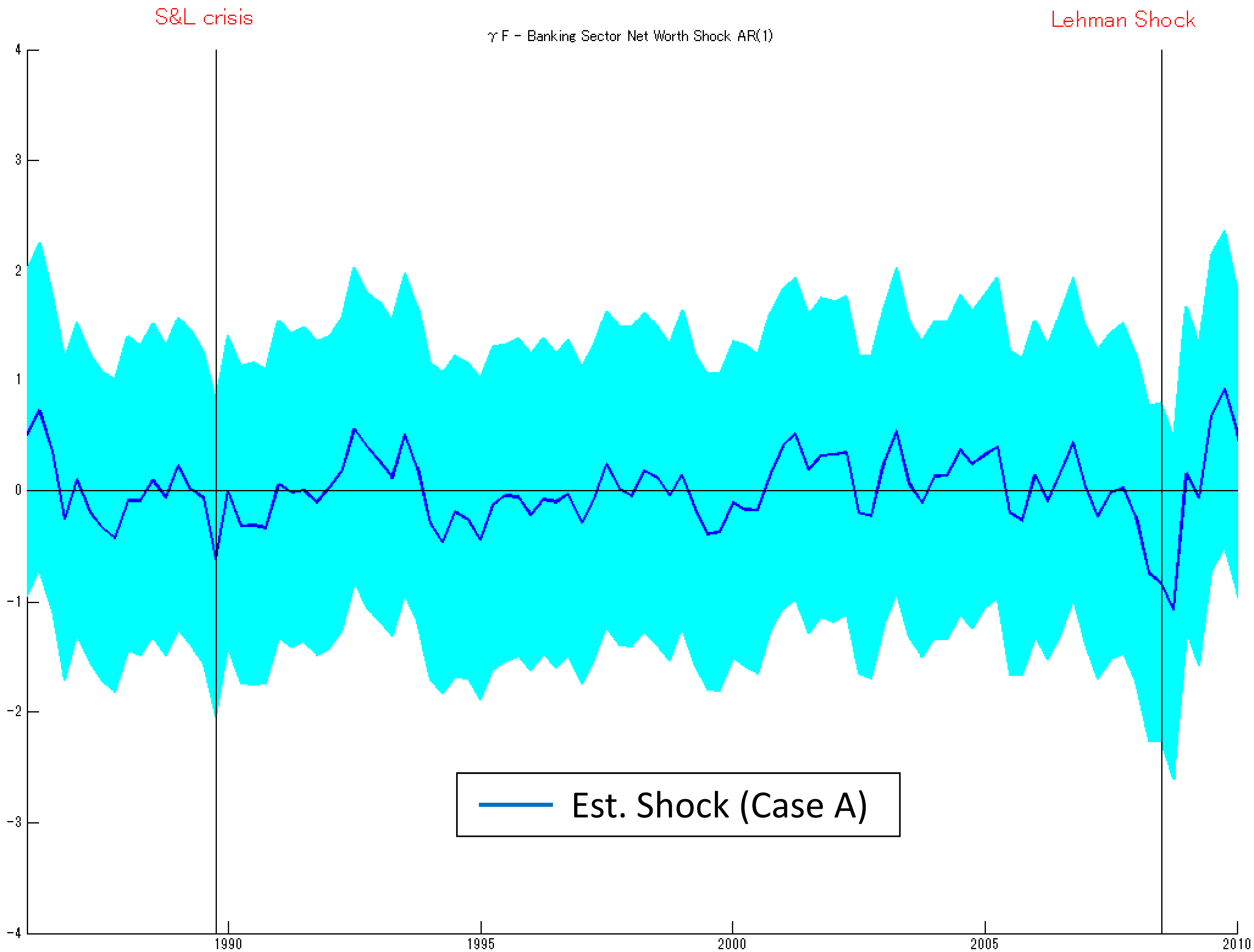
Estimation Results: Estimated Shocks



Estimation Results: Estimated Shocks

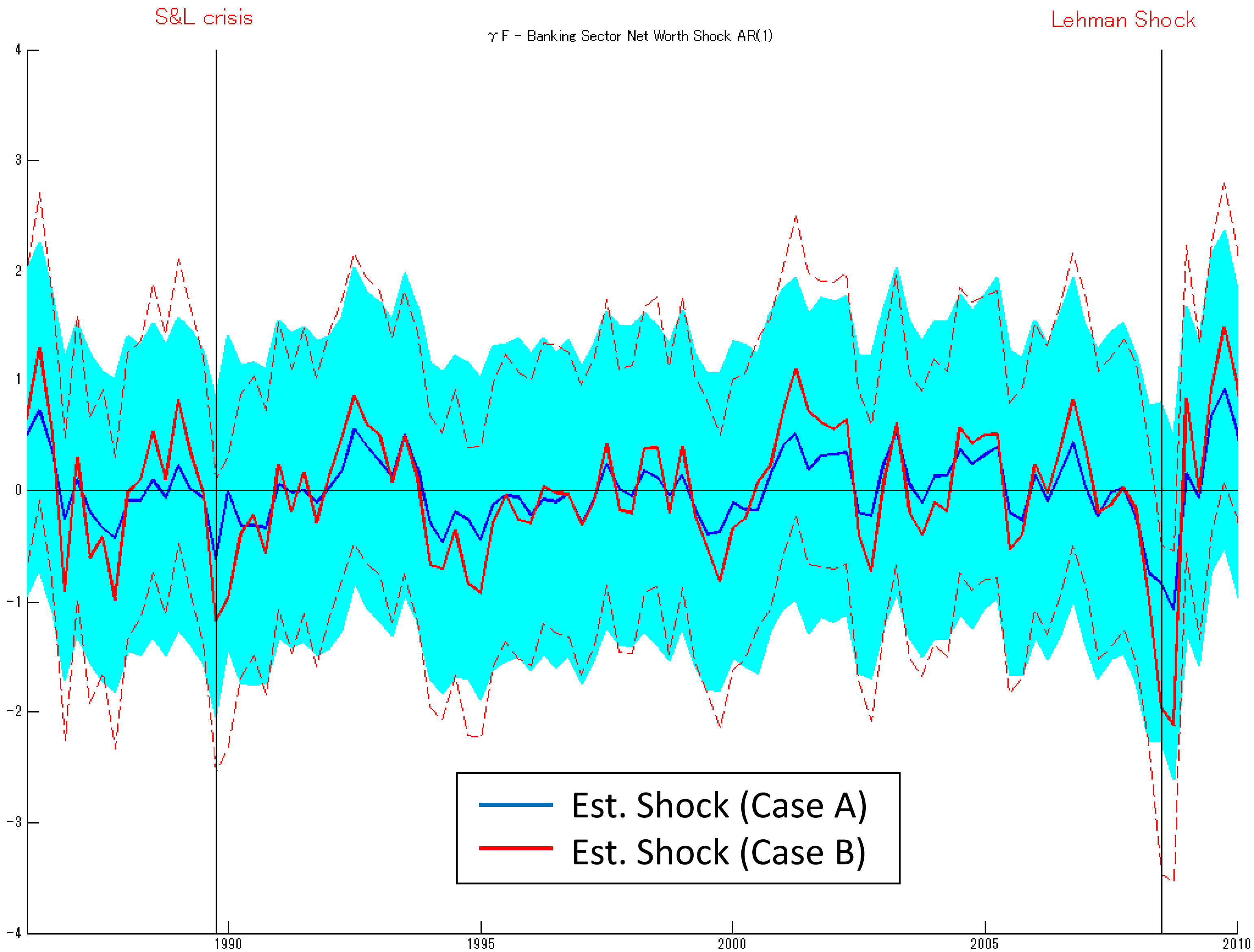


Estimation Results: Bank Net Worth Shock



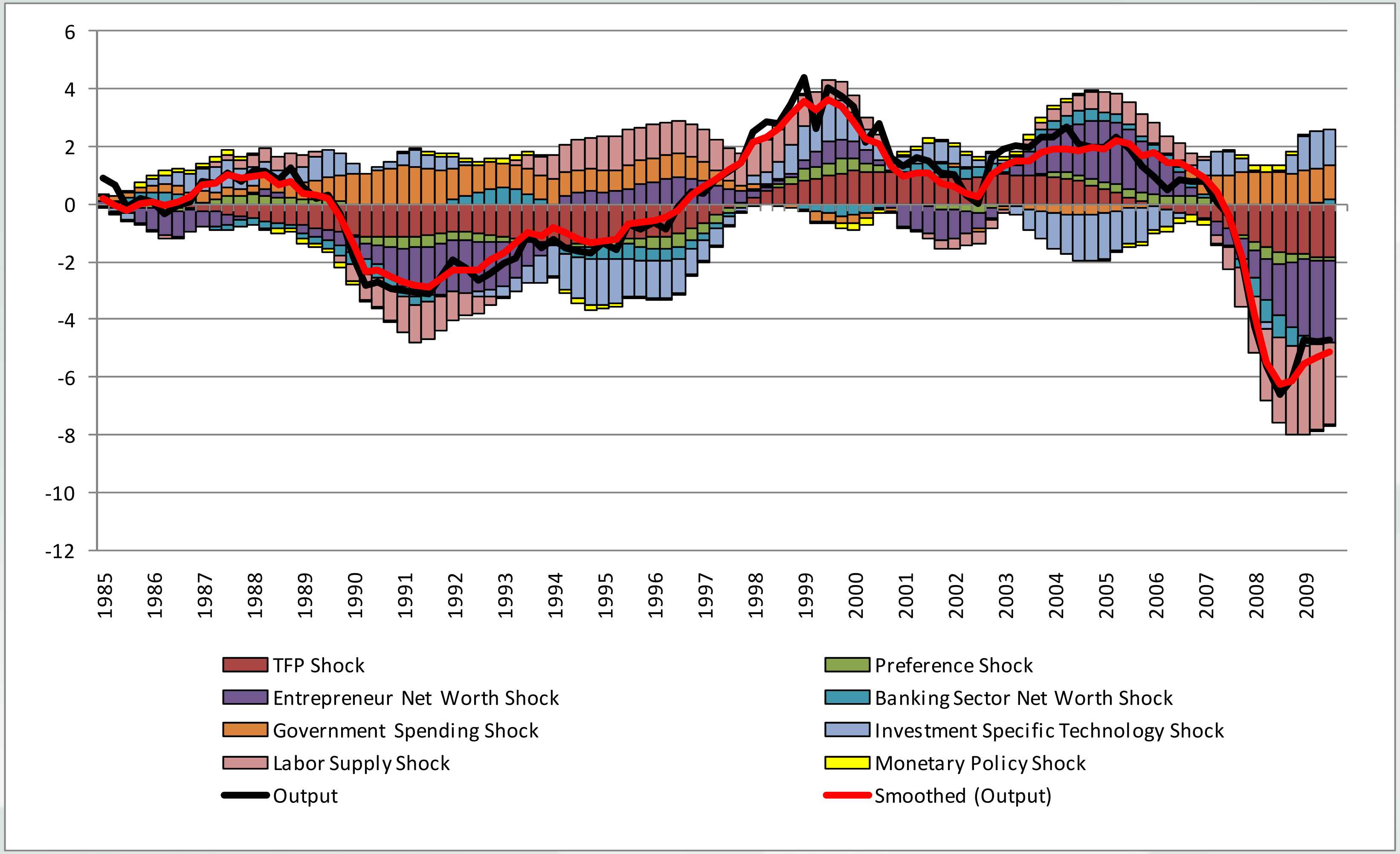
How Bad was Lehman Shock?

Estimation Results: Bank Net Worth Shock

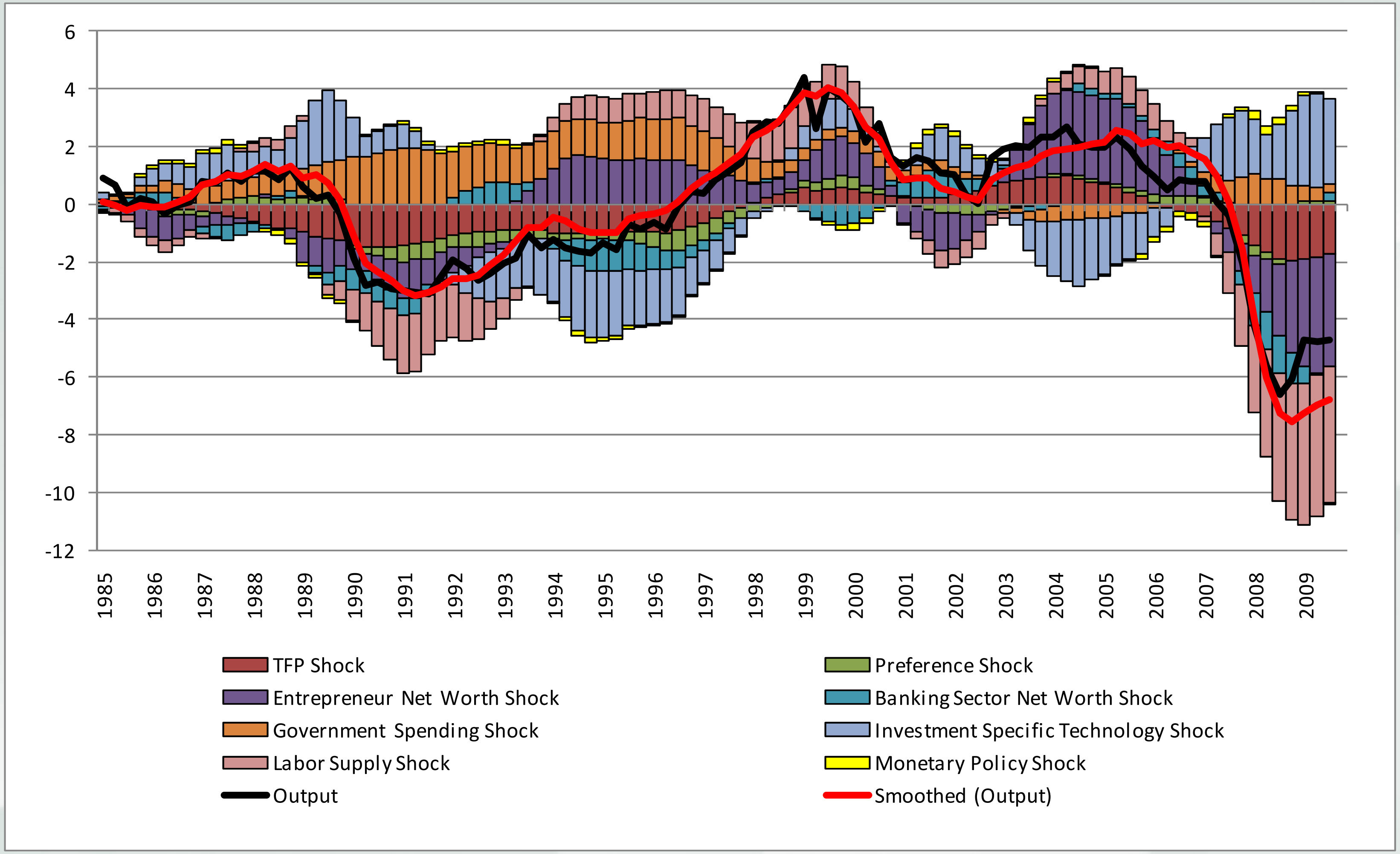


How Bad was Lehman Shock?

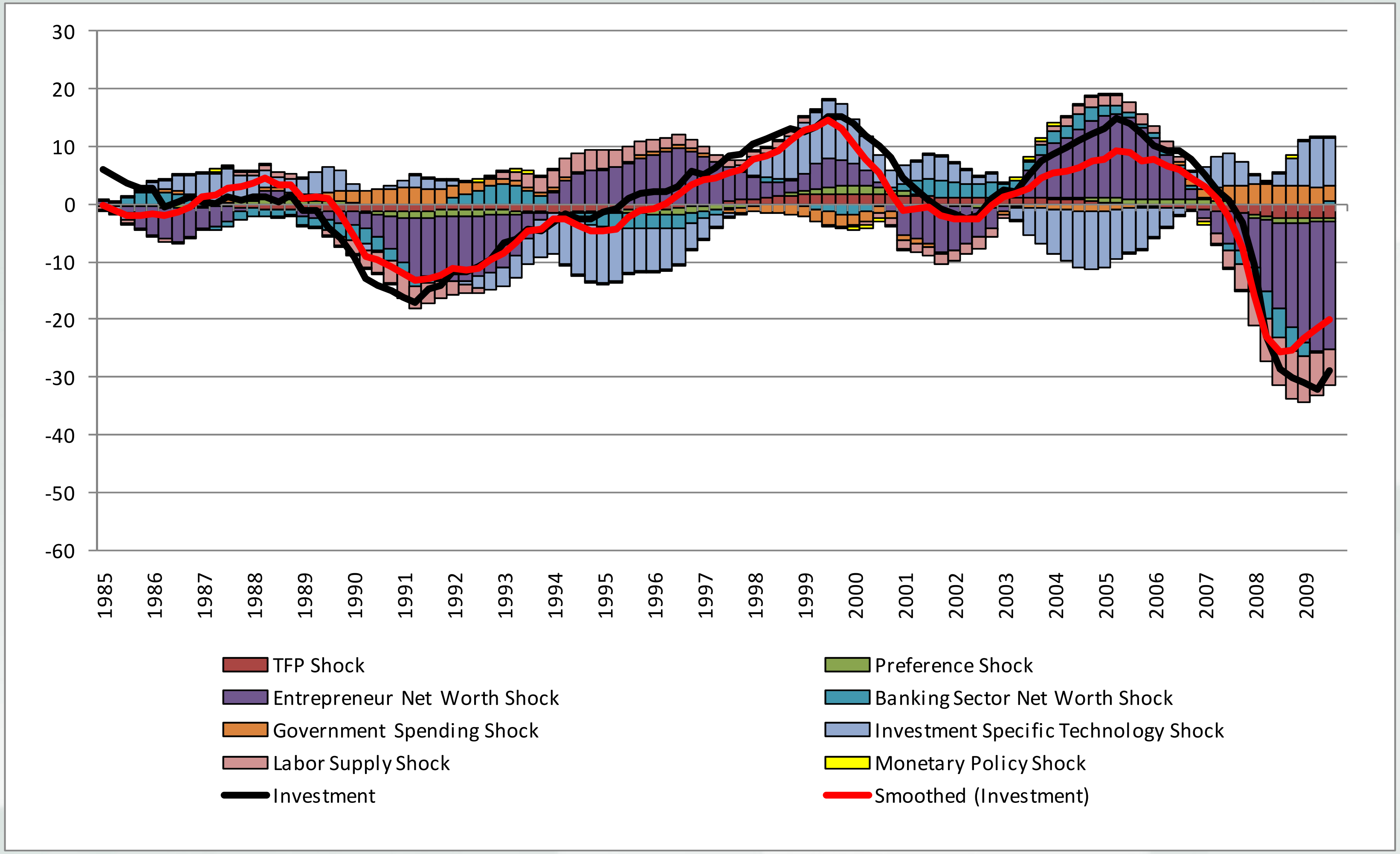
Historical Decomposition: Output (Case A)



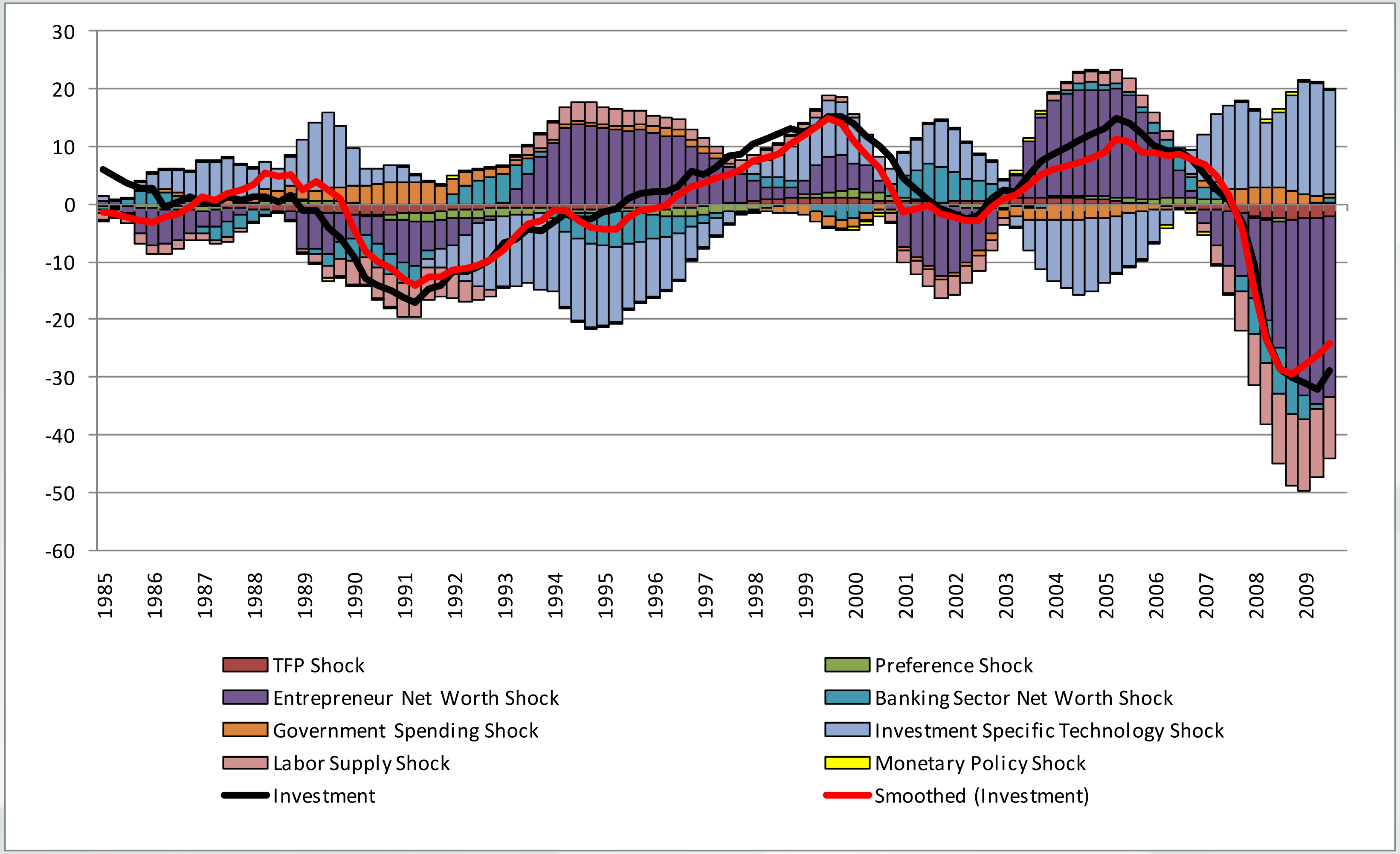
Historical Decomposition: Output (Case B)



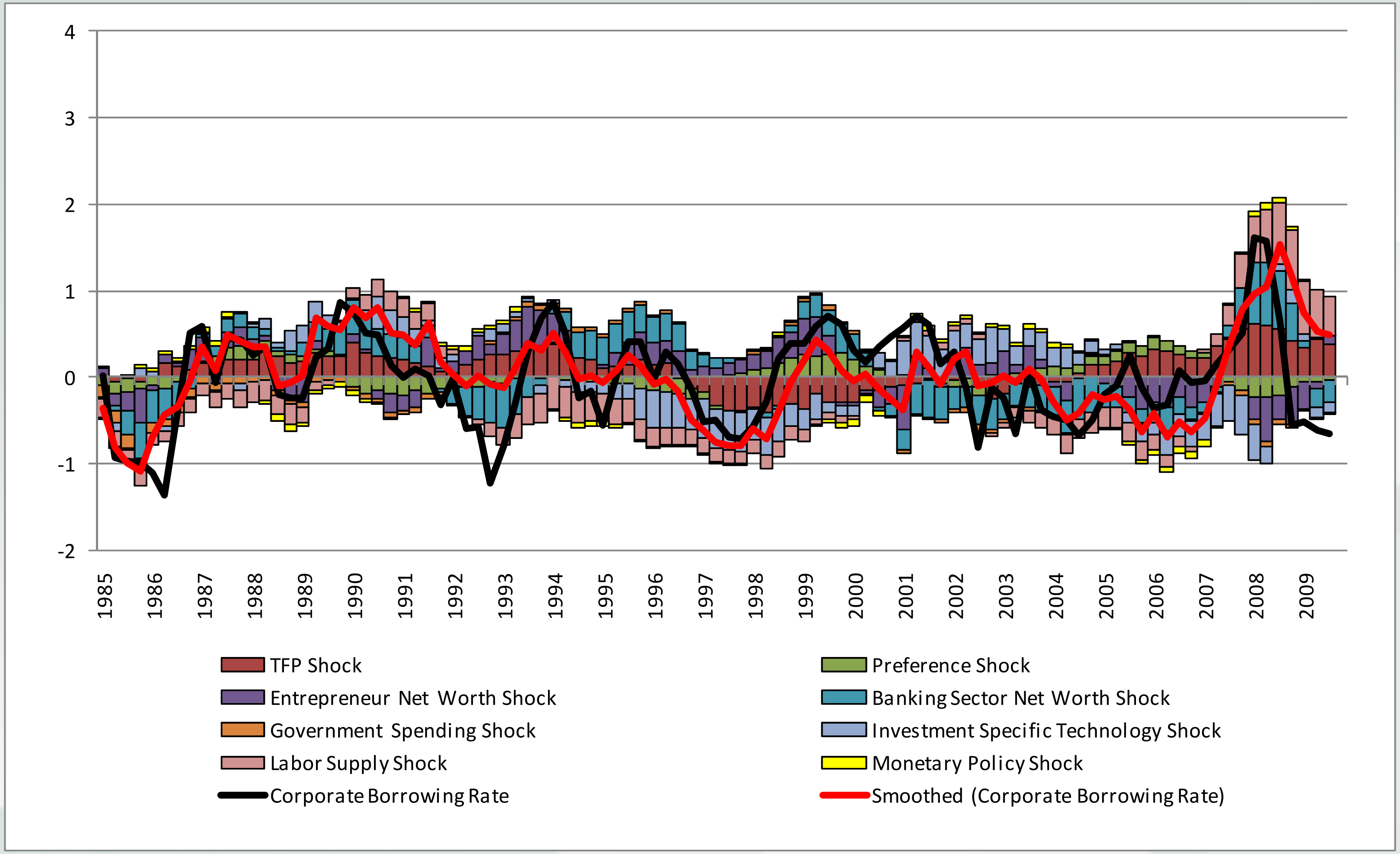
Historical Decomposition: Investment (Case A)



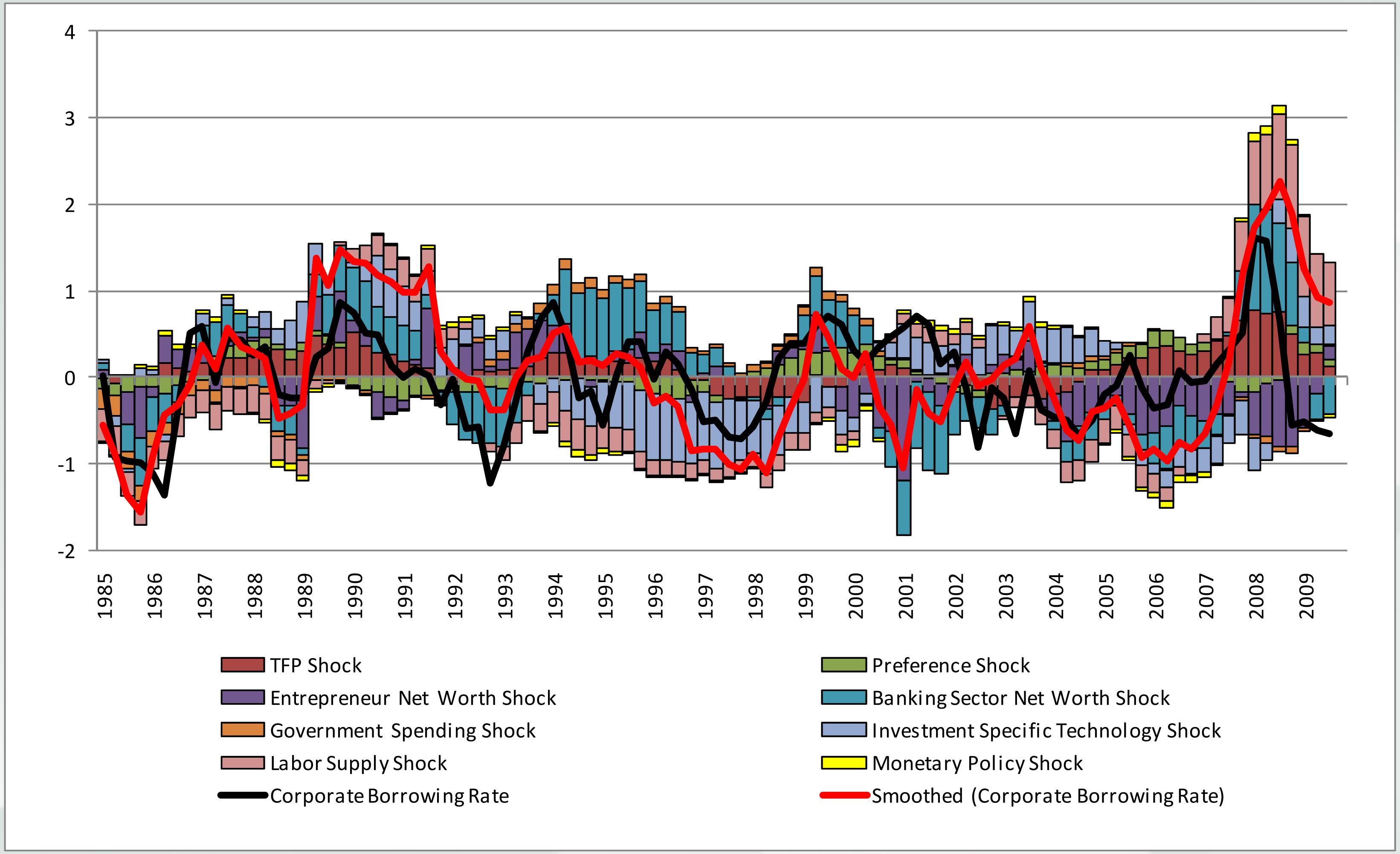
Historical Decomposition: Investment (Case B)



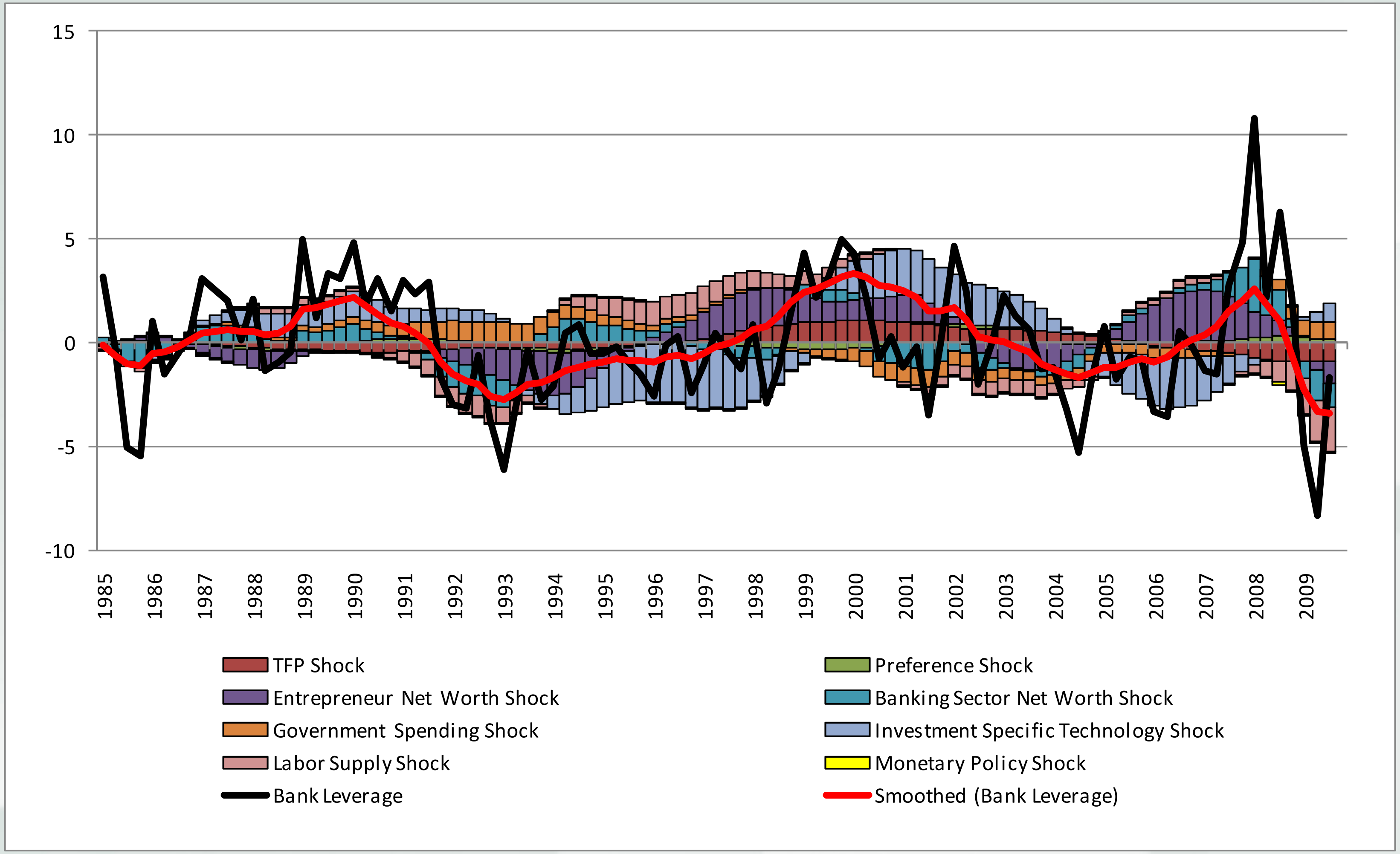
Historical Decomposition: Corporate Borrowing Rate (Case A)



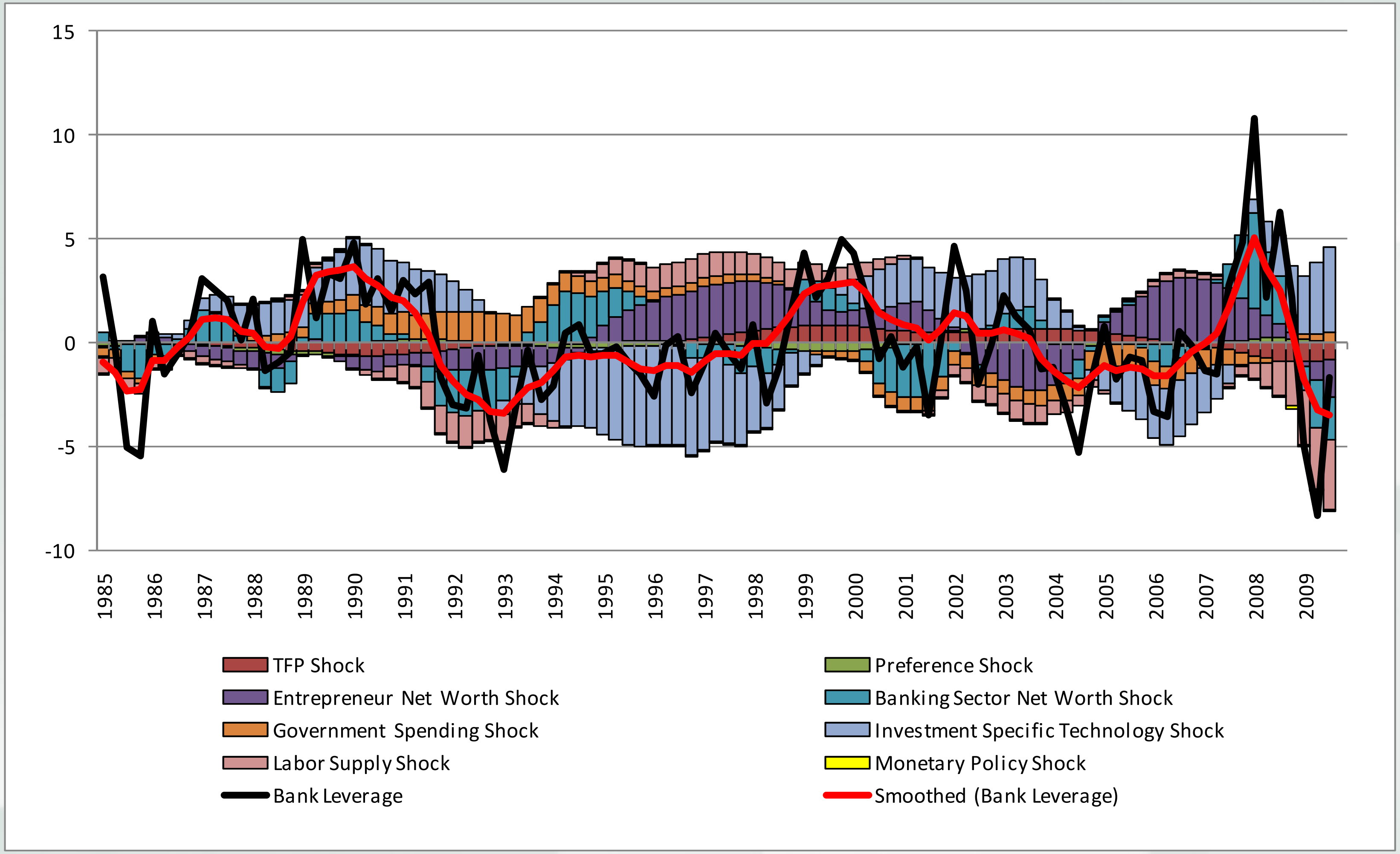
Historical Decomposition: Corporate Borrowing Rate (Case B)



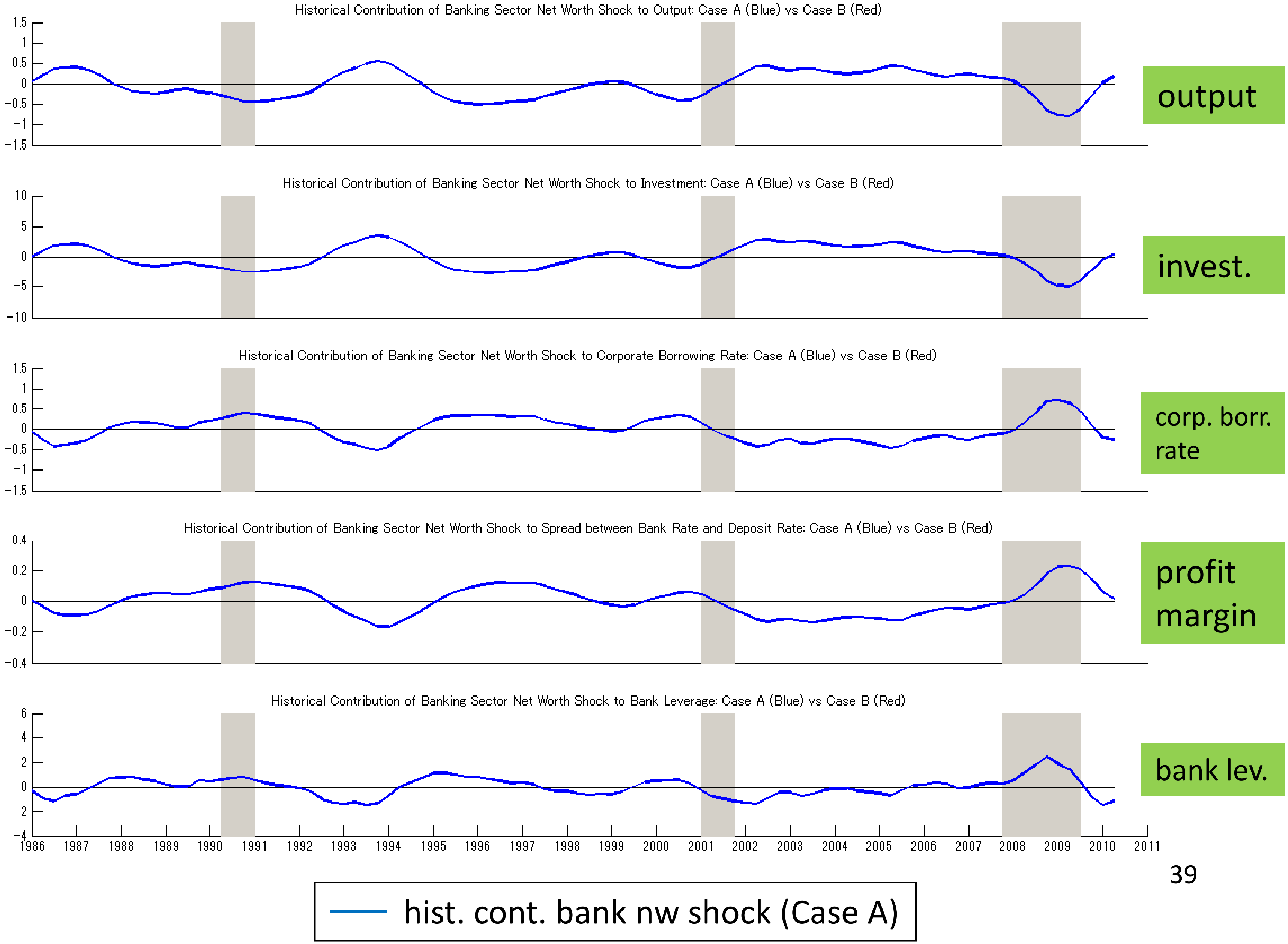
Historical Decomposition: Bank Leverage (Case A)



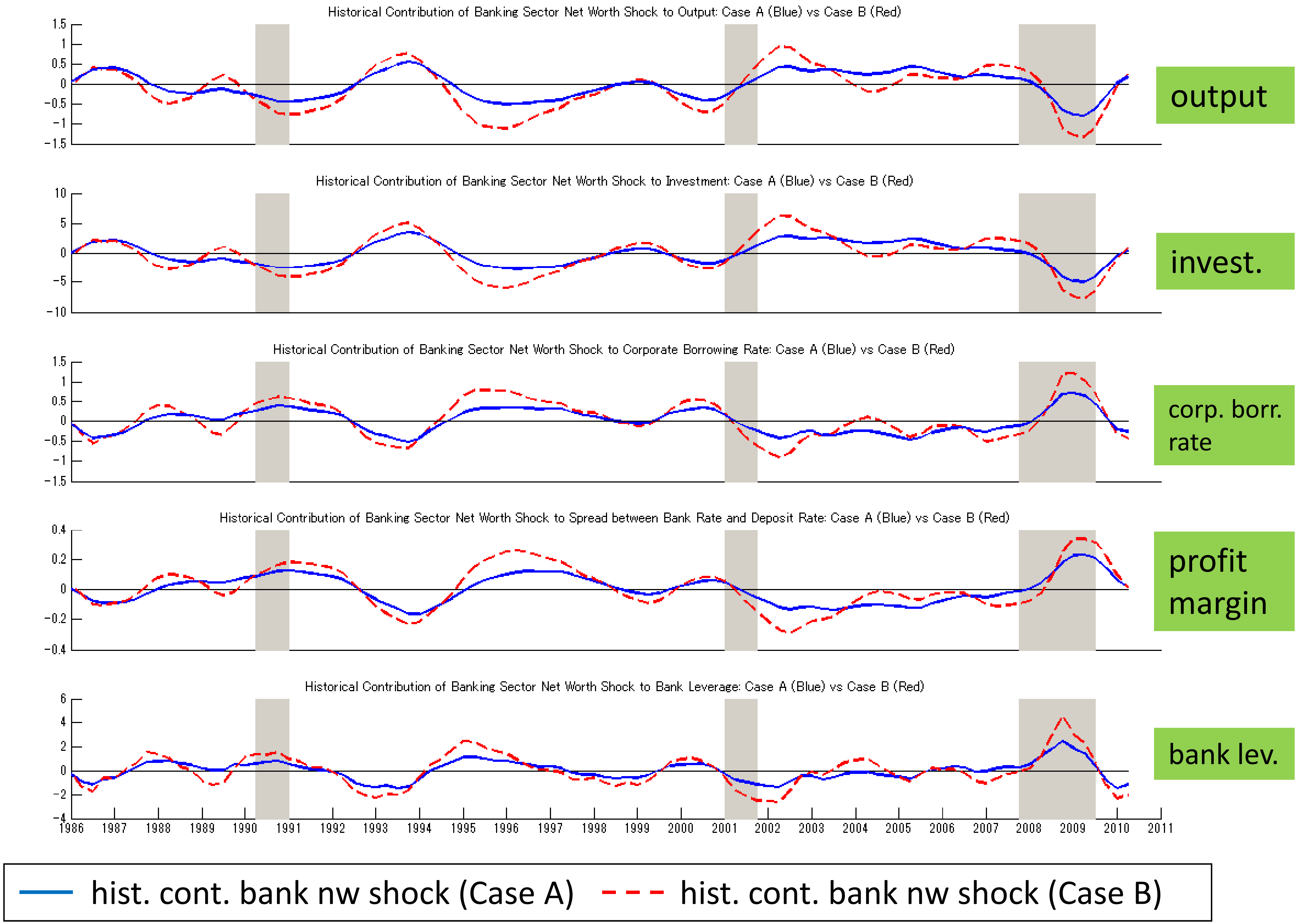
Historical Decomposition: Bank Leverage (Case B)



Historical Contribution of Bank Net Worth Shock



Historical Contribution of Bank Net Worth Shock



Conclusion: Contributions of this paper

- Theoretical Contribution:
  - Combined two canonical financial friction models and embedded to the stylized DSGE model.
- Empirical Contribution:
  - Adopted Data-Rich estimation method in estimating bank net worth shock.

Conclusion: So How Bad was Lehman Shock?

- **How large was the magnitude of Lehman Shock?**
  - Largest bank net worth shock at least in past 25 years. Much larger than those during S&L crisis.

- **How large was its impact to the economy?**
  - Quite large. Lehman Shock may have suppressed investment by nearly 10%.

- **Is it over?**
  - The shock seems to have been successfully countered by TARP and aggressive credit easing that the recessionary effect directly caused by Lehman Shock seems to be over.