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Source of the Great Recession

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Abstract

We incorporate two structural shocks associated with balance sheets of both the financial and nonfinancial firms in a medium scale New Keynesian dynamic stochastic general equilibrium (DSGE) model. The structural shocks in the model are assumed to possess stochastic volatilities with a leverage effect. Then, we estimated the model using a data-rich estimation method and utilized up to 40 macroeconomic time series. We found the following three pieces of empirical evidence in the Great Recession (Dec. 2007–Jun. 2009) worsened further by the collapse of Lehman Brothers in September 2008. First, the net-worth shock of financial firms had gradually declined prior to a huge decrease of net-worth of nonfinancial firms. Second, the net worth shock of nonfinancial firms accounted for large weight of the business cycles after the Great Recession, in terms of the data-rich approach with the SV of structural shocks, unlike the standard DSGE model. Third, the Troubled Asset Relief Program would have immediately worked to improve balance sheets of financial institutions, although it would not have stopped worsening those of the corporate sector for a while.

Keywords: new Keynesian model, DSGE model, data-rich approach, Bayesian estimation, financial friction, stochastic volatility, net-worth shock

1. Introduction

The Great Recession (Dec. 2007–Jun. 2009) is thought to have deeply worsened by simultaneous collapse of several big financial institutions besides many bankrupts of the corporate firms and households in the US economy. Recently, a couple of survey papers researching causes of the Great Recession by prominent economists (i.e., Gertler and Gilchrist [1], Kehoe et al. [2]) are published in terms of macroeconomic models, say dynamic stochastic general equilibrium (DSGE) models. Since we obtained a broad consensus that solvency and liquidity problems of the financial institutions are chief among the fundamental factors causing the recession itself, as described in above papers, it is plausible to incorporate financial frictions in both the banking and the corporate sectors of a New Keynesian (NK) DSGE model in order to analyze the recession. Meanwhile, Mian and Sufi [3] analyzed the Great Recession from the aspect of household balance sheets and employment.

The purpose of this study is to identify what structural exogenous shocks contributed to the Great Recession by analyzing the mutual relationship among macroeconomic and financial endogenous variables in terms of business cycles from

the point of view of a DSGE model. In fact, according to Ireland [4], there are three sets of considerations that are premature for existing DSGE models. First, failures of financial institutions and liquidity drain should be endogenously described with other fundamental macroeconomic variables for producing economic insights. Second, most recessions have been associated with a rise in bankruptcies among banking and corporate sectors alike. And recessions have featured systematic problems in the banking and loan industry. And third, declines in housing prices and problems in the credit markets might have played an independent and causal role in the Great Recession's severity. Our study challenges to struggle with the former two exercises of Ireland [4], by identifying two different unobservable net-worth shocks of both banking and corporate sectors in a medium scale NK-DSGE model, into which two different financial frictions are newly embedded. And, we estimate time-varying volatility of these structural shocks in order to examine rapid changes of uncertainty and risk for financial crisis across financial markets and the economy as a whole.

As advanced econometric tool, we adopt a data-rich environment to estimate a NK DSGE model following Smets and Wouters [5, 6] but adding above two financial frictions for the US economy. The advantage of incorporating a data-rich environment into a NK DSGE model is that we can more robustly identify two different net-worth shocks generated by two financial frictions because of decomposing comovements of model variables and idiosyncrasy of measurement errors from observable variables of big macroeconomic panel dataset. And this advantage is also useful to estimate a time-varying stochastic volatilities (SVs) of the structural shocks including financial shocks in the DSGE model and to estimate contributions of financial frictions on the real economy both during the Great Recession and after it, because this framework allows the structural shocks to relax the specifications thanks to big dataset.

By adopting the data-rich environment and SV shocks, we will consider four alternative cases, based on the number of observation variables (11 vs. 40 observable variables) and the specification of the volatilities of the structural shocks (constant volatility vs. time-varying volatility). By comparing the four cases, we report the following three findings of empirical evidence in the Great Recession: (1) the net-worth shock of financial institution had gradually declined prior to a huge decrease of net-worth of corporate sector. (2) The net worth shock of nonfinancial firms played an important role during the Great Recession and after it, in terms of the data-rich NK DSGE model with the SV of structural shocks, unlike the standard NK DSGE model. (3) The Troubled Asset Relief Program (TARP) would have immediately worked to improve balance sheets of financial institutions, although it would not have stopped worsening those of the corporate sector for a while. These findings suggest that it is effective to strengthen the regulation, supervision and risk management of banks for preventing financial crisis. And they seem to support the Basel III framework developed by the Basel Committee in response to the global financial crisis of 2007–2009.

As describing our estimation results, introducing structural SV shocks to a DSGE model has their credible interval narrower than half of the model with constant volatilities that indicates a realistic assumption of the time-varying structural shocks. And it is plausible that the uncertainty is trivial in ordinary times but it becomes to a huge size at the turning points of recessions.

The chapter is organized as follows. Section 2 illustrates two financial frictions of the New Keynesian model. Section 3 presents the estimation technique and data description. Sections 4 and 5 discuss the estimation results and interpretation of the Great Recession in terms of the New Keynesian model. Section 6 concludes the paper.

2. Model

We adopt the stylized DSGE model, often referred to as the medium-scale New Keynesian (NK) model, following Christiano et al. [7] and Smets and Wouters [5, 6], which focused on the nominal rigidities of price level and wage as well as the quadratic adjustment cost of investment and habit formation of consumption as blue arrows shown in **Figure 1(a)**. In this NK model, it is generally assumed that

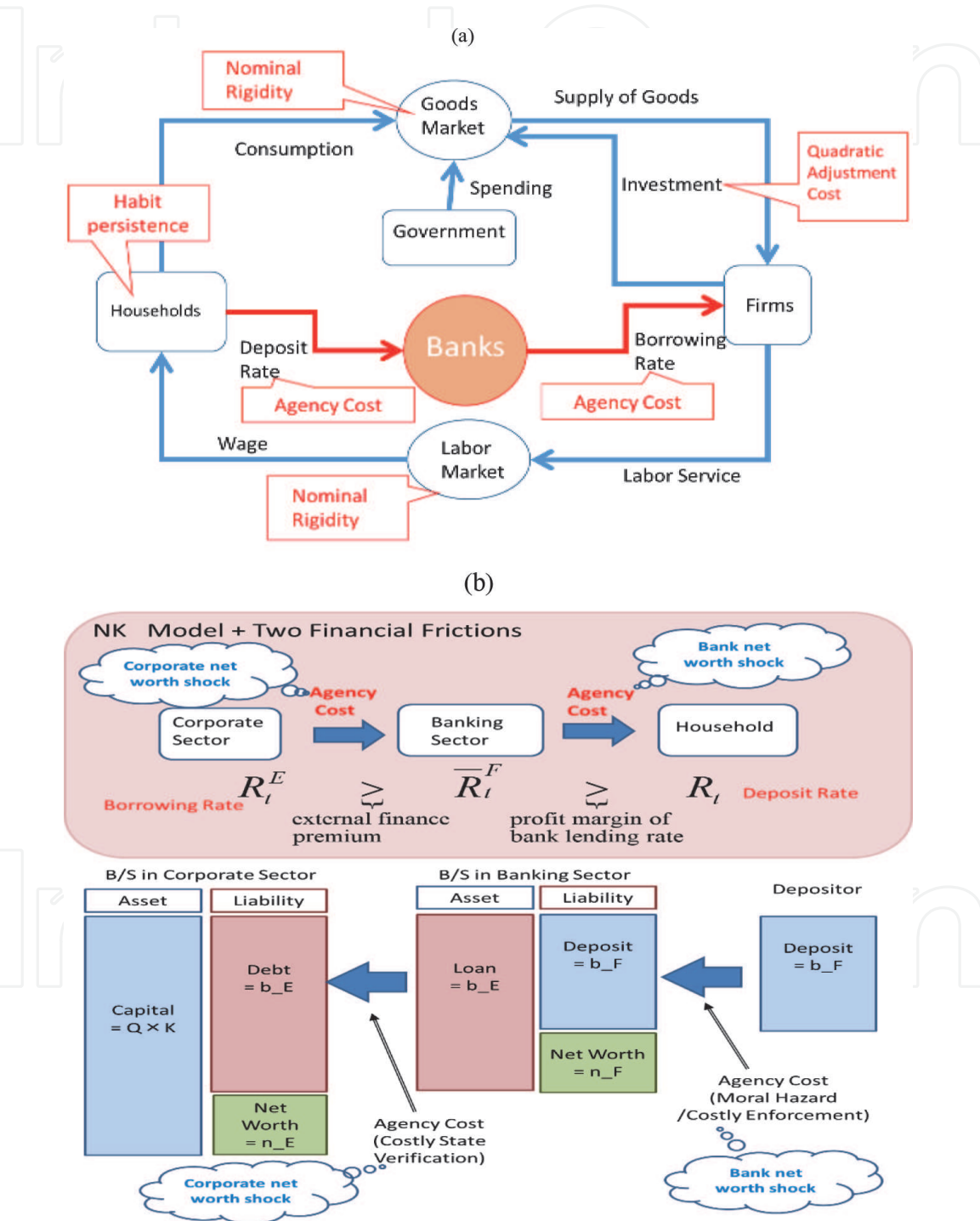


Figure 1. Our NK model. (a) Flowchart of economy. (b) Two financial frictions. Notes: Panel (a) shows the medium-scale NK model, following Christiano et al. [7] and Smets and Wouters [5, 6], which assume the nominal rigidities of price level and wage as well as the quadratic adjustment cost of investment and habit formation of consumption. Panel (b) shows two financial frictions in which the spread between lending rate R_t^E and deposit rate R_t is divided into two portions by introducing the risk-adjusted return for banks \bar{R}_t^F in between, and which are modeled to reflect the two different relationship between the balance sheets of the corporate and banking sectors and the borrowers' agency costs against the lenders, respectively.

there are six structural shocks, i.e., (1) preference shock, (2) labor supply shock in households, (3) total factor productivity (TFP) shock, (4) investment-specific technology shock in production function, (5) monetary policy shock and (6) government spending shock in the policy and government sectors.

And, shown as two red arrows in **Figure 1(a)**, we additionally incorporate two different financial frictions in our NK model, since banks have two roles in generating two agency costs with asymmetric information between borrowers and lenders. One is as the lenders to the corporate sector and the other is as the borrowers from depositors. These two financial frictions are designed to reflect the two different relationship between the balance sheets of the corporate and banking sectors and the borrowers' agency costs against the lenders, respectively. The former friction between the bank and the corporate sectors was developed by Bernanke et al. [8], and estimated by Christensen and Dib [9] and Christiano et al. [10]. The latter friction between banks and depositors was proposed by Gertler and Karadi [11] and Gertler and Kiyotaki [12]. Recently, comparisons of both frictions have been studied by Villa [13] and Rannenberg [14] etc. Brumermeier et al. [15] summarized the recent development of these financial friction models of macroeconomics.

In our NK model with the financial frictions, the spread between lending rate R_t^E and deposit rate R_t is divided into two portions by introducing the risk-adjusted return for banks R_t^F in between, as shown in **Figure 1(b)**. The positive corporate net-worth shock shrinks the difference between R_t^E and R_t^F by enlarging the liability of the corporate sector, while the positive bank's net-worth shock shortens the difference between R_t^F and R_t by expanding the liability of the bank sector. Most of DSGE studies adopt independent assumptions of structural shocks, since they are set up originally but not accessional from others and the relaxation of this assumption is involved in difficulty to identify shocks. Following them, it is plausible to assume that these two shocks are independent from one other, since our purpose is to identify different impacts of balance sheet channels of financial and nonfinancial firms on the recessions by measuring sizes of the both financial frictions through the both net-worth shocks of the balance sheets in the these firms.

Decomposing the effects of the two financial frictions on macroeconomic fluctuations might be important for finding out the origin of the Great Recession as well as measuring the degree of damage to the US economy. More detail explanation of this model is described in Iiboshi et al. [16].

3. Estimation methods and data

3.1 Econometric methods

To estimate our NK DSGE model, we adopt two econometric approaches. One is the data-rich approach proposed by Boivin and Giannoni [17], whose method followed by Shorfheide et al. [18], Nishiyama et al. [19] and Iiboshi et al. [20]. The other is to incorporate SV structural shocks in the DSGE model that was proposed by Justiniano and Primiceri [21]. They focused on the Great Moderation using a NK DSGE model with structural shocks with SV framework.

This econometric framework such as the data-rich approach with SV structural shocks can be described as

$$X_t = \Lambda S_t + e_t, \quad (1)$$

$$S_t = \Gamma(\theta)S_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_t^2), \quad (2)$$

$$\log \sigma_t^2 = \mu + \phi \log \sigma_{t-1}^2 + \eta_t, \quad \eta_t \sim N(0, 1), \tag{3}$$

where X_t and S_t are vectors of observable and model variables, respectively. ε_t is a vector of structural shocks. σ_t^2 is time-varying variance following autoregressive process such as the third equation, say the SV model. In the framework of the data-rich environment, we make one to many matching relation between S_t and X_t , whereas a standard DSGE model takes one to one matching between them, as shown in **Figure 2**.

3.2 Setting of four cases

Based on above econometric framework, we consider four *alternative* cases based on the specification of the volatilities of the structural shocks, σ_t^2 , (constant vs. time-varying volatility) and on the number of observation variables, X_t , (11 vs. 40 observable variables) as summarized in **Table 1**. The first case (referred to as **Case A**) dealt with one of the standard DSGE models that used 11 observable variables in the measurement equation and the structural shocks with i.i.d. Normal distribution in the transition equation. The second case (**Case B**) was extended to SV shocks from Case A. The third case (**Case C**) extends to the data-rich approach

Standard DSGE			Data-rich DSGE		
Model Variables		Observations	Model Variables = Common Factor		Observations
"output"	↔	Real GDP	"output"	↔	① real GDP
"inflation"	↔	GDP deflator			② IIP (Final Products)
					③ IIP (Total Index)
⋮		⋮	"inflation"	↔	① GDP deflator
					② Core CPI
					③ Price Index (PCE)
			⋮		⋮

Figure 2.
Data-rich approach. Notes: In the data-rich environment (right panel), we make one to many matching relation between model variables and observations. And in a standard DSGE model (left panel), we take one to one matching relation between them.

	Case A	Case B	Case C	Case D
Types of econometrics framework	Standard DSGE	Standard DSGE	Data-rich DSGE	Data-rich DSGE
Num. of Obs.	11	11	40	40
Matching between Model Variables and Obs.	1 to 1	1 to 1	1 to 4	1 to 4
Types of Struct. Shocks	iid normal	SV	iid normal	SV

Notes: The second row denotes types of econometrics framework as shown in **Figure 2**. The third and fourth rows stand for number of observations for estimation and relation between model variables and observations, respectively. The fifth row represents type of distribution of independent structural shocks. Abbreviation "iid" and "SV" denotes identical and independent distribution and stochastic volatilities, respectively.

For the third row, contents of the observations are described in table of Appendix. 11 observations of Cases A and B are in the first 11 rows of this table, while 40 observations of Cases C and D are all of the table including remains.

For the forth row, "1 to 4" denotes matching one model variables with four observations. A model variable which each observation belongs to is described in the second column of the table.

Table 1.
Setting of four cases.

with i.i.d shocks, including 40 observable variables, which indicate more or less four observable variables corresponding to one specified model variable. And the fourth case (**Case D**) extends to the data-rich approach with SV shocks from Case C.

3.3 Data description

By adopting the data-rich approach, we can adopt a relatively large and quarterly panel dataset with 40 observable variables. (More detail explanation of the observations is in the section, Appendix, in the end of the chapter.) In order to focus on the period of Great Moderation after 1984, we estimate between 1985:Q2 and 2012:Q2 including the Great Recession (Dec. 2007–Jun. 2009) and after it, since avoiding the period of the instable monetary policy regime, especially around the end of the 1970s and the early 1980s, say Hyper Inflation, directed by chairmen of the FRB, P. Volcker and A. Greenspan.

The contents of 40 observations are described in **Appendix** in the end of this chapter. Here, we mention about how to assort them based on the four cases. In Cases A and B, we looked at the following 11 series: (1) output, (2) consumption, (3) investment, (4) inflation, (5) real wage, (6) labor input, (7) the nominal interest rate, (8) the nominal corporate borrowing rate, (9) the external finance premium, (10) the corporate leverage ratio, and (11) the bank leverage ratio. The first seven series are following Smets and Wouters [5, 6]. The four remaining financial observable variables were selected for matching the model variables corresponding to the two financial frictions. The entrepreneur's nominal borrowing rate is the yield on Moody's Baa-rated corporate bonds detrended by the Hodrick-Prescott filter.

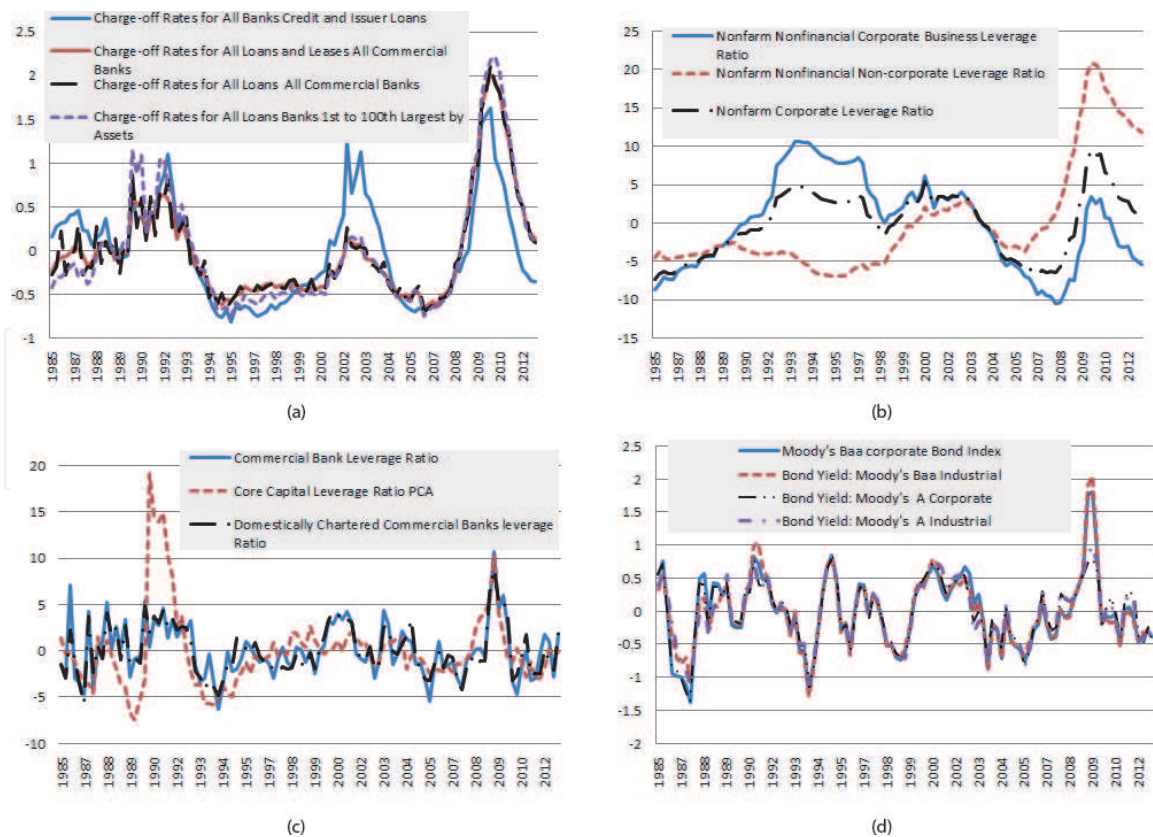


Figure 3. Observed financial data for identifying two financial shocks. (a) External finance premium. (b) Corporate leverage ratio. (c) Bank leverage ratio. (d) Borrowing rate. Notes: Four panels show 11 series involved in both the financial and nonfinancial sectors corresponding to the four model variables of the two financial frictions, respectively. These observations are used to identify the two financial shocks. For more detail description, see Appendix in the end of chapter.

To measure the external finance premium, we employed the charge-off rates for all banks' credits and issuer loans, measured as an annualized percentage of uncollectible loans. The two leverage ratios were calculated as their total asset divided by their net worth, respectively.

In Cases C and D, to activate the data rich environment, we populate an additional 29 series composed of 18 series of key macroeconomics and 11 series of the banking sector into the existing 11 series in Cases A and B. In **Figure 3(a)**, three different loan charge-off rates based on different institutions are selected as external finance premium. And Panel (c), we take the inverse of the commonly-used ratio, i.e., bank asset over bank equity as the leverage ratio. As shown in this figure, we can find comovements of 11 observations among four kinds of model variables related to the banking sector. In the data rich framework, these comovements are made full use as the model variables, and idiosyncrasy of an observation apart from its comovement is turned out as its measurement error in a DSGE model.

4. Empirical results

Before discussing and remaking the source of Great Recession, we firstly report estimation results, especially focusing on estimations of eight structural shocks by smoothing technique and historical decompositions of four key model variables, (a) output, (b) investment, (c) bank leverage ratio, and (d) borrowing rate, based on the four cases. Those estimations must be significant clue for figuring it out.

4.1 Structural shocks and their volatilities

In Cases A and B estimating standard data structure with the 11 observable variables, the posterior mean (deep blue solid lines) and a 90% credible band (a light blue shade) of the eight structural shocks with constant and time-varying volatilities are drawn in **Figure 4(a)** and **(b)**, respectively. And, **Figure 5(a)** and **(b)** show those of the data rich structure with the 40 observable variables, say Cases C and D, respectively. By comparing estimations of the eight structural shocks of different cases, we observe the following two points. First, although a couple of estimated shocks such as TFP and monetary policy shocks looks very similar among four cases, others, especially labor supply and government spending shocks, have different shapes among the four cases despite using the same DSGE model. Second, every structural shocks with stochastic volatilities (Case B and D) become more volatile in recessions, i.e., 1990:Q2 through 91:Q1, 2001:Q2 through 01:Q3, 2007:Q4 through 08:Q2, and more stable in remaining periods than their counterparts (Case A and C), without regard to data structure used.

Next we consider about financial and nonfinancial net-worth shocks affected on balance sheets on both sectors as shown in the second and third row of **Figures 4** and **5**, respectively. Firstly, we can see deep trough at 2008:Q3 in the banking net-worth shocks (the third row) of all cases in these four figures. In fact, in September and October 2008, major financial institutions such as Lehman Brothers, Merrill Lynch, Fannie Mae, Freddie Mac, Washington Mutual, Wachovia, Citi group, and AIG either failed, were acquired under duress, or were subject to government takeover. On the other hand, the huge troughs of the corporate net-worth shock might not coincide in all cases, and seem to split to two different periods, 2009:Q1 in constant volatility cases (Cases A and C), and 2009:Q2 in stochastic volatilities cases (Cases B and D). However it is worthy of notice that in every case, the corporate net-worth shocks have arrived at deep troughs after the banking sector shocks have experienced its huge drop.

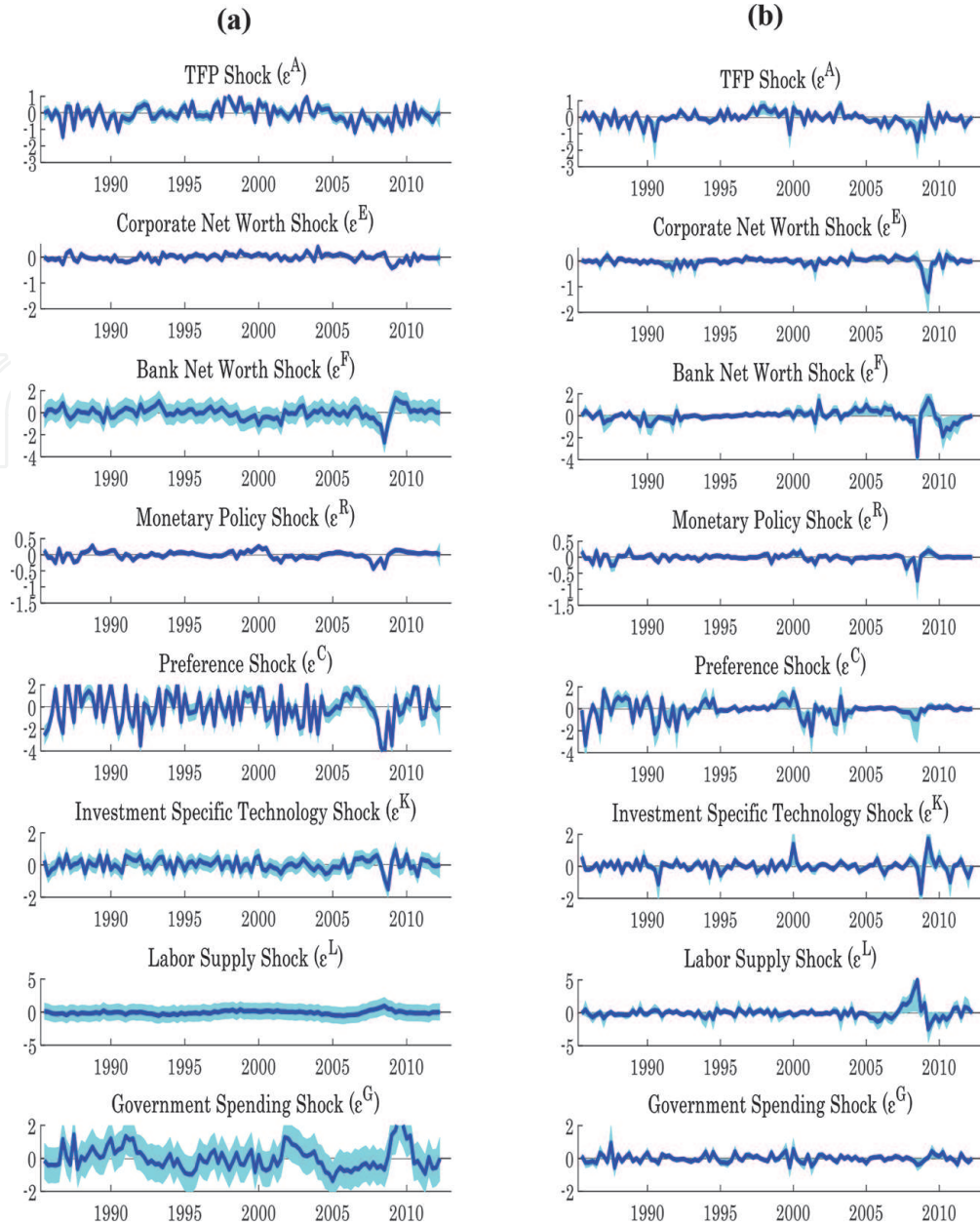


Figure 4. Structural shocks of standard data structure. (a) Constant volatility: Case A. (b) Stochastic volatility: Case B. Notes: Case A and Case B are described in **Table 1**. Eight shocks in our DSGE model are explained in Section 2. Corporate Net Worth shock and Bank Net Worth are balance sheet shocks of nonfinancial and financial sectors described in **Figure 1(b)**. TFP (total factor productivity), investment specific technology, and labor shock are belong to supply shocks, whereas preference of consumers, monetary policy, and government spending shocks belong to demand shocks. The deep blue lines and blue shaded area are posterior mean and 90% credible interval of structural shocks in Cases A and B, respectively.

In order to measure the accuracy of the eight estimated shocks, we calculate an average range of 90% credible interval across all of the sample period as **Figures 4** and **5**. When the average of 90% interval of a shock of one case become smaller than those of another case, then we can regard that the shock of the case is more precisely identified than another case. Although we leave out the explanation of detail values, averages of five shocks, say (1) preference, (2) banking net worth, (3) labor supply, (4) government spending, and (5) monetary policy, are less in stochastic volatilities cases, B and D, than constant volatilities cases, A and C. In Cases B and D, the averages in the former three shocks are around half against those in Cases A and C. Furthermore, average of government spending shocks downscales by one eighth to one tenth. From these results, we infer that the time-varying volatilities of shocks might be more fit to data generation process which we cannot

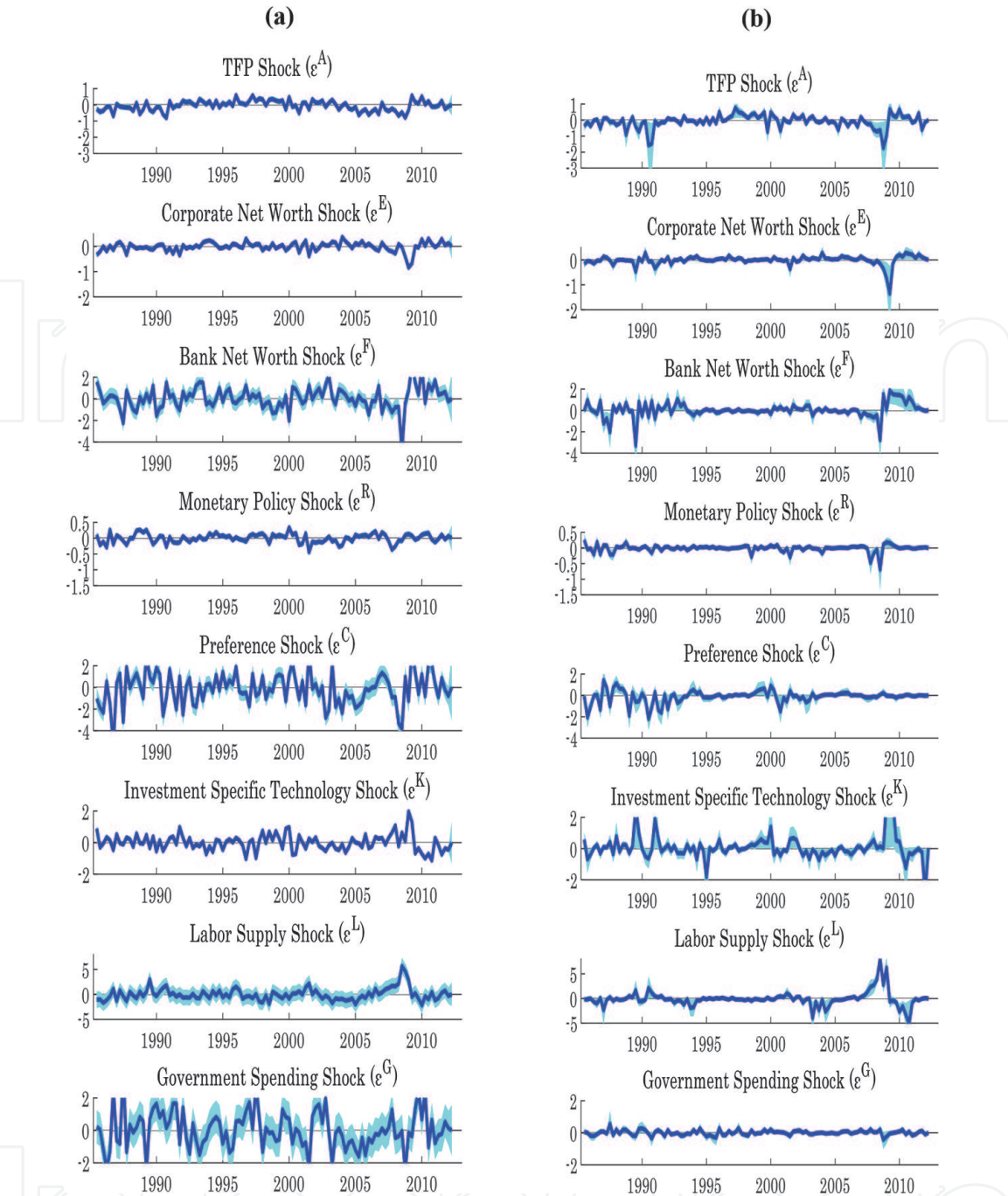


Figure 5. Structural shocks of data rich environment. (a) Constant volatility: Case C. (b) Stochastic volatility: Case D. Notes: Case C and Case D are described in **Table 1**. Eight shocks in our DSGE model are explained in Section 2. Corporate Net Worth shock and Bank Net Worth are balance sheet shocks of nonfinancial and financial sectors described in **Figure 1(b)**. TFP (total factor productivity), investment specific technology, and labor shock are belong to supply shocks, whereas preference of consumers, monetary policy, and government spending shocks belong to demand shocks. The deep blue lines and blue shaded area are posterior mean and 90% credible interval of structural shocks in Case C and D.

observe. In addition, we expect that the SV shocks are likely to match for a rapid change of uncertainty and volatilities at the turning points of the Great Recession, rather than the constant volatilities cases, as shown later.

Figure 6 shows the posterior means (deep blue lines) and 90% interval (light blue shade area) of the SVs of all eight shocks for standard data structure (Cases B) and data rich structure (Case D), as well as the posterior means of constant volatilities of the shocks (red dashed flat lines) in Case A and C. As these graphs, in ordinary period, say before the recession, a large part of the deep blue lines (Cases B and D) is under the red dashed lines (Cases A and C). Smoothing SVs of the six

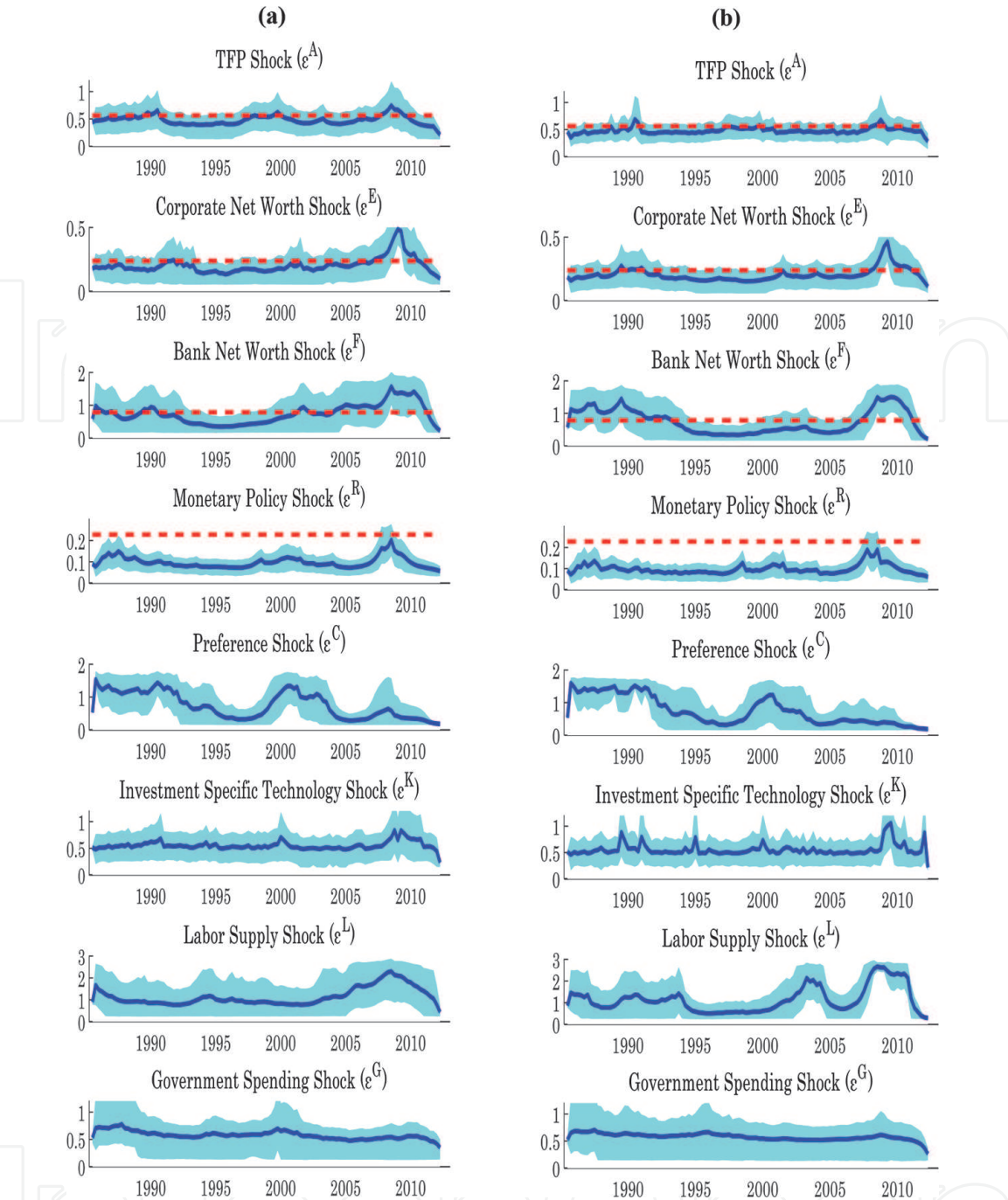


Figure 6. Stochastic volatilities of structural shocks. (a) Stochastic volatility: Case B. (b) Stochastic volatility data rich: Case D. Notes: Case B and Case D are described in **Table 1**. Eight shocks in our DSGE model are explained in Section 2. Corporate Net Worth shock and Bank Net Worth are balance sheet shocks of nonfinancial and financial sectors described in **Figure 1(b)**. TFP (total factor productivity), investment specific technology, and labor shock are belong to supply shocks, whereas preference of consumers, monetary policy, and government spending shocks belong to demand shocks. The deep blue lines and blue shaded area are posterior mean and 90% credible interval of stochastic volatility (SV) of Cases B and D, respectively. The red dashed lines denote the posterior means of constant volatilities shocks estimated in Case A and C, respectively. SV shocks are explained in Section 3.

shocks, but investment-specific technology (IST) shock and the labor supply shocks, look very similar in Cases B and D. And the SVs of the preference and labor supply shocks fluctuate with large amplitude during the period of the expansion between 2001:Q4 and 2007:Q4, and it indicates that they have played an important role of boom. Meanwhile, the SVs of the remaining shocks seem to be quiet and level off between 1990:Q1 and 2007:Q3. After August 2007, when the Great Recession began with the seizure in the banking system (in fact, BNP Paribas precipitated ceasing investment activity and was followed by three big hedge funds that

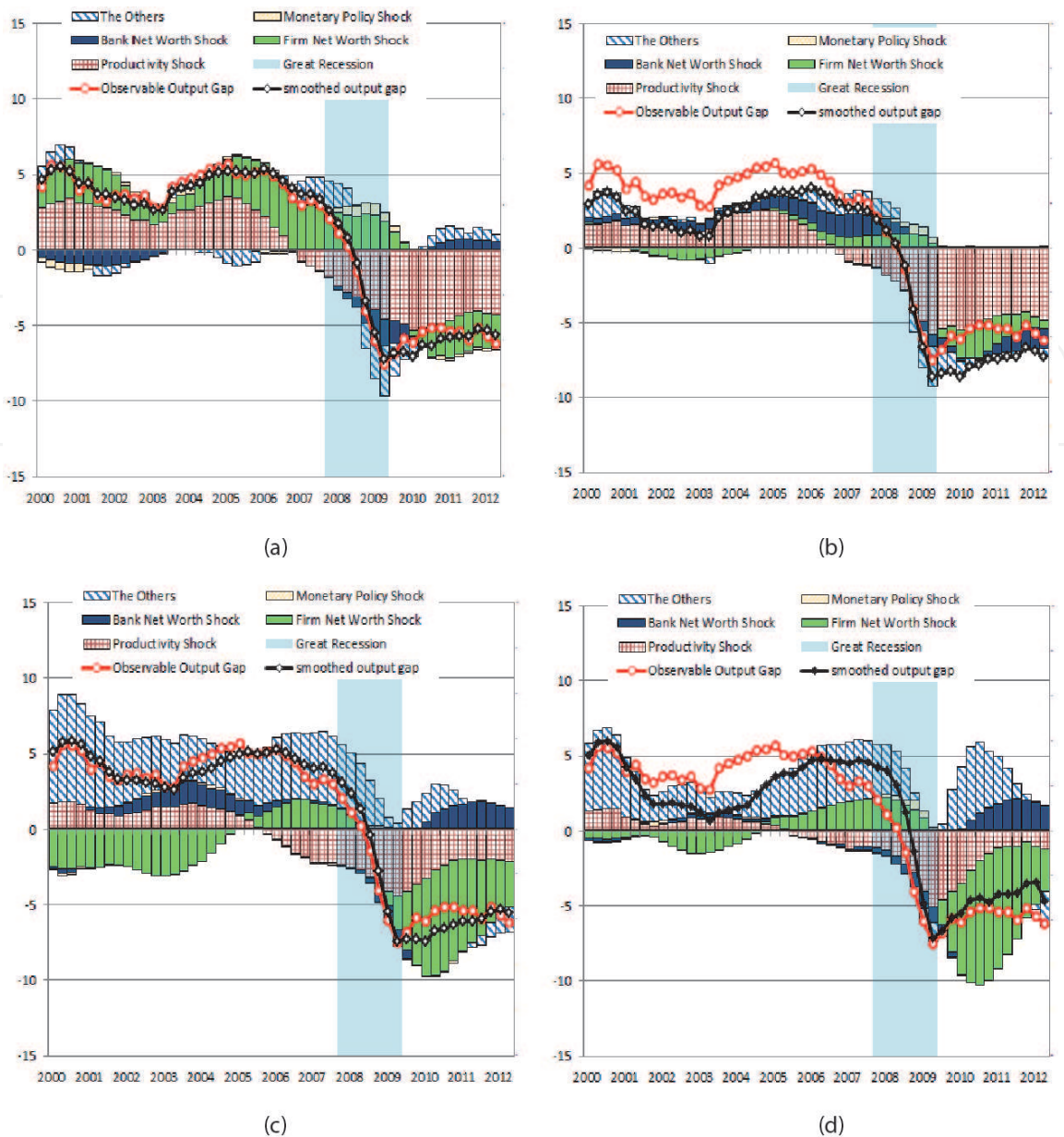
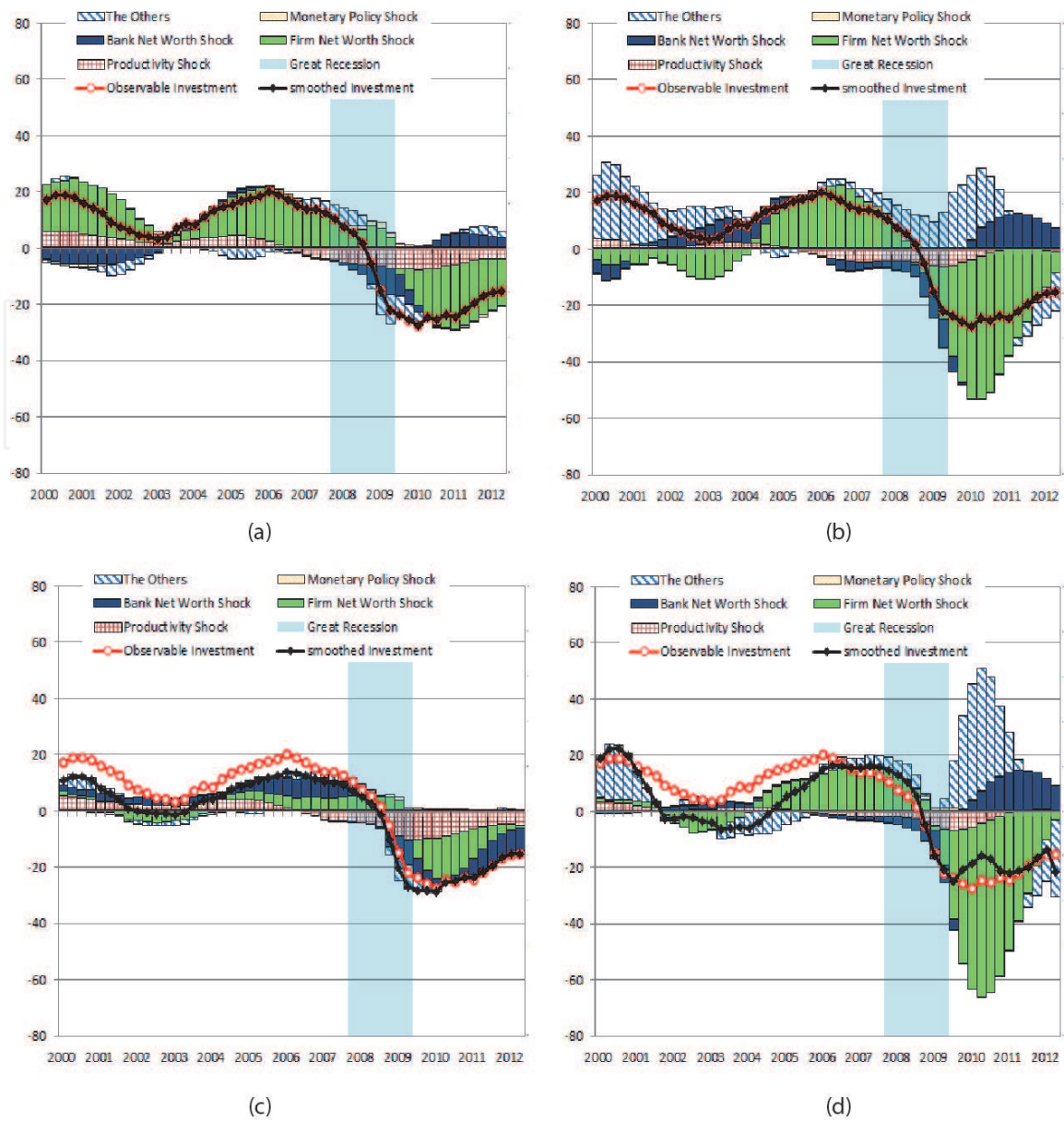


Figure 7. Historical decomposition of output. (a) Constant volatility Case A. (b) Stochastic volatility Case B. (c) Constant volatility data rich Case C. (d) Stochastic volatility data rich Case D. Notes: Four Cases A, B, C and D are described in **Table 1**. Case A; 11 observable variables and constant volatility shocks. Case B; 11 observable variables and structural shocks with SV. Case C: 40 observable variables and constant volatility shocks. Case D: 40 observable variables and structural shocks with SVs. Eight shocks are explained in Section 2 and SV shocks are explained in Section 3.

specialized in US mortgage debt at this moment.), the SVs of net-worth shocks of financial and nonfinancial sectors have rapidly jumped to ceil for both of Case B and D, as well as other shocks such as TFP, monetary policy, IST and labor supply shocks. And levels of these SVs (deep blue lines) exceed the red dashed flat lines indicating estimation of constant volatilities as **Figure 6**.

In this study, we would like to verify whether the data-rich approach contributes to the accuracy of the estimated SVs, compared with standard data structure. **Figures 4(b)** and **5(b)** show averages of the 90% interval (light shade area) in Cases B does not look different from those of Case D. And, although **Figure 6** reports difference in sizes of the 90% intervals (light shade area) of the SVs over the entire sample period between Cases B and D, we do not find obvious improvement of 90% band by the data-rich approach in Case D. From only the three figures, we cannot yet include the data-rich environment improve the accuracy of the SVs estimates. This inquiry will be remained until further research.

**Figure 8.**

Historical decomposition of investment. (a) Constant volatility Case A. (b) Stochastic volatility Case B. (c) Constant volatility data rich Case C. (d) Stochastic volatility data rich Case D. Notes: See the notes of Figure 7.

Finally, we turn to analyzing the monetary policy in the Great Recession and after it including an unconventional monetary policy by FRB such as Round 1 of quantitative easing policy (QE1), between 2008:Q4 and 2010:Q2 and Round 2 of quantitative easing policy (QE2) between 2010:Q4 and 2011:Q2, although our monetary policy rule follows linearized Taylor rules. As the fourth row of Figures 4 and 5, we can find the estimation of monetary policy shocks (deep blue lines) have two big negative troughs in this period for all cases. The first negative trough was identified at 2007:Q4 when the global financial market was disarranged by announcement of the BNP Paribas. And the second trough was ascertained at 2008:Q3, immediately before the FRB implemented QE1. Especially, the sizes of the two big negative shocks are classified in the Cases B and D with SVs shocks, as shown in Figures 4(b) and 5(b). The fourth row of Figure 6 also draws the rapid surge of these volatilities of monetary policy shocks between 2007:Q4 and 2008:Q3. In other words, the two unconventional monetary policy might be undertaken more boldly and without hesitation as well as the case of conventional tightening policy according to the 90% credible band of the SVs.

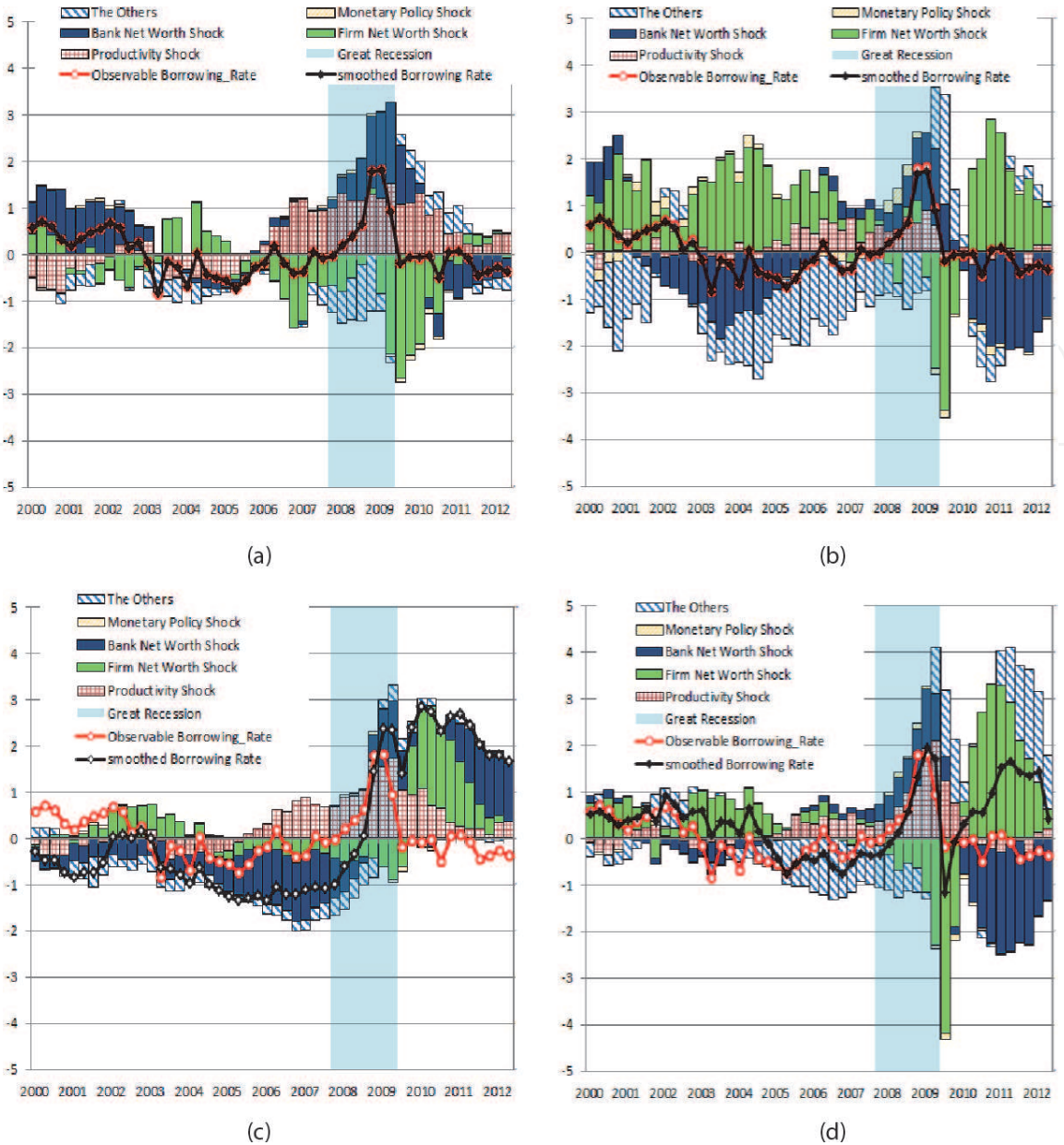


Figure 9. Historical decomposition of borrowing rate. (a) Constant volatility Case A. (b) Stochastic volatility Case B. (c) Constant volatility data rich Case C. (d) Stochastic volatility data rich Case D. Notes: See the notes of Figure 7.

4.2 Historical decompositions

Here, we move to discuss about difference of historical decompositions among the four cases. In particular, as can be seen from Figures 7(a)–(d)–10(a)–(d), we focus on the periods between 2000:Q1 and 2012:Q2 of the following four observations and model variables, say (1) the real GDP of observations matching to an output gap of model variable, similarly (2) the gross private domestic investment matching to investment, (3) Moody’s bond index (corporate Baa) matching to corporate borrowing rate, (4) the commercial banks’ leverage ratio matching to the bank leverage ratio. The red and black circle lines represent observations and smoothed estimation, respectively. The differences between both lines indicate measurement errors of observations. In these figures, the light blue shade represents the period of the Great Recession (2007:Q3 to 2009:Q2). In order to make more visible and to concentrate on the contributions of both net-worth shocks of banking sector (deep blue shade area) and corporate sector (green shade area) for the recession by remaining key shocks like the TFP (red shade area) and monetary

policy shocks (yellow shade area), we gathered the other four miscellaneous shocks as one bundle (light blue shade area) in these figures.

We start to discuss about real activities, say the real GDP and the gross private domestic investment. As shown in **Figures 7 and 8**, the contributions by each shocks show similar proportions between the real GDP and the investment. The decomposition by each shock has the same sign at every period of both variables in all four cases, but the sizes of the contribution of shocks are quite different depending on the cases. For example, the TFP shock (red shade area) accounted for a large portion of the sources of the Great Recession, whereas the bank net-worth (deep blue shade area) explained a small part of drops in Cases A and B. And the positive corporate net-worth (green shade area) increased and contributed to raising these variables by a significant portion during the recession in Case A. Meanwhile, Cases C and D showed that the positive impact by the corporate net-worth shock (green shade area) was smaller than Case A, and that the bank net-worth shock (deep blue shade area) explain a half of the downturn of both variables in the recession as well as the TFP shock.

Figure 9 draws historical decomposition of a model variable of corporate borrowing rate using an observation of Moody's bond index (corporate Baa). For all

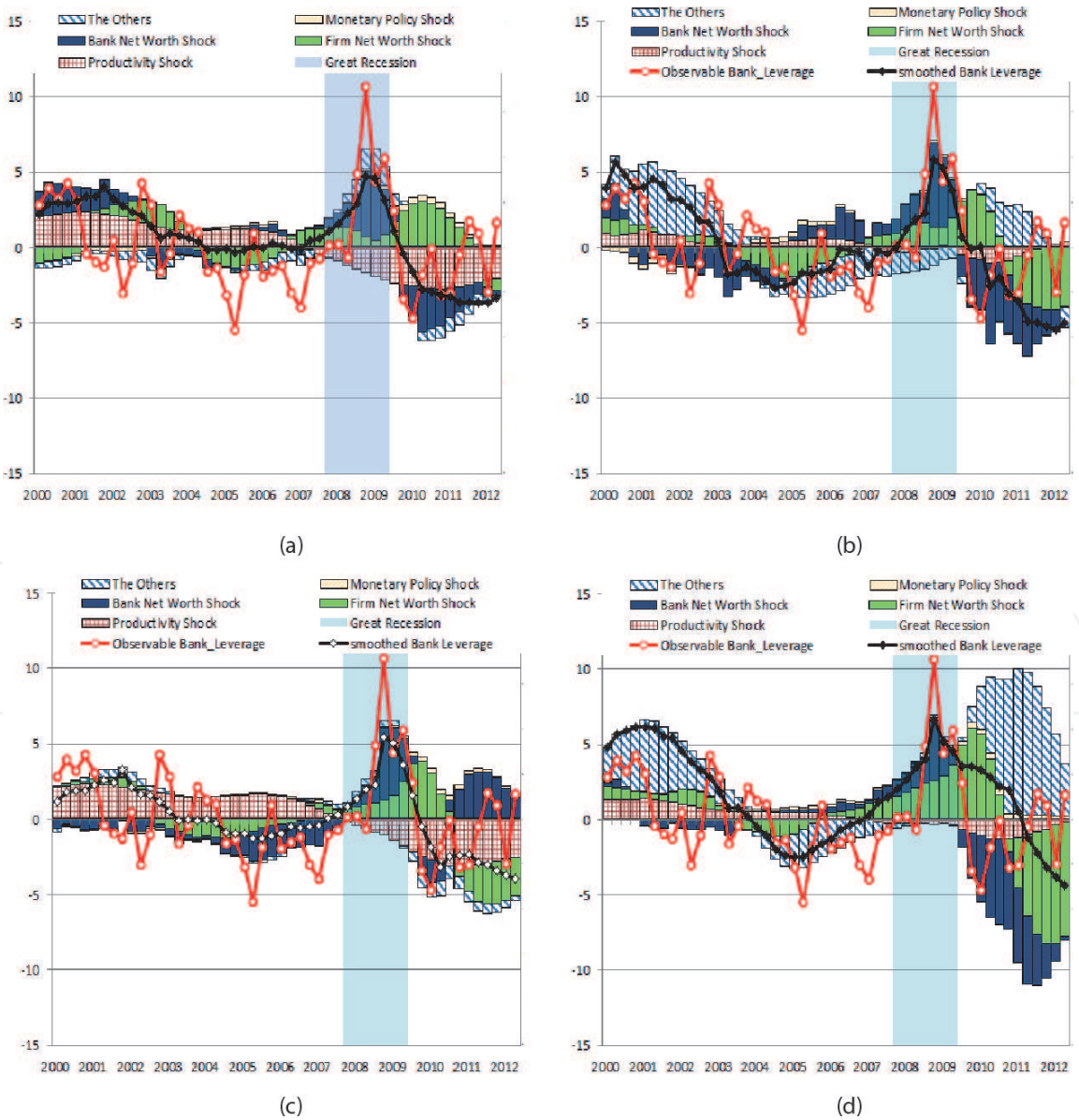


Figure 10. Historical decomposition of bank leverage ratio. (a) Constant volatility Case A. (b) Stochastic volatility Case B. (c) Constant Volatility Data Rich Case C. (d) Stochastic Volatility Data Rich Case D. Notes: See the notes of **Figure 7**.

cases, a sharp spike of the rate must be mainly contributed for the negative shock of bank net-worth (deep blue shade area) as well as from a drop of the TFP shock (red shade area), while the positive shock of corporate net-worth (green shade area) are likely to account for extending of the rate downward in the recession. On the other hand, TARP might have been effectively workable and made the net-worth of financial firms become positive, that would have contributed to decline of the borrowing rate after 2010:Q1. Especially, these findings are seen in Cases B and D with SV shock.

Figure 10 shows the decomposition of the commercial banks' leverage ratio, i.e., the ratio of the bank's asset to the bank's net-worth for all four cases. The leverage ratio fluctuates countercyclical as these figures. In the recession, two negative net-worth shocks of both sectors worsen balance sheet of banking sectors indicating sharp spike of the ratio. But, immediately after starting TARP, bank equity was likely to successfully improve, although the net-worth shock in corporate sector (green shade area) continued negatively and made the corporate balance sheet much worse even during executing TARP in 2010. And the banking loan to corporate sector declined sharply by large deficit of corporate balance sheet. A reduction of banking loan would have brought the banks' leverage ratio to decrease during implement of TARP, because the numerator of the ratio means total of loan and equity in the banks. In fact, we often observe that banking loan declines but corporate bond increases in the recession. However, the countercyclical movement of the bank's leverage ratio was not generated from the banking model by Gertler and Kiyotaki [12] which is one of our financial frictions of banking sector. On the other hand, Adrian et al. [22] intended to describe the reason why the ratio was countercyclical, using a theory of liquidity and leverage proposed by Adrian and Shin [23]. Our findings about two conflicting net-worth shocks in the recession seem to be consistent with Adrian et al.'s [22] findings.

5. Discussion and remark

Through estimation of our model, we found three key findings during the period of the Great Recession and after it, which has already described in the previous section. Without hesitating duplication, we summarize these points.

First, as can be seen from **Figures 4** and **5**, the timing of the two different financial shocks modeling as balance sheet shocks in financial and nonfinancial firms have not arisen simultaneously, but the bank's balance sheet shock has sharply rose prior to the surge of the corporate balance sheet shock. When a financial crisis brings blooming degeneration of both balance sheet, this timing pattern (not concurrent, but sequential timing) must be noted as a lead of endogenous relationship of the balance sheet conditions in both banking sector and the corporate sector. Our model, however, has limitations. That is, we assume the two balance sheet shocks to be independent from each other and further do not allow the corporate sector to keep the bank's equity as an asset of his balance sheet. Thus, it may be inappropriate to interpret the endogenous relationship between the two net-worth shocks. Yet, it is worth noting about remark of the timing pattern of the two financial shocks during the Great Recession.

Second, we found that during the Great Recession, contributions of corporate balance sheet shock are relatively smaller in models with constant volatility shocks as Cases A and C than in models with SV shocks as Cases B and D as shown in **Figures 7–10**. This result suggests that estimation without the data-rich environment is likely to under-evaluate importance of the corporate balance sheet shock. Furthermore, an accuracy of estimating the corporate balance sheet shocks during

the Great Recession play an important role of accounting for the economic recovery of the U.S. economy. For instance, in cases with constant volatility shocks as Cases A and C, a slow recovery of output is mainly explained by the negative TFP shock. On the other hand, in cases with SV shocks as Cases B and D, it is mainly explained by a prolonged negative corporate balance sheet shock. The slow recovery of the U.S. economy after the Great Recession remains as an important question, and a persuasive description of this question requests a precise estimation of trace of these shocks. To this end, especially for estimating the corporate net worth shock, we hope that a data-rich approach with SV shocks must be more reliable than standard data structure.

Third, there is another important finding from the historical decomposition which is the behavior of the bank's balance sheet shock. A sharp decline of the bank's balance sheet shock was obviously associated with the Great Recession, and rapid reductions of output and investment have stem from two net-worth shocks, as shown in **Figures 7 and 8**. Immediately after end of the Great Recession, the bank's balance sheet shock, however, quickly reversed its direction from negative to positive, and picked up both of output and investment upward. When we consider the timing of this reversal, it was plausible that the execution of the TARP is behind this counterturn. That is, TARP would have successfully made downward trend of the bank's balance sheet change upward. From our finding about the positive contribution of the bank's net-worth shock to the real GDP and investment right after the end of the Great Recession period, the executing TARP might be one of the major factors behind the stopping further degeneration of the recession and contributing to the recovery of the U.S. economy.

These three findings seem to support the Basel III framework developed by the Basel Committee in response to the global financial crisis of 2007–2009. The Basel III revised in order to strengthen the regulation, supervision and risk management of banks, by reducing excessive variability of risk-weighted assets (RWA) of banks. In particular, for preventing global financial crisis, it might be effective to restore credibility of the RWA by complementing the risk-weighted capital ratio with a finalized leverage ratio and a revised and robust capital floor, according to our empirical findings.

6. Conclusion

This study is to identify what structural exogenous shocks contributed to the Great Recession and to analyze the mutual relationship among macroeconomic and financial endogenous variables in terms of a medium scale New Keynesian DSGE model with two net-worth shocks in both the financial and nonfinancial firms, using data rich approach with as many as 40 observations. And it is plausible to incorporate two different financial frictions to a standard DSGE model to analyze the recession, since there was a broad consensus that solvency and liquidity problems of the major financial institutions such as Lehman Brothers, Merrill Lynch, Fannie Mae, Freddie Mac, Washington Mutual, Wachovia, Citi group, and AIG, which either failed, were acquired under duress, or were subject to government takeover, might be attributed causing the Great Recession itself.

We considered four alternative cases based on the number of observation variables (11 vs. 40 variables) and the specification of the volatilities of the structural shocks (constant volatility vs. time-varying-volatility). Comparing these four cases, we suggested the following two pieces of empirical evidence in the Great Recession; (1) the negative bank net worth shock gradually spread before the corporate net worth shock burst, and (2) the data-rich approach and the structural shocks with SV evaluated the contribution of the corporate net worth shock to a substantial portion

of the macroeconomic fluctuations after the Great Recession, in contrast to a standard DSGE model.

From a view of evaluating policies, the implementation of TARP has sufficiently worked to mitigate the bank’s negative net-worth shocks und upturned the output and the investment. The model and empirical results in this study suggest that such a bail-out program must be workable effectively in case of a serious recession followed by a financial crisis with failures of financial institutions. On the other hand, the slow recovery of the U.S. economy after the Great Recession can be explained by the wounded balance sheet of the non-financial corporate sector, which is not healed in a short period.

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Appendix

No.	Variables	Proc.	Observation explanation	Unit of data	Source
Case A and Case B: The standard Data Structure					
1	R	6	Interest rate: Federal Funds Effective Rate	% per annum	FRB
2	Y ₁	5	Real gross domestic product (excluding net export)	Billion of chained 2000	BEA
3	C ₁	5*	Gross personal consumption expenditures	Billion dollars	BEA
4	I ₁	5*	Gross private domestic investment - Fixed investment	Billion dollars	BEA
5	π ₁	8	Price deflator: Gross domestic product	2005Q1 = 100	BEA
6	w ₁	2	Real Wage (Smets and Wouters, 2007)	1992Q3 = 0	SW (2007)
7	L ₁	1	Hours Worked (Smets and Wouters, 2007)	1992Q3 = 0	SW (2007)
8	RE ₁	6	Moody’s bond indices - corporate Baa	% per annum	Bloomberg
9	Lev ₁ ^F	7	Commercial banks leverage ratio	Total asset/net worth ratio	FRB
10	Lev ₁ ^E	3	Nonfarm non-fin. Corp. business leverage ratio	Total asset/net worth ratio	FRB
11	s ₁	1	Charge-off rates for all banks credit and issuer loans	% per annum	FRB

No.	Variables	Proc.	Observation explanation	Unit of data	Source
Case C and Case D: The data-Rich Environment					
12	Y_2	4	Industrial production index: final products	Index 2007 = 100	FRB
13	Y_3	4	Industrial production index: total index	Index 2007 = 100	FRB
14	Y_4	4	Industrial production index: products	Index 2007 = 100	FRB
15	C_2	5*	PCE excluding food and energy	Billions of dollars	BEA
16	C_3	5	Real PCE, quality indexes; non-durable goods	Index 2005 = 100	BEA
17	C_4	5	Real PCE, quality indexes; services	Index 2005 = 100	BEA
18	I_2	5	Real gross private domestic investment	Billions of Chained 2005	BEA
19	I_3	5*	Gross private domestic investment: fixed nonresidential	Billions of dollars	BEA
20	I_4	5	Manufactures' new orders: non-defense capital goods	Millions of dollars	DOC
21	π_2	8	Core CPI excluding food and energy	Index 2005 = 100	BEA
22	π_3	8	Price index - PCE excluding food and energy	Index 2005 = 100	BEA
23	π_4	8	Price index - PCE - Service	Index 2005 = 100	BEA
24	w_2	4*	Average hourly earnings: manufacturing	Dollars	BLS
25	w_3	4*	Average hourly earnings: construction	Dollars	BLS
26	w_4	4*	Average hourly earnings: service	Dollars	BLS
27	L_2	4	Civilian Labor Force: Employed Total	Thous.	BLS
28	L_3	4	Employees, nonfarm: total private	Thous.	BLS
29	L_4	4	Employees, nonfarm: goods-producing	Thous.	BLS
30	RE_2	6	Bond yield: Moody's Baa industrial	% per annum	Bloomberg
31	RE_3	6	Bond yield: Moody's A corporate	% per annum	Bloomberg
32	RE_4	6	Bond yield: Moody's A industrial	% per annum	Bloomberg
33	Lev_2^F	9	Core capital leverage ratio PCA all insured institutions	Core capital/total asset	FDIC
34	Lev_3^F	7	Domestically chartered commercial banks leverage ratio	Total asset/net worth	FRB
35	Lev_4^F	7	Brokers and dealers leverage ratio	Total asset/net worth	FOF
36	Lev_2^E	3	Nonfarm nonfinancial non-corporate leverage ratio	Total asset/net worth	FOF
37	Lev_3^E	3	Nonfarm corporate leverage ratio	Total asset/net worth	FRB
38	s_2	1	Charge-off rate on all loans and leases all commercial banks	% per annum	FRB
39	s_3	1	Charge-off rate on all loans all commercial banks	% per annum	FRB
40	s_4	1	Charge-off rate on all loans banks 1st to 100th largest by assets	% per annum	FRB

Notes: Table is composed from the following five columns, say Number, Model Variable Name, Transformation Procedures, Observation Explanations, Unit of Data, and Data Source. Abbreviations such as “PCE” and “SW (2007)”, stand for personal consumption expenditure and Smets and Wouters (2007), respectively. In a column of the Transformation Procedures, numbers stand for 1: Demeaned, 2: Linear and De-trended, 3: Logarithm and Demeaned, 4: Logarithm, Linear De-trended, and Multiplied by 100, 5: Logarithm per Capita, Linear De-trended and Multiplied by 100, 6: De-trended using Hodrick-Prescott (HP) filter, 7: Logarithm, De-trended using HP Filter, and Multiplied by 100, 8: First Difference Logarithm, De-trended using HP Filter, and Multiplied by 400, 9: the Reciprocal number, Logarithm, De-trended using HP Filter, and Multiplied 100.
A * indicate a series that is deflated with the GDP deflator.

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