Sources of Great Recession:

A Bayesian Approach of a Data Rich DSGE model with Time-Varying-Volatility Shocks (with H. Iiboshi and T. Matsumae)

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Motivation for this paper

- Great Recession (Dec. 2007 to Jun. 2009)
  Because we obtain broad consensus that solvency and liquidity problems of the financial institutions was the chief factor in causing the Great Recession.
- Which financial friction important for the Great Recession?
  - We adopt standard NK model + Two Financial Frictions.
  1. Agency Cost between Banks - Firms
  2. Agency Cost between Depositors - Banks
- Econometric Feature 1: Data Rich approach
  1. Separates measurement errors and structural shocks from observations
  2. Utilize up to 40 macroeconomic time series in the estimation.
- Econometric Feature 2: Stochastic Volatility Shocks + Leverage Effects
  1. In ordinary times volatilities are small, but at the turning points of business cycles they become large. $\Rightarrow$ Needs time-varying volatility
  2. Do Financial Friction Shocks have leverage effects ?
     - Leverage Effects = A negative shock leads to its large volatility

Related Literature

1. Two Financial Frictions
   - ① Agency Cost between Bank and Firm:
     Bernanke, Gertler, Gilchrist (1999), and Christensen and Dib (2008).
   - ② Agency Cost between Bank and Depositors:
     Gertler and Karadi (2011), and Gertler and Kiyotaki (2011).
2. Time varying volatility of the structural disturbances
   - ① Justiniano and Primiceri (2008, AER) estimate NK DSGE model with time varying volatility shocks by SV model.
   - ② Liu, Waggoner, Zha (2011) estimated NK DSGE model with time varying volatility shocks by regime-switching.
3. Data Rich Approach
   Boivin and Giannoni (2006), Kryshko (2011), Iiboshi et al. (2012).

- Our study is the first attempt of combination of data rich approach and time varying volatilities of structural shocks to DSGE model with financial frictions.

Summary of Empirical Findings

- In the light of a DSGE model, we suggest the following three empirical evidences in Great Recession;

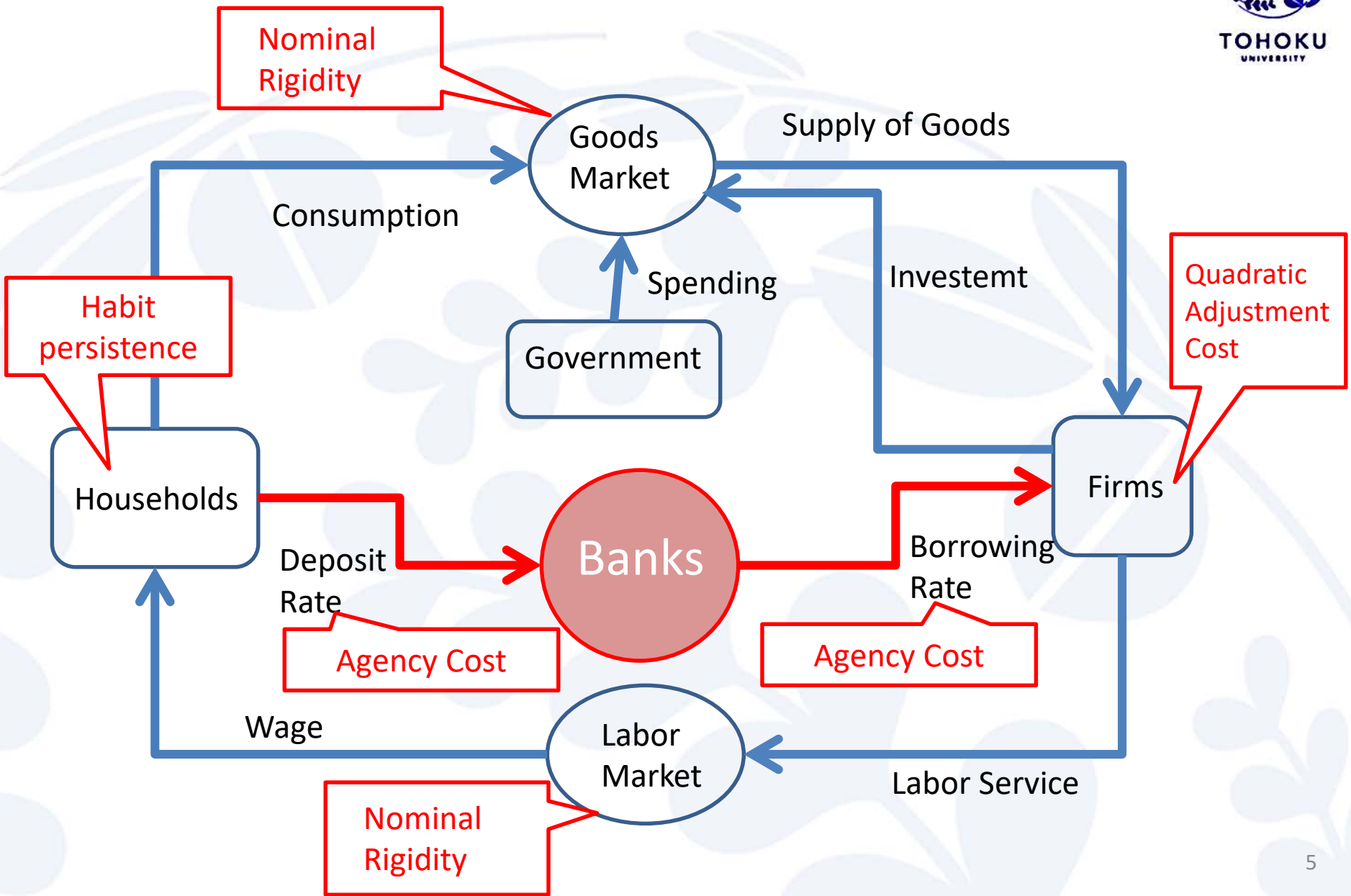
1. Negative bank net worth shock preceded the negative corporate net worth shock.

2. Corporate net worth shock contributes to the large portion of macroeconomic fluctuations after Great Recession.

3. Troubled Asset Relief Program (TARP) worked to alleviate the banking sector net worth shock. But balance sheets in corporate sector did not stop deteriorating.

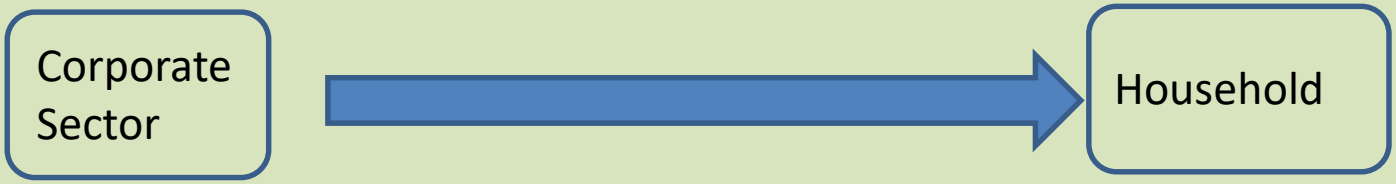
- Incorporating time-varying-volatilities of shocks into the DSGE model, we indeed observed that both corporate and banking sector net worth shock to be time-varying, especially during the Great Recession period.

DSGE Model with Financial Frictions



Two Financial Frictions

Standard NK Model



$$R_t^E = \overline{R}_t^F = R_t$$

Borrowing Rate — Interbank Rate — Deposit Rate

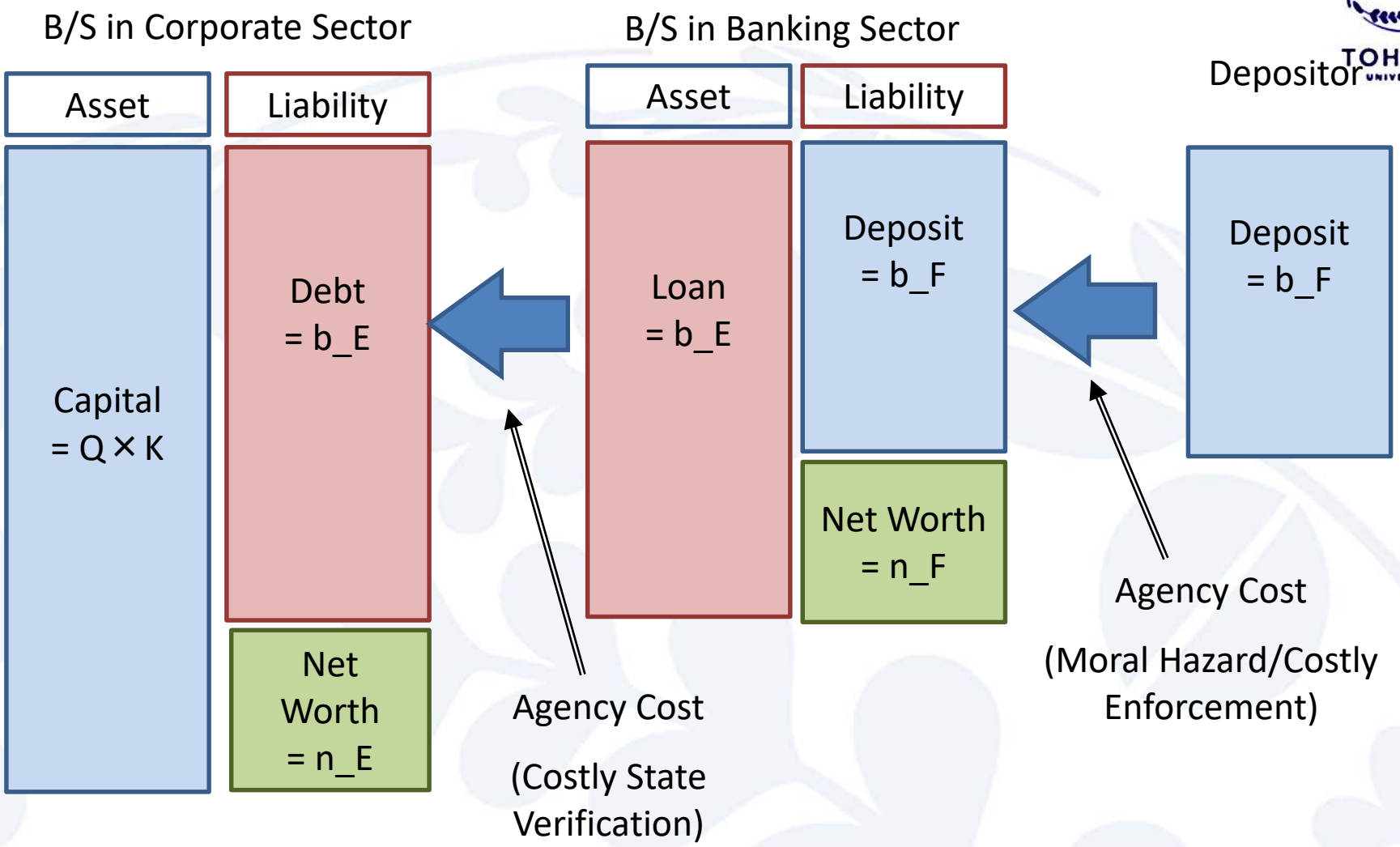
NK Model + Two Financial Frictions

Borrowing Rate R_t^E $\geq$ $\overline{R}_t^F$ $\geq$ R_t Deposit Rate

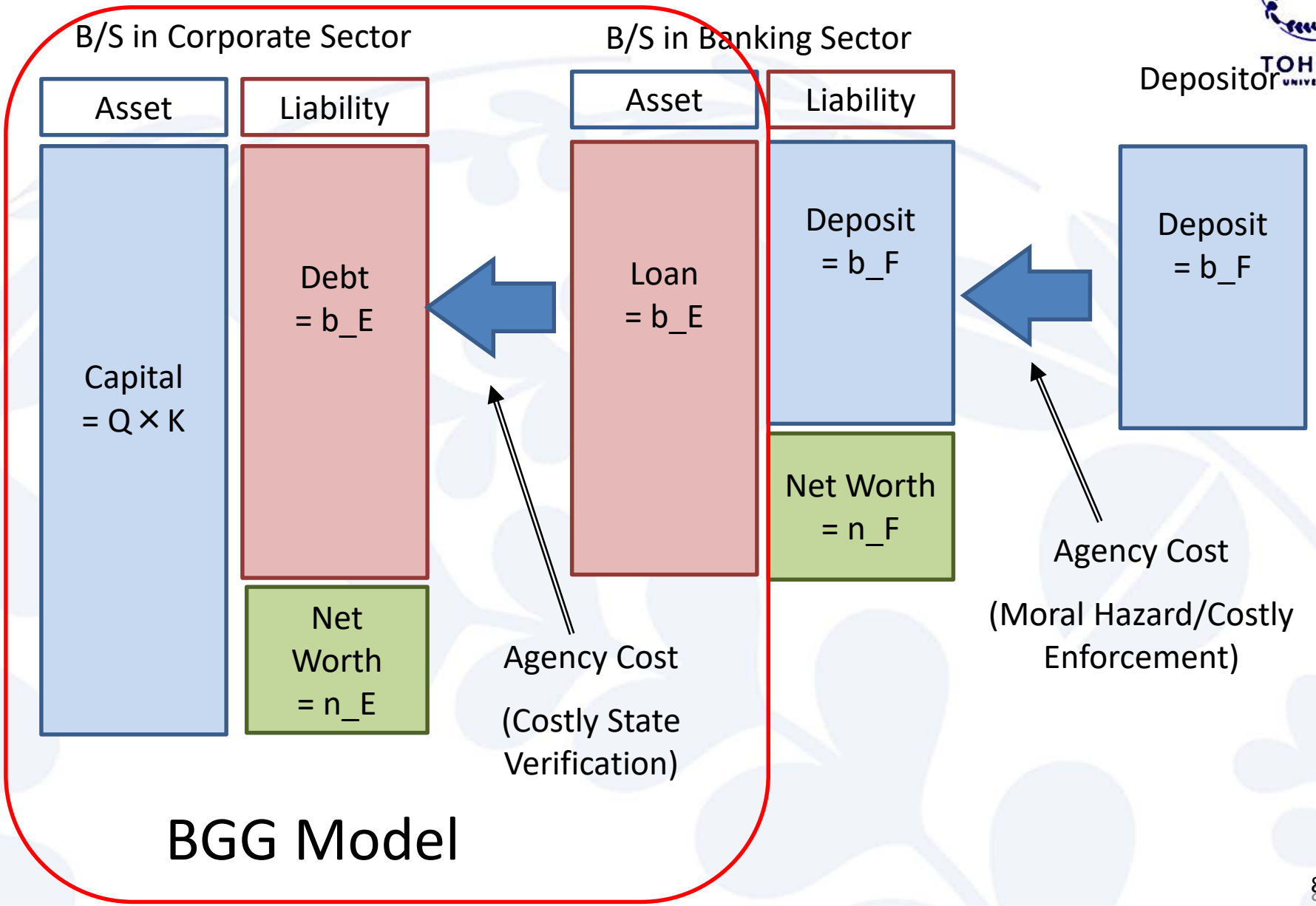
$\underbrace{\quad}$ external finance premium

$\underbrace{\quad}$ profit margin of bank lending rate

Financial Frictions in B/S Channel



Financial Friction in Corporate Sector



Model Description: Entrepreneur's Problem

- Capital demand equation:

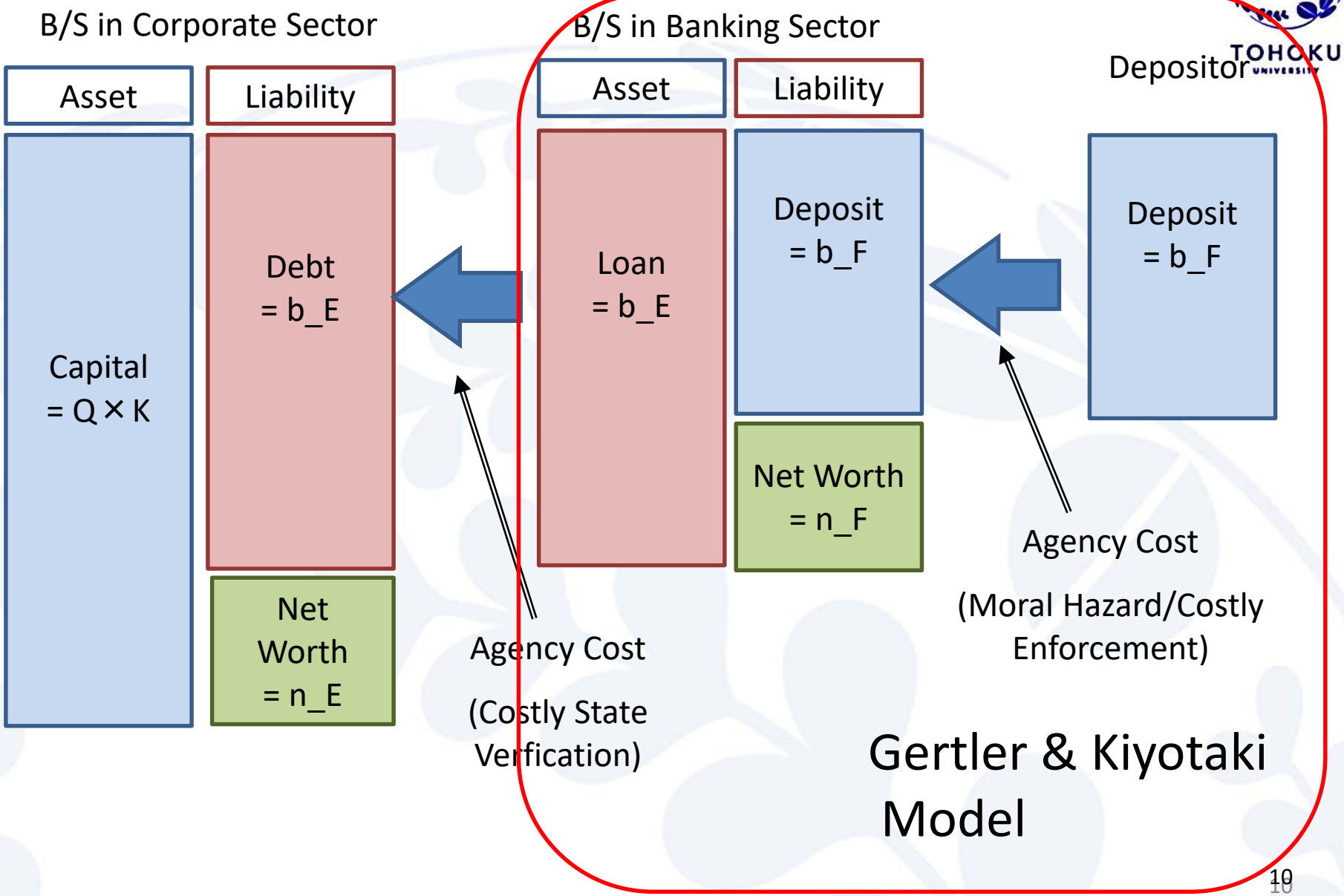
$$\underbrace{E_t\left[\frac{R_t^E(j)}{\pi_{t+1}}\right]}_{\text{expected corporate real borrowing rate}} = \underbrace{E_t\left[\frac{p_{t+1}^{mc}(j)mpk_{t+1}(j)+(1-\delta)q_{t+1}}{q_t}\right]}_{\text{expected marginal return of capital investment}}$$

- Debt contract between entrepreneur and banker
  - Asymmetric information exists: costly state verification

$$\underbrace{s_t(j)}_{\text{external finance premium}} = s\underbrace{\left(\frac{q_t k_{t+1}(j)}{n_t^E(j)}\right)}_{\text{leverage ratio}}$$

$$\underbrace{E_t R_{t+1}^F(m)}_{\text{risk-adjusted lending rate}} + s_t(j) = R_t^E(j)$$

Financial Friction in Banking Sector



Model Description: Banker's Problem

- Banker's objective function:

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

- Moral hazard / costly enforcement problem
  - Bankers have 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) show 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 the 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

What is Data Rich Approach?

Standard DSGE

Model Variables		Observations
“output”	⇔	Real GDP
“inflation”	⇔	GDP deflator
⋮		⋮

Data-rich DSGE

Model Variables = Common Factor		Observations
“output”	⇔	① real GDP ② IIP (Final Products) ③ IIP (Total Index)
“inflation”	⇔	① GDP deflator ② Core CPI ③ Price Index (PCE)
⋮		⋮

The idea of data-rich approach is
(1) to extract the common factor from panel data,
(2) and to match the model variable to the common factor

Advantage of Data Rich Approach

Observations $\underbrace{X_t}_{J\times 1} = \underbrace{\Lambda(\theta)}_{J\times N}\underbrace{\bar{S}_t}_{N\times 1} + \underbrace{e_t}_{J\times 1},$ **Measurement Errors**

Endogenous Variables $\underbrace{\bar{S}_t}_{N\times 1} = \underbrace{G(\theta)}_{N\times N}\underbrace{\bar{S}_{t-1}}_{N\times 1} + \underbrace{H(\theta)}_{N\times M}\underbrace{\varepsilon_t}_{M\times 1},$ Structural Shocks $\varepsilon_t \sim \text{i.i.d. } N(0, Q(\theta)),$

Law of motions of endogenous variables

1. By increasing observations, easier to identify endogenous variables (common factors) and structural shocks.

2. Decompose Structural Shocks and Measurement Errors from Observations.
   1. discrepancy between model variable and just one Observation → Measurement Errors
   2. discrepancy between model variable and dynamic of model variable → Structural Shocks

3. Improve the estimation accuracy of deep parameters, as collecting more observations.

Data Rich Approach with SV Shocks

$$\underbrace{\boldsymbol{X}_t}_{J\times 1} = \underbrace{\boldsymbol{\Lambda}(\boldsymbol{\theta})}_{J\times N}\underbrace{\boldsymbol{S}_t}_{N\times 1} + \underbrace{\boldsymbol{e}_t}_{J\times 1},$$

$$\underbrace{\boldsymbol{S}_t}_{N\times 1} = \underbrace{\mathbf{G}(\boldsymbol{\theta})}_{N\times N}\underbrace{\boldsymbol{S}_{t-1}}_{N\times 1} + \underbrace{\mathbf{E}(\boldsymbol{\theta})}_{N\times M}\underbrace{\boldsymbol{\varepsilon}_t}_{M\times 1},$$

Structural Shocks

$$\underbrace{\boldsymbol{e}_t}_{J\times 1} = \underbrace{\boldsymbol{\Psi}_t}_{J\times J}\underbrace{\boldsymbol{e}_{t-1}}_{J\times 1} + \underbrace{\boldsymbol{\nu}_t}_{J\times 1}, \qquad \boldsymbol{\nu}_t \sim \text{i.i.d. } N(\mathbf{0}, \mathbf{R}),$$

Stochastic Volatilities
With Leverage effect

$$\boldsymbol{\varepsilon}_t = \underbrace{\boldsymbol{\Sigma}_t}_{\mathbf{M}\times\mathbf{M}}\underbrace{\boldsymbol{z}_t}_{\mathbf{M}\times\mathbf{1}},$$

$$\boldsymbol{z}_t \sim \text{i.i.d. } \boldsymbol{N}(\mathbf{0}, \boldsymbol{I}_M),$$

Volatilities $\boldsymbol{\Sigma}_t = \mathbf{diag}(\sigma_{1,t}, \sigma_{2,t} \cdots \sigma_{M,t}),$

$$\log \sigma_{i,t+1} = \mu_i + \phi_i(\log \sigma_{i,t} - \mu_i) + \eta_{i,t}, \quad i = 1, 2, \cdots, M,$$

Leverage effect

$$\begin{pmatrix} z_{i,t} \\ \eta_{i,t} \end{pmatrix} \sim \text{i.i.d. } N(0, \Omega_i), \quad \Omega_i = \begin{bmatrix} 1 & \rho_i\omega_i \\ \rho_i\omega_i & \omega_i^2 \end{bmatrix}$$

SV model with Leverage Effect

Structural Shocks

Volatilities

$$\varepsilon_t = \sigma_t \times z_t$$

Innovation followed by Standard Normal : N(0,1)

Time Varying Volatilities

$$\log \sigma^2{}_{t+1} = \mu + \phi\left(\log \sigma^2{}_t - \mu\right) + \eta_t$$

mean

$$\begin{pmatrix} z_t \\ \eta_t \end{pmatrix} \sim \text{i. i. d. } N(0, \Omega),$$

Covariance Matrix

$$\Omega = \begin{bmatrix} 1 & \rho\omega \\ \rho\omega & \omega^2 \end{bmatrix}$$

ρ measures the correlation between z_t and η_t

What is Leverage Effect of Stochastic Volatility? Why is it used?

$$\begin{pmatrix} z_t \\ \eta_t \end{pmatrix} \sim \text{i. i. d. } N(0, \Omega), \quad \Omega = \begin{bmatrix} 1 & \rho\omega \\ \rho\omega & \omega^2 \end{bmatrix}$$

Leverage Effect ρ (correlation between z_t and η_t) < 0

Structural Shock, ε_t (or z_t) < 0 (negative)

↓

Volatility $\log \sigma^2{}_{t+1}$ (or η_t) become Large

Most Stock Returns Have Leverage Effect

Our Question

Do Bank and Corporate Net Worth Shocks have leverage Effects ?

Data Set

- Sample Period: 1985Q2 to 2012Q2

- Cases A and C, 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)

- Cases B and D, Data Set (40 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)

Observations of Financial Section

Cases A and C, (1 to 1 matching)

Model Variable		Observation
"Bank Leverage Ratio"	⇔	Commercial Bank Leverage Ratio
"Corporate Leverage Ratio"	⇔	Nonfarm Nonfinancial Corporate Business Leverage Ratio
"Borrowing Rate"	⇔	Moody's Baa corporate Bond Index
External Finance Premium	⇔	Charge-off Rates for All Banks Credit and Issuer Loans

Observations of Financial Section

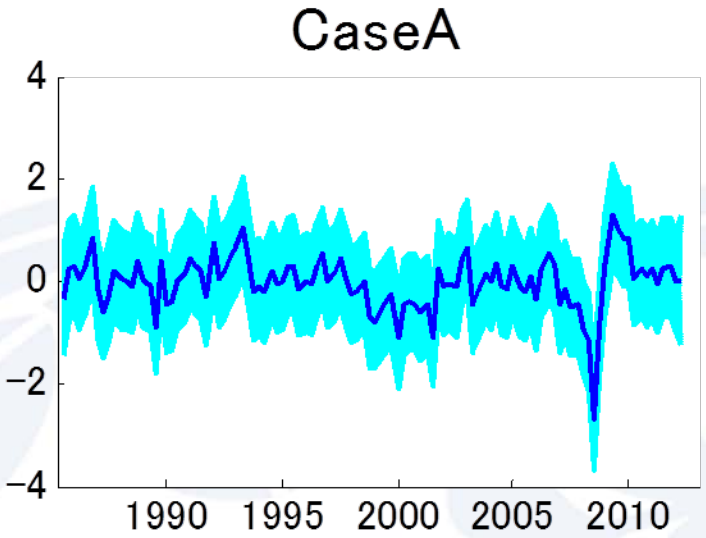
Cases B and D: Data-rich DSGE (1 to 4 matching)

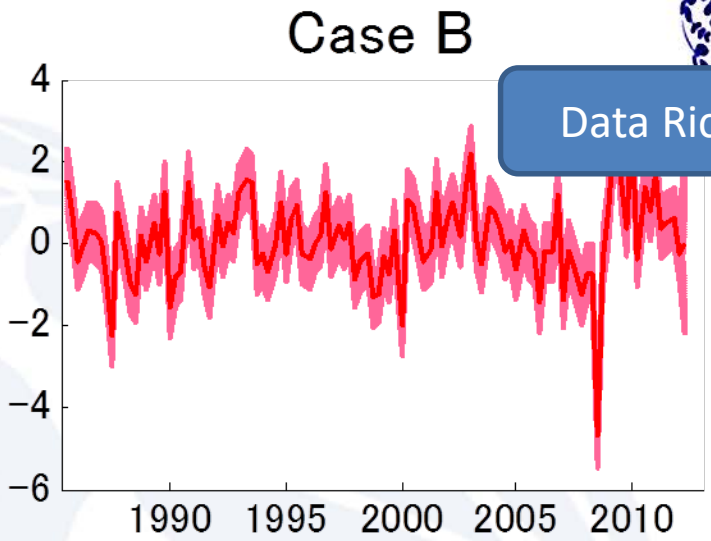
Model Variable		Observation
"Bank Leverage Ratio"	⇔	①Commercial Bank Leverage Ratio ②Core Capital Leverage Ratio PCA ③Domestically Chartered Commercial Banks leverage Ratio ④Brokers and Dealers Leverage Ratio
"Corporate Leverage Ratio"	⇔	①Nonfarm Nonfinancial Corporate Business Leverage Ratio ②Nonfarm Nonfinancial Non-corporate Leverage Ratio ③Nonfarm Corporate Leverage Ratio
"Borrowing Rate"	⇔	①Moody's Baa corporate Bond Index ②Bond Yield: Moody's Baa Industrial ③Bond Yield: Moody's A Corporate ④Bond Yield: Moody's A Industrial
External Finance Premium	⇔	①Charge-off Rates for All Banks Credit and Issuer Loans ②Charge-off Rates for All Loans and Leases All Commercial Banks ③Charge-off Rates for All Loans All Commercial Banks ④Charge-off Rates for All Loans Banks 1st to 100th Largest by Assets

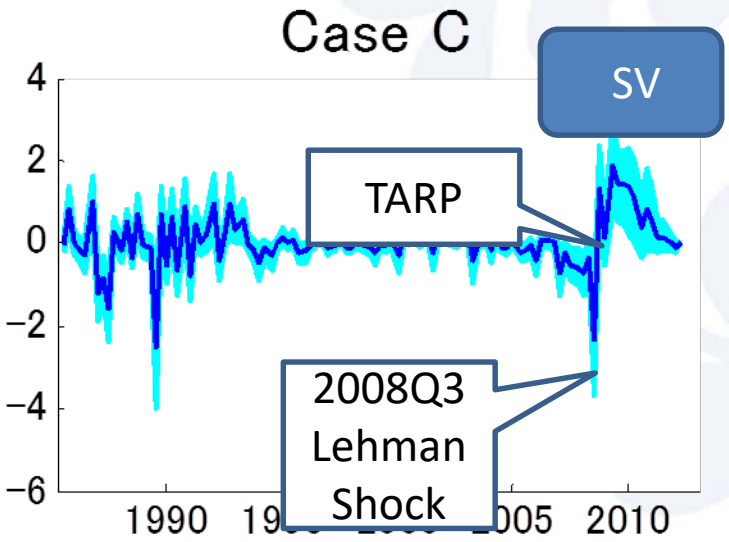
Specifications of 4 Cases

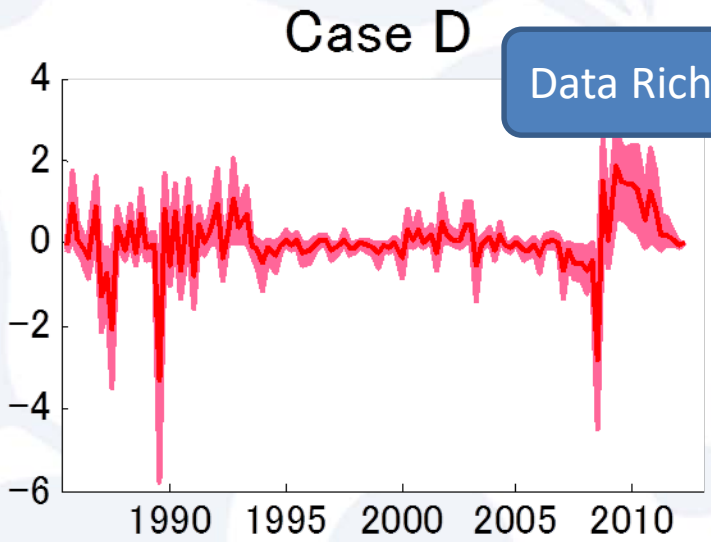
	Case A	Case B (Data Rich)	Case C (SV)	Case D (DR + SV)
Number of Observation	11	40	11	40
Model Variable to Obs.	1 to 1	1 to 4	1 to 1	1 to 4
Structural Shock	i.i.d. Normal	i.i.d. Normal	SV with Leverage	SV with Leverage

Bank Net Worth Shock

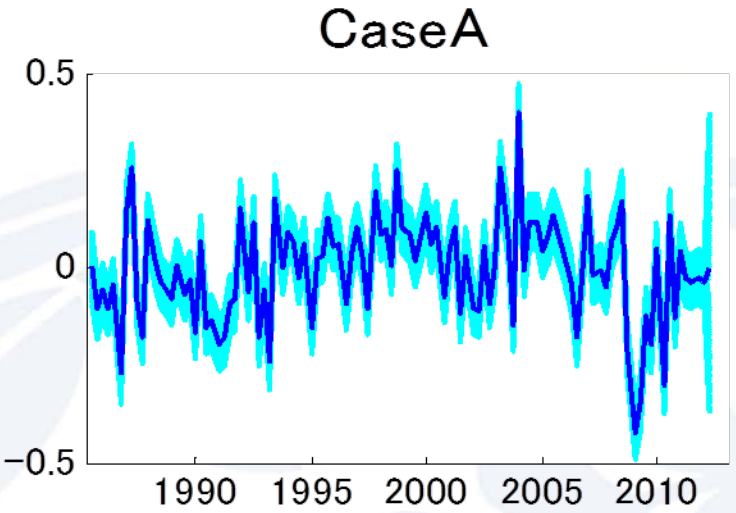


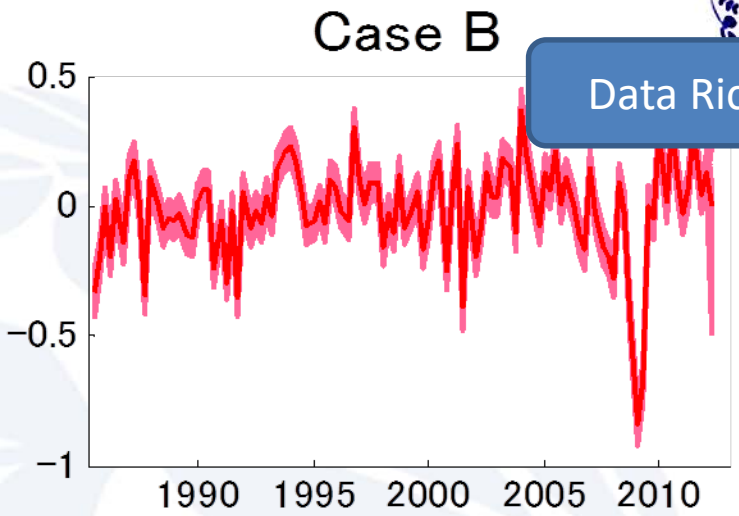


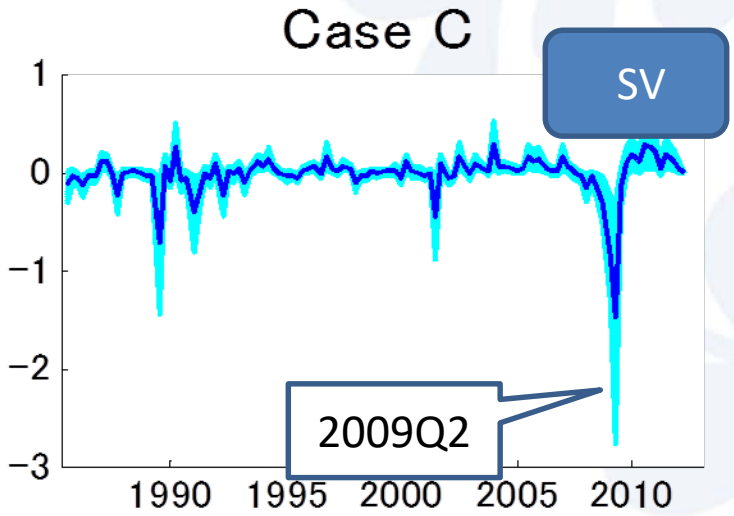


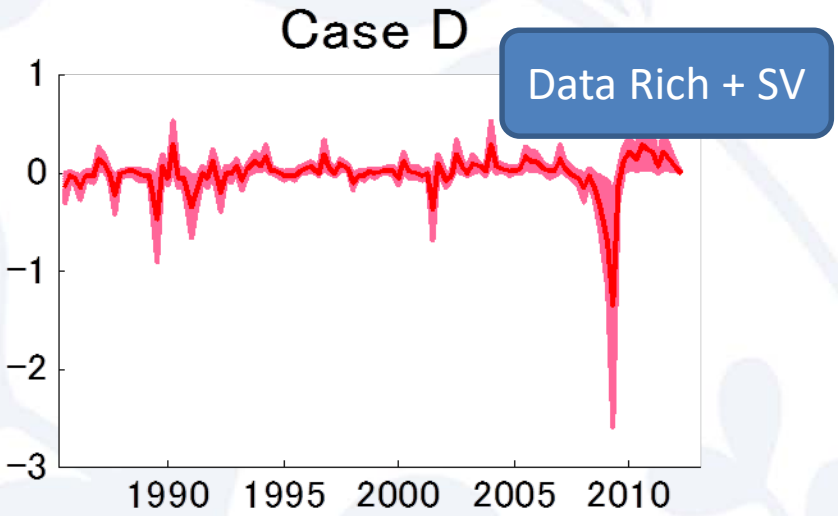


Corporate Net Worth Shock









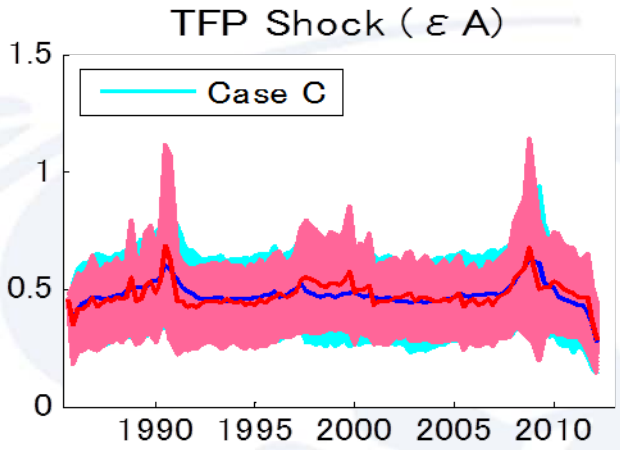
- Notice the timing of bank net worth shock and corp. net worth shock. Bank net worth shock precedes corp. net worth shock by 3qtrs.

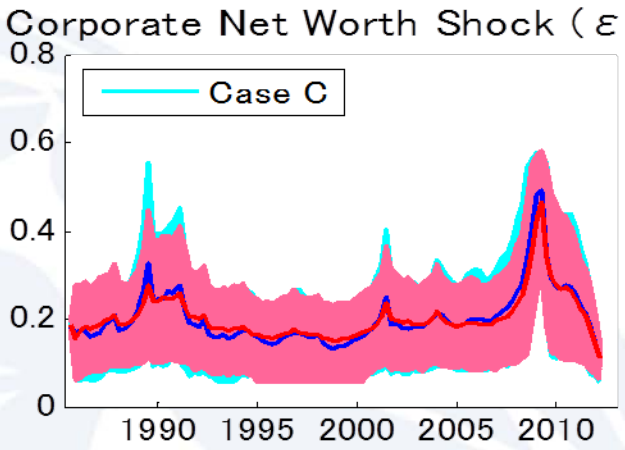
Average of 90% Credible Interval of Structural Shocks

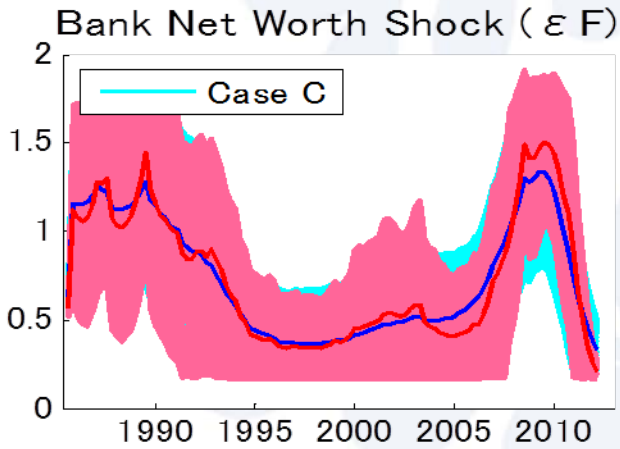
Structural Shocks	Case A	Case B (Data Rich)	Case C (SV)	Case D (DR + SV)
TFP	0.64	0.35	0.46	0.54
Preference	1.59	1.63	0.90	0.82
Corp. Net Worth	0.14	0.15	0.23	0.22
Bank Net Worth	1.90	1.43	0.81	0.91
Government Expenditure	2.21	2.02	0.20	0.32
Investment	0.98	0.24	1.13	1.11
Labor Supply	2.52	3.13	1.69	1.43
Monetary Policy	0.12	0.18	0.13	0.13

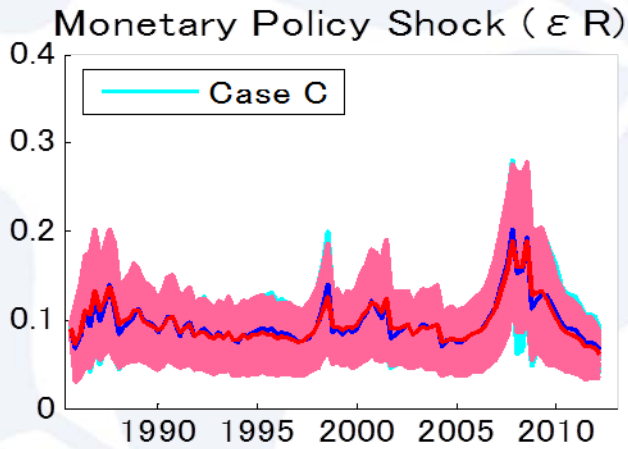
- Bank net worth shock's volatility is smaller for Case C and D (perhaps, due to SV).
- Corporate net worth shock's volatility is smaller for Case A and B (underestimation?)

Stochastic Volatilities of Structural Shocks (Case D: Data Rich + SV)









- Volatility clearly heightens for corp. net worth shock and bank net worth shock during Great Recession period.

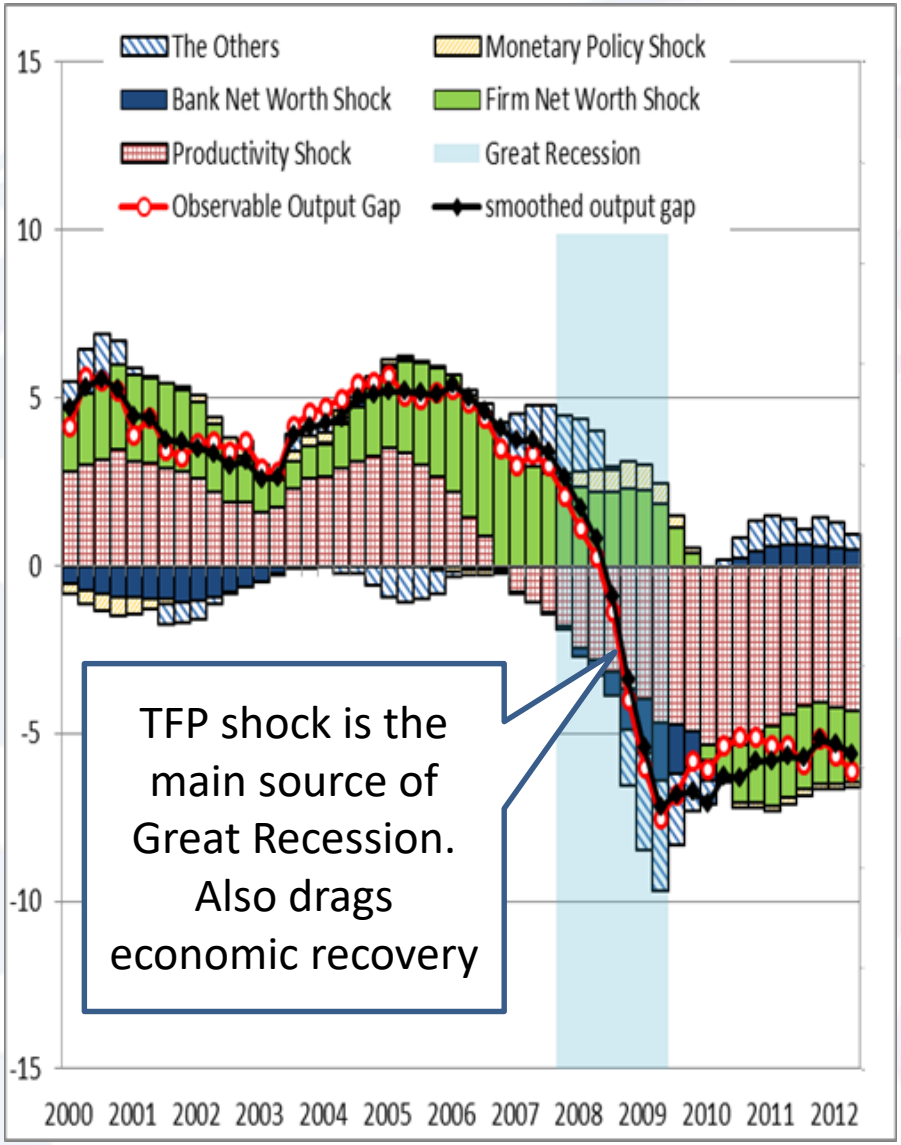
Leverage Effects of Structural Shocks

Structural Shocks	Case C (SV)	Case D (Data Rich + SV)
TFP	0	0
Preference	+	+
Corp. Net Worth	0	0
Bank Net Worth	0	0
Government Expenditure	0	0
Investment	0	0
Labor Supply	0	0
Monetary Policy	+	+

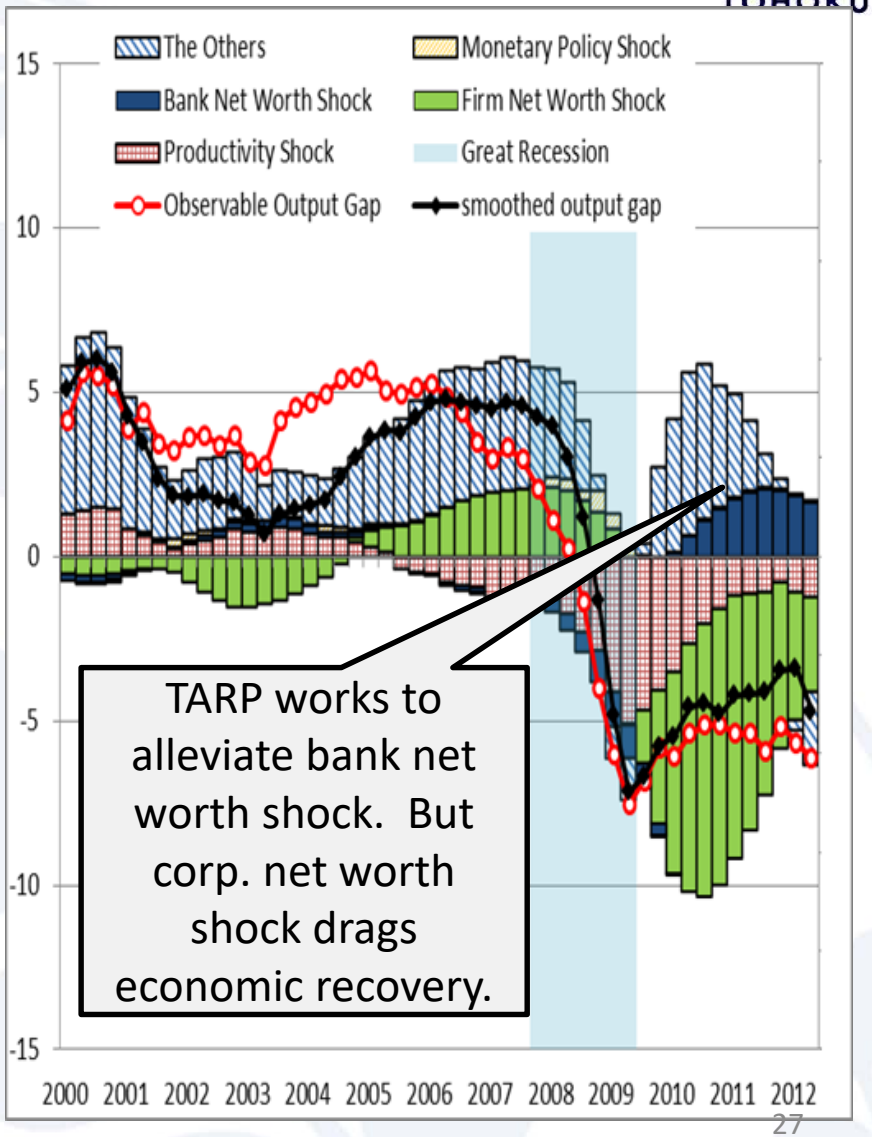
- Leverage effect observed for preference shock and monetary policy shock, but not for corp. net worth shock or bank net worth shock.

Historical Decomposition of **Real GDP**

Case A: Standard DSGE approach

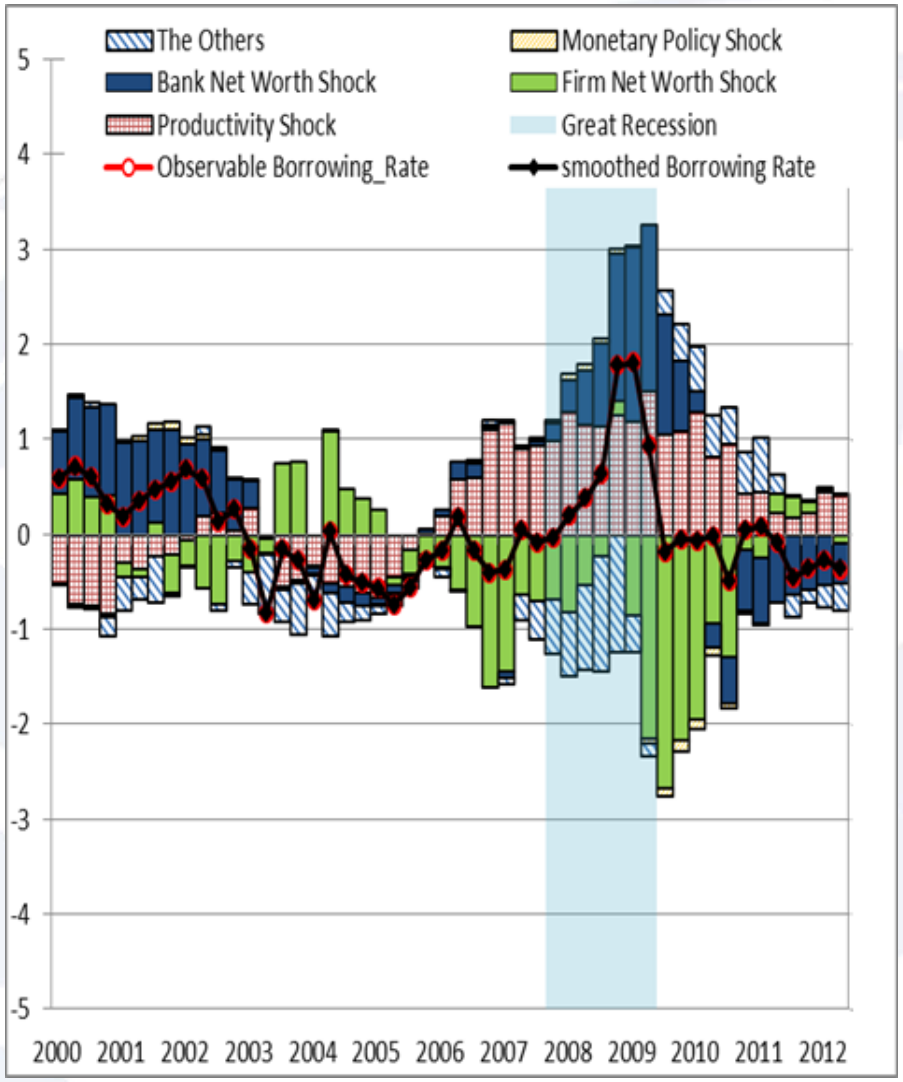


Case D: Data Rich DSGE + SV approach

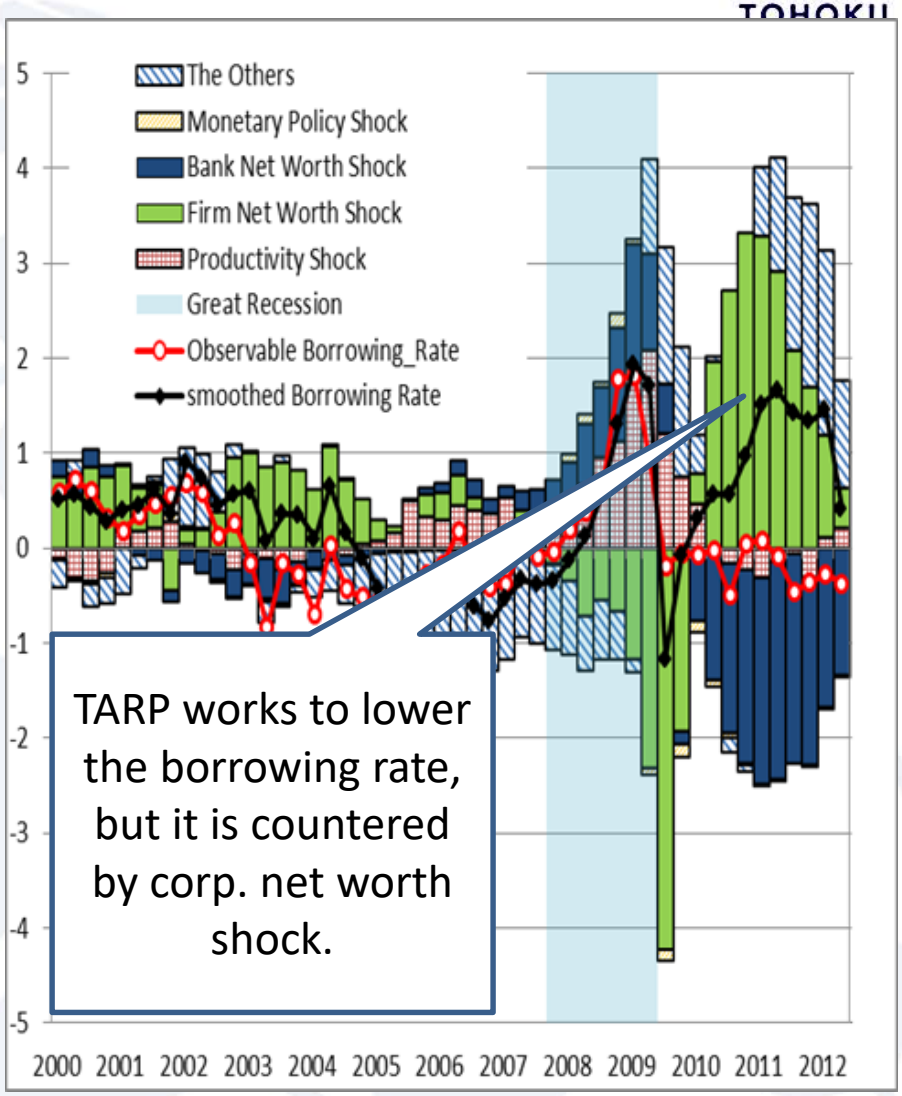


Historical Decomposition of **Borrowing Rate**

Case A: Standard DSGE approach



Case D: Data Rich DSGE + SV approach



Conclusion

Methodological Contributions:

- Based on the DSGE model with two financial frictions, we incorporated time-varying volatilities of the structural shocks.
- Further, we have allowed for the leverage effects in time-varying volatilities of the structural shocks.
- The volatilities of corporate and banking sector net worth shocks were clearly time-varying, especially during the Great Recession period. However, we did not observe leverage effect in SV.

Conclusion

Three Empirical Observations:

- As for the timing of two financial shocks during Great Recession, bank net worth shock (2008 Q3)preceded corporate net worth shock (2009 Q2).
  $\Rightarrow$ May points to the endogenous relationship between banking sector and corporate sector balance sheets.

- Corporate net worth shock during Great Recession and post-Great Recession period relatively minor in Case A estimation, but quite major in Case B, C, and D.
  $\Rightarrow$ May points to the underestimation of corporate net worth shock under plain-vanilla Bayesian estimation. It may be the case that Data-Rich or SV methods are more reliable in estimating the corporate net worth shock during this period.

- Bank net worth shock pushes down GDP sharply during Great Recession, but then right after Great Recession, bank net worth shock quick reverses its direction and contributes positively to lead economic recovery in the U.S.
  $\Rightarrow$ May points to the successful implementation of TARP to end Great Recession.