Does Financial Risk Explain Japan’s Great Stagnation?

Ayato ASHIHARA[1]

【修士論文概要書】

Abstract:

Japan has experienced a long-lasting stagnation since the early 1990s. According to the Reference Dates of Business Cycle, the Cabinet Office of Japan, there are four recession periods between 1987 and 2010, and three of them are considered to be financially-related. This implies that the stagnation was triggered by financial factors. Nonetheless, many studies using Dynamic Stochastic General Equilibrium models claim that a decline in Total Factor Productivity is the main driver of the stagnation. To resolve this contradiction, this study estimates the Japanese economy by a New-Keynesian DSGE model augmented with financial friction used in Christiano, Motto and Rostagno (2014), where “risk shock” is newly incorporated into the model that refers to uncertainty in the financial market. According to our estimation results, the estimated risk shock can explain the overall fluctuations of GDP and investment, and thus it is considered to be the main driver of the stagnation. We also find that it is highly correlated with the Business condition Diffusion Index, the Financial Position Diffusion Index and the Lending Attitude Index of Financial Institutions in Tankan released by the Bank of Japan. Therefore, we conclude that the estimated risk shock can be interpreted as the firms’ distrust toward their business conditions, and it delayed their investment decisions, then causing the prolonged economic contraction.

Key words and Phrases: Japan’s Great Stagnation in the 1990s, Risk shock, Estimated DSGE models

1. Background and Motivation

Japan has experienced a long-lasting stagnation since the early 1990s. During this period, the average growth rate was down to 1.1%, compared to 4.4% in the 1980s. Figure 1 plots its real GDP growth rate from 1987 to 2010. The impacts on the Japanese society was enormous. Deterioration of the employment environment is one example of these. According to Recruit Works Institute, the effective job offer rate for university graduates started to decline from 1990, and eventually went below unity in 2000. To avoid the same circumstance in the future, it is desirable to consider what it was that brought this stagnation.

According to the Reference Dates of Business Cycle, the Cabinet Office of Japan, there are four

[1] 2-1, Gakuen, Sanda, Hyogo, Japan 669-1337. a.ashihara@kwansei.ac.jp

recession periods, which are shown as the shaded areas in Figure 1. In particular, three of them are related to financial crisis. The first was due to the corruption of asset price bubbles in the early 1990s. Prices of stock and real estate, which had risen from middle-1980s, dropped sharply, and this affected the real economy through the negative wealth effect and malfunction of financial intermediation (Bayoumi, 2001). The second recession, which happened in the late 1990s, stemmed from the successive bankruptcies of financial institutions that had suffered from the impairment of their balance sheets after the former recession. The confusion in the inter-bank market due to the default of Sanyo Securities triggered a considerable number of bankruptcies of financial institutions, such as Hokkaido-Takushoku bank and Yamaichi securities, and many literatures including Motonishi and Yoshikawa (1999) mention that this crisis influenced the real economy through the credit crunch channel. The third was what is called the Great Recession. Although it originated in U.S., the spillover effect decreased exports from Japan. Considering these episodes, Japan's Great Stagnation is considered to be caused by financial factors. However, the previous literature using DSGE model points out a decline in TFP, or neutral technology, as the main factor (the detail explained later).

2. Previous Studies

Since the asset bubble burst in the early 1990s, a considerable number of studies about Japan's Great Stagnation have been conducted. Hayashi and Prescott (2002), a pioneering study, refer to the decline in TFP and the reduction of workweek length from 44 to 40 hours as the main causes in a RBC model framework. On the other hand, Christiano and Fujiwara (2006), using a standard DSGE model with "news shock", suggest that the combination of Pigue effect and reduction of workweek length can also replicate the stagnation.[2] They also suggest the importance of incorporating Investment Specific Technological (IST) shock because the relative price of investment had continuously fallen for ten years from 1990. Hirose and Kurozumi (2012) incorporate the IST shock into an otherwise standard DSGE model and obtain the similar results to Hayashi and Prescott (2002). They also find that Marginal Efficiency of Investment shock (hereafter M.E.I. shock) is more important than the IST shock for investment fluctuation.[3] According to Justiniano, Primiceri and Tambalotii (2011), the M.E.I shock is related to financial factors, and thus Kaihatsu and Kurozumi (2014) use a standard new Keynesian model embodied with Financial Accelerator of BGG and find similar results to Hayashi and Prescotti (2002). They also find a high correlation between the dynamics of the neutral technology shock and the diffusion index of firms' financial position in Tankan and conclude that the tight financing position decreased R&D investment, and thus neutral technology.

[2] While Christiano and Fujiwara (2006) calibrate structural deep parameters of the model, Fujiwara, Hirose and Shintani (2008) estimate the parameters by the Smets and Wouters (2003, 2007) method. They conclude that news shock in TFP largely accounts for the fluctuation of the Japan's Great Stagnation.

[3] Sugo and Ueda (2008) use a New-Keynesian model similar to those of Christiano, Eichenbaum and Evans (2005), Smets and Wouters (2003) and Levin, Onatski, Williams and Williams (2005), and also find the same results.

Almost all studies using DSGE model refer to the TFP shock as the main factor of Japan's Great Stagnation.[4] However, these studies have some problems. First, five studies do not incorporate financial frictions into their model. As explained above, financial friction is the essential factor for analyzing Japan's Great Stagnation. Second, Kaihatsu and Kurozumi (2014)'s result implies rather the tight firms' financial position as the main driver rather than the decline in TFP. The reason why TFP shock becomes the main factor may be that the financial shocks used in their model fail to express actual business cycles we can observe in data. In fact, CMR (2014), using the model embodied with "risk shock" in addition to standard shocks, suggest that canonical financial shocks cannot replicate the U.S. business cycle. They also find that the estimated risk shock accounts for 62% of GDP and 73% of investment. Therefore, in this paper, we reconsider Japan's Great Stagnation by using their model.

3. The model

DSGE model is a kind of macroeconomic models, which considers dynamic optimal behaviors of economic agents (such as household and firm) explicitly. It is mainly used for the factor analysis of business cycles. It can be expressed as a linear state space model when its equations are log-linearized and then solved under the assumption of rational expectation, for example Blanchard and Khan (1980) and Sims (2002). Namely, formularizing both its optimization equations and constraint equations as simultaneous differential equations, considering predetermined variables in the model as state variables in transition equation of the state space model and adding observation equations which connect state variables to observed variables, we can express DSGE model as such a way. Therefore, Bayesian estimation methods with MCMC method are often used for the DSGE estimation.

Smets and Wouters (2003, 2007) is a pioneering study which estimates a standard New-Keynesian DSGE model in this way. They estimate Europe and U.S. economies and conclude that the model fits to the data enough to bear comparison with vector autoregressive models whose model restriction is weaker than that of DSGE. Now, many researches using this method are conducted all over the world.

The model we use is CMR (2014). This model has six frictions to fit the data; both nominal price and wage stickiness, adjustment costs of investment and capital utilization, asymmetric information (between lender and borrower) and Costly State Verification (CSV, hereafter) which is originally analyzed in Townsend (1978). The combination of last two frictions is so-called Financial Accelerator developed by BGG (1999). It enables us to incorporate a channel through a financial crisis into the business cycle analysis. There are 7 agents in the model; the final goods producer, intermediate goods producers, entrepreneurs, the mutual fund, the household, the wage contractor and the government.

---

[4] The exception is Hirakata, Sudo, Takei and Ueda (2014). They use a canonical New-Keynesian model with the extended version of BGG (1998) and suggest that the investment adjustment shock drives Japan's Great Stagnation.

We briefly explain the setting of financial market, which is deeply concerned with *risk shock*.[5] For simplicity, we focus on the essence of financial market mechanism, so the explanation is not strict. There exist entrepreneurs and mutual fund. Entrepreneurs combine their net worth N and borrowings B^N_{t+1} from the mutual fund (its ultimate source is household), and purchase raw capital K^N_{t+1} (ex. iron, steel, plastic, etc.). They transform it into effective capital and sell it to household.

$$K^N_{t+1} = N + B^N_{t+1} \tag{1.1}$$

After capital purchase, entrepreneurs receive an idiosyncratic shock ω, and the raw capital converts into effective capital $\omega K^N_{t+1}, \omega \sim F(1, \sigma_t)$. $F(\cdot)$ is a log-normal cumulative function. σ_t is standard deviation of ω and follows AR(1) process. We call this *risk shock* because it captures uncertainty about the future success of their products. Entrepreneurs rent effective capital to firms at rental rate r_{t+1} in $t+1$. After firms' production, they sell undepreciated capital $\omega K^N_{t+1}(1-\delta)$. δ is depreciation rate. Total capital return rate is $\omega(1+R^K_{t+1})$ where $1+R^K_{t+1} \equiv r_{t+1} + 1 - \delta$ is a constant rate of return project. New worth of an entrepreneur with net worth N in $t+1$ and who experiences shock ω is

$$N' = \max\{0, (1+R^K_{t+1})K^N_{t+1}\omega - Z_{t+1}B^N_{t+1}\}. \tag{1.2}$$

where Z_{t+1} is gross rate of interest on loan. The banking system in period t is competitive. The following zero profit condition must be satisfied.

$$L_t \equiv \frac{K^N_{t+1}}{N} = \frac{1}{1 - \frac{1+R^K_{t+1}}{1+R_t}[\Gamma(\bar{\omega}_{t+1}, \sigma_t) - \mu G(\bar{\omega}_{t+1}, \sigma_t)]} \tag{1.3}$$

$$\Gamma_t(\bar{\omega}_{t+1}, \sigma_t) \equiv [1 - F_t(\bar{\omega}_{t+1}, \sigma_t)]\bar{\omega}_{t+1} + G_t(\bar{\omega}_{t+1}, \sigma_t), G_t(\bar{\omega}_{t+1}, \sigma_t) = \int_0^{\bar{\omega}_{t+1}} \omega dF_t(\omega, \sigma_t),$$

where L_t is leverage. $\bar{\omega}_{t+1}$ is a cutoff value which divides entrepreneurs who can repay interest and principle from those who cannot. The mutual fund audit entrepreneurs who receive $\omega \le \bar{\omega}_{t+1}$ and get back their all earnings. μ is a parameter of their monitoring cost. Therefore, $\Gamma(\bar{\omega}_{t+1}) - \mu G(\bar{\omega}_{t+1})$ means the mutual fund's share of average entrepreneurial earnings. Entrepreneurs select the borrowing contract at period t which maximizes the expected N' subject to the zero profit condition and N. To increase their profit, entrepreneurs select high leverage. However, the mutual fund rise interest on loan (or $\bar{\omega}_{t+1}$) according to the zero profit condition. Entrepreneurs' first order condition with regard to $\bar{\omega}_{t+1}$ is

$$\frac{1 - F(\bar{\omega}_{t+1}, \sigma_t)}{1 - \Gamma(\bar{\omega}_{t+1}, \sigma_t)} = \frac{\frac{1+R^K_{t+1}}{1+R_t}[1 - F(\bar{\omega}_{t+1}, \sigma_t) - \mu\bar{\omega}_{t+1}F'(\bar{\omega}_{t+1}, \sigma_t)]}{1 - \frac{1+R^K_{t+1}}{1+R_t}[\Gamma(\bar{\omega}_{t+1}, \sigma_t) - \mu G(\bar{\omega}_{t+1}, \sigma_t)]}. \tag{1.4}$$

The left side of (1.4) means elasticity of entrepreneur's expected return with regard to $\bar{\omega}_{t+1}$, and the right side means elasticity of leverage with regard to $\bar{\omega}_{t+1}$. Given the cutoff, we can solve for leverage through

[5] The complete model is shown in CMR (2014) and Appendix A.

the zero profit condition (K_{t+1}^{N} is also determined). *Risk shock* σ_t deviates the shape of $F(\overline{\omega}_{t+1}, \sigma_t)$. To satisfy the zero profit constraint, the mutual fund rise the cutoff value and interest on loan, which impedes capital accumulation.

4. Empirical methodology and results

Following Smets and Wouters (2003, 2007), the model presented in the previous section is estimated, using a Bayesian likelihood approach with twelve quarterly time series: output, consumption, investment, labor, real wage, inflation, relative price of investment goods, monetary policy rate, real loans, real net worth, price of stock and term premium. First, we estimate unobservable variables by the following linear state space model. The reason why we use the linear state space model is to estimate unobservable endogenous variables in the model whose corresponding data is difficult to find (ex. risk premium).

$$\boldsymbol{y_t} = \boldsymbol{A}(\boldsymbol{\theta}) + \boldsymbol{B}(\boldsymbol{\theta})\boldsymbol{\hat{s}_t}, \tag{2.1}$$

$$\boldsymbol{\hat{s}_t} = \boldsymbol{\Phi_1}(\boldsymbol{\theta})\boldsymbol{\hat{s}_{t-1}} + \boldsymbol{\Phi_\varepsilon}(\boldsymbol{\theta})\boldsymbol{\varepsilon_t}, \tag{2.2}$$

where $\boldsymbol{y_t}$ and $\boldsymbol{\hat{s}_t}$ are vectors of observable variable (data) and unobservable variable (endogenous variables in the model) respectively. $\boldsymbol{A}(\boldsymbol{\theta})$ and $\boldsymbol{B}(\boldsymbol{\theta})$ are vectors depend on structural deep parameters, $\boldsymbol{\theta}$. $\boldsymbol{\Phi_1}(\boldsymbol{\theta})$ and $\boldsymbol{\Phi_\varepsilon}(\boldsymbol{\theta})$ are coefficient matrixes, which are also dependent on $\boldsymbol{\theta}$. $\boldsymbol{\varepsilon_t}$ denotes the aggregate shock vector.

Second, we simultaneously estimate by the Bayesian Inference the structural deep parameters necessary for the first estimation.[6]

Third, we conduct historical decomposition in order to detect the most influential aggregate shock on the economy. Equation (2.2) can be rewritten so that unobservable endogenous variables, $\boldsymbol{\hat{s}_t}$, is expressed by its initial values, $\boldsymbol{\hat{s}_1}$, and the sum of each aggregate shock, $\boldsymbol{\varepsilon_i}$, from period 1 to t.

$$\boldsymbol{\hat{s}_t} = \boldsymbol{\Phi}_1^{t-1}(\boldsymbol{\theta})\boldsymbol{\hat{s}_1} + \sum_{\boldsymbol{t=1}}^{\boldsymbol{t-1}} \boldsymbol{\Phi}_1^{t-i-1}(\boldsymbol{\theta})\boldsymbol{\Phi}_\varepsilon(\boldsymbol{\theta})\boldsymbol{\varepsilon_{i+1}}$$

Since the observation equations are $\boldsymbol{y_t} = \boldsymbol{A}(\boldsymbol{\theta}) + \boldsymbol{B}(\boldsymbol{\theta})\boldsymbol{\hat{s}_t}$, the fluctuation of $\boldsymbol{y_t}$ can be decomposed by its initial values, $\boldsymbol{\hat{s}_1}$, and the cumulative sum of exogenous shocks, $\boldsymbol{\varepsilon_t}$, and we can observe the best shock that replicate some selected variables of $\boldsymbol{y_t}$.[7] This is called the historical decomposition.

Equilibrium conditions and resource constraints are rewritten to be detrended since the model converges the balanced growth path in longer term, and these equations are log-linearized around deterministic steady states.

Figure 2 to 4 illustrate comparisons between time series of the selected data, GDP, consumption and investment, and those of corresponding endogenous variables calculated by historical decomposition of

---

[6] For the detail discussion, see An and Schorfheide (2007). Parameter estimate results are shown in Appendix B.

[7] The fluctuation of GDP is often used for the object. We also use consumption and investment.

three aggregate shocks and actual data, respectively. The lines with circle represent results of simulating model response to selected shocks and initial conditions. The solid lines are growth rates of the actual data.

The comparison between time series of the selected data and those of corresponding endogenous variables produced by a sum of the estimated persistent and transitory technological shocks is shown in Figure 2. It is difficult to mention that the two technology shocks can account for fluctuations of the actual data. Rather, the lines with circle of GDP and investment indicate the opposite behaviors to the solid lines (actual data).

Figure 3 shows the comparison between time series of the selected data and those of corresponding endogenous variables produced by the estimated marginal efficiency of investment (M.E.I) shock.The estimated M.E.I shock reproduces the opposite fluctuation to sharp drops in recessions. In particular, this is clearly found in investment. According to CMR (2014), M.E.I. shock represents supply shifter in the capital market. Therefore, the implication from this comparison is that the fall of investment throughout the stagnation does not stem from supply side in the capital market.

The comparison between time series of the selected data and those of corresponding endogenous variables produced by the estimated risk shock is shown in Figure 4. A remarkable feature in this figure is the closeness between the lines with circle and the solid lines. Above all, in terms of GDP and investment, explanations of the estimated risk shock are highly accurate from 1990:1Q to 2001:4Q which corresponds so-called “Lost Decade”. Therefore, this graph suggests that the estimated risk shock can largely account for the sharp falls of GDP and investment in recessions. Because the estimated risk shock represents demand shifter in the capital market, it is possible that the fall of investment during 1990s stems from the demand side in the capital market. In addition, the movement of actual consumption can be explained better by the estimated risk shock than by the other two estimated shocks. Therefore, it can be said that the estimated risk shock is more significant than the other shocks and the main driver of the Japan’s great stagnation.

The historical decomposition clarifies the significance of “risk shock” in the Japan’s Great Stagnation. Then, it should be figured out what the estimated risk shock represents. This subsection analyzes the implication of the estimated risk shock from various perspectives.

To do this, we calculate the correlation coefficient between the estimated risk shock and various measures: Diffusion Index for Business Condition, Financial Position and Lending Attitude in Tankan released by the Bank of Japan (Table 4). It is highly correlated with the Business condition Diffusion Index, the Financial Position Diffusion Index and the Lending Attitude Index of Financial Institutions (Figure5). Therefore, we conclude that the estimated risk shock can be interpreted as the firms’ distrust toward their business conditions, and it delayed their investment decisions, then causing the prolonged economic contraction.

AppendixA: Complete model

- Production function

$$Y_{jt} = \varepsilon_t K_{jt}^{\alpha}\left(z_t l_{jt}\right)^{1-\alpha} - \Phi z_t^* \tag{A.1}$$

- Optimal capital and labor input

$$r_t^k = \alpha\varepsilon_t\left(\frac{z_t l_{j,t}}{K_{j,t}}\right)^{1-\alpha} s_t \tag{A.2}$$

$$W_t = (1-\alpha)\varepsilon_t\left(\frac{z_t l_{j,t}}{K_{j,t}}\right)^{-\alpha} z_t s_t \tag{A.3}$$

- Marginal cost and optimal capital-labor ratio

$$s_t = \frac{1}{\varepsilon_t}\left(\frac{r_t^k}{\alpha}\right)^{\alpha}\left(\frac{W_t}{(1-\alpha)z_t}\right)^{1-\alpha} \tag{A.4}$$

$$\frac{K_{j,t}}{l_{jt}} = \frac{K_t}{l_t} = \frac{\alpha W_t}{(1-\alpha)r_t^k} \tag{A.5}$$

- Optimal price setting: Calvo-style price setting

$$p_t^* = \left[(1-\xi_p)\left(\frac{K_{p,t}}{F_{p,t}}\right)^{\frac{\lambda_f}{1-\lambda_f}} + \xi_p\left(\frac{\tilde{\pi}_t}{\pi_t}p_{t-1}^*\right)^{\frac{\lambda_f}{1-\lambda_f}}\right]^{\frac{1-\lambda_f}{\lambda_f}} \tag{A.6}$$

$$F_{p,t} = E_t\left\{\zeta_{c,t}\lambda_t z_t^* P_t Y_t + \left(\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}}\right)^{\frac{1}{1-\lambda_f}}\beta\xi_p F_{p,t+1}\right\} \tag{A.7}$$

$$K_{p,t} = \zeta_{c,t}\lambda_f\lambda_t z_t^* P_t Y_t s_t + \beta\xi_p\left(\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}}\right)^{\frac{\lambda_f}{1-\lambda_f}} K_{p,t+1} \tag{A.8}$$

$$F_{p,t}\left[\frac{1-\xi_p\left(\frac{\tilde{\pi}_t}{\pi_t}\right)^{\frac{1}{1-\lambda_f}}}{1-\xi_p}\right]^{1-\lambda_f} = K_{p,t}, \tilde{p}_t = \frac{K_{p,t}}{F_{p,t}} \tag{A.9}$$

$$\tilde{\pi}_t = \left(\pi_t^{target}\right)^{\iota}(\pi_{t-1})^{1-\iota}. \tag{A.10}$$

- Capital dynamics

$$\bar{K}_{t+1} = (1-\delta)\bar{K}_t + \left(1 - S\left(\zeta_{\mathrm{I,t}}\, I_t/I_{t-1}\right)\right) I_t. \tag{A.11}$$

- Optimal wage setting: Calvo-style setting

$$F_{w,t} = \zeta_{C,t}\lambda_{Z,t}\frac{(w_t^*)^{\frac{\lambda_w}{\lambda_w-1}}h_t(1-\tau^l)}{\lambda_w} + \beta\xi_w(\mu_{Z^*})^{\frac{1-\iota_\mu}{1-\lambda_w}}E_t\left\{\left(\mu_{Z,t+1}^*\right)^{\frac{\iota_\mu}{1-\lambda_w}-1}\left(\frac{1}{\pi_{w,t+1}}\right)^{\frac{\lambda_w}{1-\lambda_w}}\frac{\tilde{\pi}_{w,t+1}^{\frac{1}{1-\lambda_w}}}{\pi_{t+1}}F_{w,t}\right\} \quad \text{(A.12)}$$

$$K_{w,t} = \zeta_{c,t}\left[(w_t^*)^{\frac{\lambda_w}{\lambda_w-1}}h_t\right]^{1+\sigma_L} + \beta\xi_w E_t\left\{\left(\frac{\tilde{\pi}_{w,t+1}\left(\mu_{z,t+1}^*\right)^{\iota_\mu}(\mu_z^*)^{1-\iota_\mu}}{\pi_{w,t+1}}\right)^{\frac{\lambda_w}{1-\lambda_w}(1+\sigma_L)}K_{w,t+1}\right\} \quad \text{(A.13)}$$

$$K_{w,t} = \frac{1}{\psi_L}\left[\frac{1-\xi_w\left(\frac{\tilde{\pi}_{w,t}}{\pi_{w,t}}\left(\mu_{z,t}^*\right)^{\iota_\mu}(\mu_z^*)^{1-\iota_\mu}\right)^{\frac{1}{1-\lambda_w}}}{1-\xi_w}\right]^{1-\lambda_w(1+\sigma_L)}\tilde{w}_t F_{w,t} \quad \text{(A.14)}$$

$$w_t^* = \left[(1-\xi_w)\left(\frac{1-\xi_w\left(\frac{\tilde{\pi}_{w,t}}{\pi_{w,t}}\left(\mu_{z,t}^*\right)^{\iota_\mu}(\mu_z^*)^{1-\iota_\mu}\right)^{\frac{1}{1-\lambda_w}}}{1-\xi_w}\right)^{\lambda_w} + \xi_w\left(\frac{\tilde{\pi}_{w,t}\left(\mu_{z,t}^*\right)^{\iota_\mu}(\mu_z^*)^{1-\iota_\mu}}{\pi_{w,t}}w_{t-1}^*\right)^{\frac{\lambda_w}{1-\lambda_w}}\right]^{\frac{1-\lambda_w}{\lambda_w}} \quad \text{(A.15)}$$

- Marginal utility and First order condition with regard to investment

$$(1+\tau^C)\zeta_{C,t}\lambda_t P_t = \frac{\zeta_{C,t}}{(C_t-bC_{t-1})} - b\beta E_t\frac{\zeta_{C,t+1}}{(C_{t+1}-bC_t)} \quad \text{(A.16)}$$

$$\frac{\zeta_{C,t}\lambda_t P_t}{\mu_{\Upsilon,t}} = \zeta_{C,t}\lambda_t P_t q_t\left[1-S\left(\frac{\zeta_{i,t}\Upsilon i_t}{I_{t-1}}\right)-S'\left(\frac{\zeta_{i,t}\Upsilon I_t}{I_{t-1}}\right)\frac{\zeta_{i,t}\Upsilon I_t}{I_{t-1}}\right] + E_t\frac{\beta\lambda_{t+1}P_{t+1}\zeta_{C,t+1}q_{t+1}}{\Upsilon}S'\left(\frac{\zeta_{i,t+1}\Upsilon I_{t+1}}{I_t}\right)\left(\frac{\zeta_{i,t+1}\Upsilon I_{t+1}}{I_t}\right)^2 \quad \text{(A.17)}$$

- Optimal short and long bonds holdings

$$\zeta_{C,t}\lambda_t = E_t\zeta_{C,t+1}\lambda_{t+1}(1+R_t) \quad \text{(A.18)}$$

$$\zeta_{C,t}\lambda_t = E_t\zeta_{C,t+40}\lambda_{t+40}\beta^{40}(1+R_t^L)^{40} \quad \text{(A.19)}$$

- Constant return rate of project and optimal capital utilization

$$R_{t+1}^k \equiv \frac{(1-\tau^k)[u_{t+1}r_{t+1}^k - a(u_{t+1})]\Upsilon^{-(t+1)}P_{t+1} + (1-\delta)Q_{\bar{K},t+1} + \tau^k\delta Q_{\bar{K}',t}}{Q_{\bar{K},t}}. \qquad \text{(A.20)}$$

$$r_t^k = \ a'(u_t) \qquad \text{(A.21)}$$

- Net worth dynamics

$$N_{t+1} = \gamma_t[1-\Gamma_{t-1}(\bar{\omega}_t)]R_t^k Q_{\bar{K},t-1}\bar{K}_t + W_t^e. \qquad \text{(A.22)}$$

- Monetary policy rule and resource constraint

$$R_t - R = \rho_p(R_{t-1} - R)$$
$$+(1-\rho_p)\left[\alpha_\pi(\pi_{t+1} - \pi_t^*) + \alpha_{\Delta y}\frac{1}{4}\left(g_{y,t} - \mu_{z^*}\right)\right] + \frac{1}{400}\varepsilon_t^p, \qquad \text{(A.23)}$$

$$Y_t = D_t + G_t + C_t + \frac{I_t}{\Upsilon^t\mu_{\Upsilon,t}} + a(u_t)\Upsilon^{-t}\bar{K}_t \qquad \text{(A.24)}$$

Appendix B: Calibrated and estimated parameters

Table 1 Calibrated parameters

Parameter	Parameter name	Value
β	Discount rate	0.996
σ_L	Curvature on disutility of labor	4.126
Ψ_L	Disutility weight on labor	0.7705
λ_w	Steady-state markup, suppliers of labor	0.2
μ_z	Growth rate of the economy	0.41
Υ	Trend rate of investment-specific technological change	0.42
δ	Depreciation rate on capital	0.015
α	Power on capital in production function	0.40
λ_f	Steady-state markup, intermediate good firms	0.20
$1-\gamma$	Fraction of entrepreneurial net worth transferred to households	1-0.985
W^e	Transfer received by entrepreneurs	0.005
η_g	Steady-state government spending-GDP ratio	0.2
π^{target}	Steady-state inflation rate (APR)	2.43
τ^c	Tax rate on consumption	0.08
τ^k	Tax rate on capital income	0.32
τ^l	Tax rate on labor income	0.5

Table 2: Prior distribution

Parameter name	Parameter	Prior distribution		
		Prior dist	Mean	SD
Panel1. Economic parameters				
Calvo wage stickiness	ξ_w	Beta	0.375	0.100
Habit parameter	b	Beta	0.700	0.150
Steady-state probability of default	$F(\bar{\omega})$	Beta	0.007	0.0037
Monitoring cost	μ	Bata	0.275	0.150
Curvature, utilization cost	σ_a	Beta	1.000	1.000
Curvature, investment adjust cost	S''	Gamma	4.000	1.500
Calvo price stickiness	ξ_p	Beta	0.375	0.100
Policy weight on inflation	α_π	Gamma	1.700	0.100
Policy smoothing parameter	ρ_p	Beta	0.800	0.100
Price indexing weight on inflation target	ι	Beta	0.500	0.250
Wage indexing weight on inflation target	ι_w	Beta	0.500	0.250
Wage indexing weight on persistent technology growth	ι_μ	Beta	0.500	0.250
Policy weight on output growth	$\alpha_{\Delta y}$	Gamma	0.125	0.050
Panel2. Shocks				
Correlation among signals	$\rho_{\sigma,n}$	Normal	0	0.5
Autocorrelation, price markup shock	ρ_{λ_f}	Beta	0.5	0.2
Autocorrelation, price of investment goods shock	ρ_{μ_ψ}	Beta	0.5	0.2
Autocorrelation, government	ρ_g	Beta	0.5	0.2
Autocorrelation, persistent technology growth	ρ_{μ_z}	Beta	0.5	0.2
Autocorrelation, transitory technology	ρ_ϵ	Beta	0.5	0.2
Autocorrelation, risk shock	ρ_σ	Beta	0.5	0.2
Autocorrelation, consumption preference shock	ρ_{ζ_c}	Beta	0.5	0.2
Autocorrelation, marginal efficiency of investment	ρ_{ζ_I}	Beta	0.5	0.2
Autocorrelation, term structure shock	ρ_η	Beta	0.5	0.2
Standard deviation, anticipated risk shock	$\sigma_{\sigma,n}$	Invg2	0.001	0.0012
Standard deviation, unanticipated risk shock	$\sigma_{\sigma,0}$	Invg2	0.002	0.0033
SD. Measurement error on net worth	$SD_{m,n}$	Weibull	0.01	5
Standard deviation, shock innovations				
Price markup	σ_{λ_f}	Invg2	0.002	0.0033
Investment price	σ_{μ_ψ}	Invg2	0.002	0.0033
Government consumption	σ_g	Invg2	0.002	0.0033
Persistent technology growth	σ_{μ_z}	Invg2	0.002	0.0033
Equity	σ_γ	Invg2	0.002	0.0033
Temporary technology	σ_ϵ	Invg2	0.002	0.0033
Monetary policy	σ_{ε^p}	Invg2	0.583	0.825
Consumption preference	σ_{ζ_c}	Invg2	0.002	0.0033
Marginal efficiency of investment	σ_{ζ_I}	Invg2	0.002	0.0033
Term structure	σ_η	Invg2	0.002	0.0033

Note: Invg2 means the inverse gamma distribution.

Table 3: Posterior distribution

	Hirakata et al (2014)	Hirose and Kurozumi (2012)	Kaihatsu and Kurozumi (2014)	Christiano et al (2014)	This paper	
Parameter	Mean	Mean	Mean	Mode	Mode	90% confident interval
ξ_w	-	0.567	0.497	0.81	0.7659	[0.7104,0.8185]
b	0.8447	0.508	0.258	0.74	0.9009	[0.8619,0.9443]
$F(\bar{\varpi})$	-	-	-	0.0056	0.0504	[0.0429,0.0583]
μ	0.0146	-	-	0.21	0.1196	[0.1058,0.1341]
σ_a	-	4.411	0.475	2.54	1.0047	[0.1059.1.9117]
S''	8.6739	7.118	0.425	10.78	10.4058	[8.6997,12.1906]
ξ_p	0.6064	0.715	0.675	0.74	0.7688	[0.6994,0.8419]
α_π	1.4832	1.694	1.652	2.40	1.6594	[1.5140,1.8130]
ρ_p	-	0.794	0.749	0.85	0.8813	[0.8563,0.9055]
ι	0.0739	0.31	0.408	0.90	0.7321	[0.5342,0.9461]
ι_w	-	0.159	0.503	0.49	0.2854	[0.1934,0.3740]
ι_μ	-	-	-	0.94	0.9800	[0.9576,0.9998]
$\alpha_{\Delta y}$	0.0238	0.0065	0.065	0.36	0.1264	[0.0427,0.2103]
$\rho_{\sigma,n}$	-	-	-	0.39	0.4204	[0.2127,0.6415]
ρ_{λ_f}	0.68	0.933	0.976	0.91	0.9126	[0.8747,0.9459]
ρ_{μ_ψ}	-	-	0.929	0.99	0.9956	[0.9926,0.9989]
ρ_g	0.8045	0.945	0.991	0.94	0.8812	[0.7797,0.9807]
ρ_{μ_z}	-	0.0032	0.051	0.15	0.1564	[0.0427,0.2656]
ρ_ϵ	0.8719	-	-	0.81	0.9681	[0.9536,0.9827]
ρ_σ	-	-	-	0.97	0.3244	[0.2124,0.4419]
ρ_{ζ_c}	0.9145	0.91	0.858	0.90	0.1970	[0.0464,0.3361]
ρ_{ζ_I}	0.377	0.461	0.999	0.91	0.9230	[0.8990,0.9474]
ρ_η	-	-	-	0.97	0.9564	[0.9408,0.9725]
$\sigma_{\sigma,n}$	-	-	-	0.028	0.0181	[0.0138,0.0225]
$\sigma_{\sigma,0}$	-	-	-	0.07	0.5084	[0.4122,0.6010]
$SD_{m,n}$	-	-	-	0.018	0.0126	[0.0111,0.0140]
σ_{λ_f}	0.0814	0.152	0.165	0.011	0.0060	[0.0040,0.0081]
σ_{μ_ψ}	-	-	0.4113	0.004	0.0014	[0.0012,0.0015]
σ_g	0.0256	0.454	0.517	0.023	0.0042	[0.0037,0.0048]
σ_{μ_z}	-	1.632	1.291	0.0071	0.0031	[0.0027,0.0036]
σ_γ	0.3736	-	1.39	0.0081	0.0002	[0.0002,0.0003]
σ_ϵ	0.0111	-	-	0.0046	0.0026	[0.0022,0.0029]
σ_{ε^p}	0.0015	0.098	0.138	0.49	0.5829	[0.4625,0.6961]
σ_{ζ_c}	0.0019	4.996	-	0.023	0.0058	[0.0035,0.0082]
σ_{ζ_I}	0.0256	4.147	3.768	0.055	0.0147	[0.0105,0.0187]
σ_η	-	-	-	0.0016	0.0056	[0.0039,0.0070]

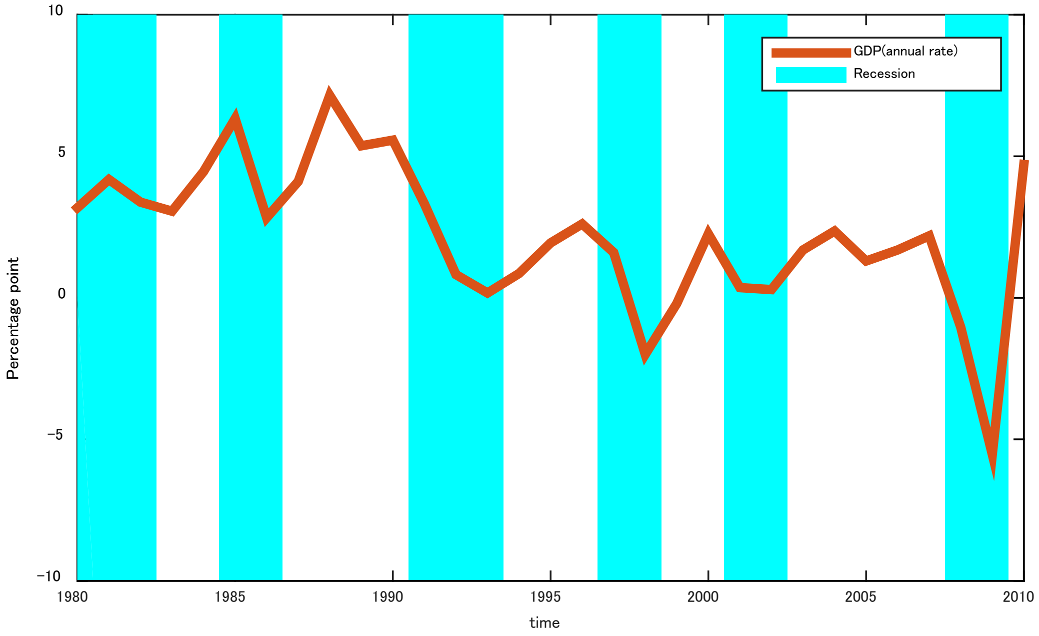
References

1. Adjemian, S., Bastani, H., Juillard, M., Mihoubi, F., Perendia, G., Ratto, M., Villemot, S., 2011. Dynare: reference manual version 4. *CEPREMAP, Dynare Working Papers 1*.
2. Alexopoulos, M., 2011. Read All about It!! What Happens Following a Technology Shock? *American Economic Review*, 101 (4): 1144–79.
3. Andolfatto, D., 1996. Business Cycles and Labor-Market Search. *American Economic Review*, 86 (1): 112–32.
4. An, S., Schorfheide, L, 2007. Bayesian Analysis of DSGE Models. *Econometric Review*, 26, 113-219.
5. Bayoumi, T., 2001. The morning after: explaining the slowdown in Japanese growth in the 1990s. *Journal of International Economics,* 53 (2), 241–259.
6. Bernanke, B.S., Gertler, M., Gilchrist, S., 1999. The financial accelerator in a quantitative business cycle framework. In: Taylor, J.B., Woodford, M. (Eds.), *Handbook of Macroeconomics*, vol. 1C. Elsevier, Amsterdam, pp. 1341–1393.
7. Blanchard, O.J., C.M., Kahn, 1980. The Solution of Linear Difference Models under Rational Expectations. *Econometrica*, 48, 1305-1312.
8. Bloom, N., 2009. The Impact of Uncertainty Shocks. *Econometrica*, 77 (3): 623–85.
9. Calvo, G.A., 1983. Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12 (3), 383–398.
10. Christiano, L.J., Fujiwara, I., 2006. Bubbles, excess investments, working hour regulation, and lost decade. *Bank of Japan Working Paper Series* 06-J-8.
11. Christiano, L. J., Eichenbaum, M., Evans, C., 2005. Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*, 113(1), 1-45.
12. Christiano, L. J., Ikeda, D., 2013. Leverage Restrictions in a Business Cycle Model. National Bureau of Economic Research Working Paper 18688.
13. Christiano, L.J., Motto, R., Rostagno, M.V., 2014. Risk shocks. *American Economic Review*, 104 (1), 27–65.
14. Davis, J. M., 2008. Noews and the Term Structure in General Equilibrium. In *Three Essays in Macroeconomics*, 9-57, PhD diss., Northwestern University.
15. De Graeve, F., 2008. The External Finance Premium and the Macroeconomy: US Post-WWII Evidence, *Journal of Economic Dynamics and Control*, 32, 3415-3440.

16. Eberly, J., Sergio R., 2012. What explains the lagged-investment effect? *Journal of Monetary Economics*, 59, 370-380.
17. Erceg, C. J., Henderson, D. W., Levin, A. T., 2000. Optimal Monetary Policy with Staggered Wage and Price Contracts. *Journal of Monetary Economics*, 46 (2), 281-313.
18. Fujiwara, I., Hirose, Y., Shintani, M., 2008. Can News Be a Major Source of Aggregate Fluctuations? A Bayesian DSGE Approach. *IMES Discussion Paper Series* 08-E-16, Institute for Monetary and Economic Studies, Bank of Japan.
19. Gertler, M., Karadi, P., 2011. A Model of Unconventional Monetary Policy. *Journal of Monetary Economics*, 58, 17-34.
20. Gertler, M., Kiyotaki, N., 2011. Financial Intermediaries and Monetary Economics. *Handbook of Monetary Economics*, ed. Benjamin Friedman and Michael Woodford. Amsterdam, New York and Oxford: Elsevier Science, North-Holland.
21. Hayashi, F., Prescott, E.C., 2002. The 1990s in Japan: the lost decade. *Review of Economic Dynamics*, 5 (1), 206–235.
22. Hirakata, N., Sudo, N., Ueda, K., 2011. Do banking shocks matter for the U.S. economy? *Journal of Economic Dynamics*, Control 35 (12), 2042–2063.
23. Hirose, Y., Kurozumi, T., 2012. Do investment-specific technological changes matter for business fluctuations? evidence from Japan. *Pacific Economic Review*, 17 (2), 208–230.
24. Justiniano, A., Primiceri, G.E., Tambalotti, A., 2011. Investment shocks and the relative price of investment. *Review of Economic Dynamics*, 14 (1), 102–121.
25. Kaihatsu, S., Kurozumi, T., 2014. What caused Japan's Great Stagnation in the 1990s? Evidence from an estimated DSGE model. *Journal of the Japanese and International Economies*, Elsevier, 34(C), 217-235.
26. Kawamoto, T., 2004. What Do the Purified Solow Residuals Tell Us about Japan's Lost Decade? *IMES Discussion Paper Series*, No. 2004-E-5.
27. Levin, A., Onatski, A., Williams, J., Williams, N., 2005. Monetary Policy under Uncertainty in Micro-Founded Macroeconometric Models. In: *NBER Macroeconomics Annual*, 20, 229-287.
28. Lucca, D. O., 2006. Essays in Investment and Macroeconomics. Phd dissertation, Northwestern University, Department of Economics.

29. Matsuyama, K., 1984. A Learning Effect Model of Investment: An Alternative Interpretation of Tobin's Q. unpublished manuscript, Northwestern University, available at http://faculty.wcas.northwestern.edu/~kmatsu/ALearningEffectModel.pdf
30. Merz, M., 1995. Search in the Labor Market and the Real Business Cycle. *Journal of Monetary Economics*, 36, 269-300.
31. Motonishi, T., Yoshikawa, H., 1991. Causes of the Long Stagnation of Japan during the 1990s: Financial or Real? *Journal of the Japanese and International Economies*, 13, 181-200.
32. Ogama, K., 2007. Debt, R&D investment and technological progress: a panel study of Japanese manufacturing firms' behavior during the 1990s. *Journal of the Japanese and International Economies*, 21(4), 403-423.
33. Ramey, V.A., 2011. Identifying Government Spending Shocks: It's All in the Timing. *Quarterly Journal of Economics*, 126 (1): 1–50.
34. Sims, C.A., 2002. Solving Linear Rational Expectation Models. *Computational Economics*, 20, 1-20.
35. Smets, F., Wouters, R., 2003. An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association*, 1(5), 1123-1175, 09.
36. Smets, F., Wouters, R., 2007. Shocks and frictions in US business cycles: a Bayesian DSGE approach. *American Economic Review*, 97 (3), 586–606.
37. Sugo, T., Ueda, K., 2008. Estimating a dynamic stochastic general equilibrium model for Japan. *Journal of the Japanese and International Economy*, 22 (4), 476–502.
38. Topel, R., Rosen, S., 1988. Housing Investment in the United States. *Journal of Political Economy*, 96 (4), 718-740.
39. Watanabe, W., 2007. Prudential Regulation and the "Credit Crunch": Evidence from Japan. *Journal of Money, Credit and Banking*. 39(2-3), 639-665.

Figure 1: The transition of GDP of Japan



Note: GDP is an actual GDP growth rate (seasonally adjusted) from the Cabinet Office of Japan. Shaded areas are recession periods, according to the Reference Dates of Business Cycle, the Cabinet Office of Japan.

Figure 2: The comparison between time series of the selected data and those of corresponding endogenous variables calculated by the estimated TFP shock

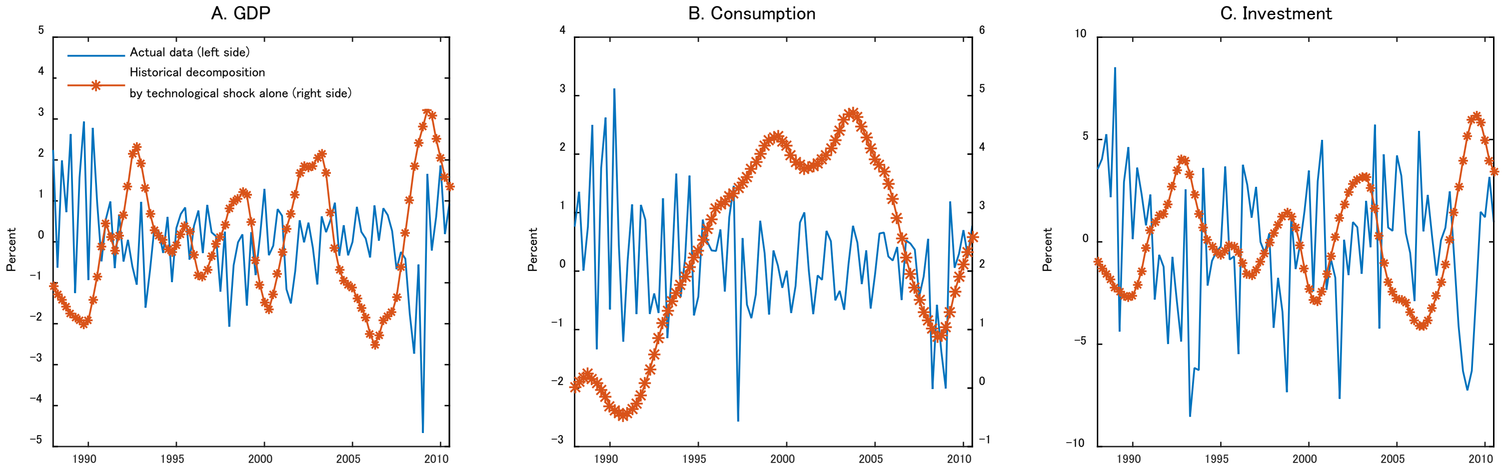


Figure 3: The comparison between time series of the selected data and those of corresponding endogenous variables calculated by the estimated Marginal Efficiency of Investment shock

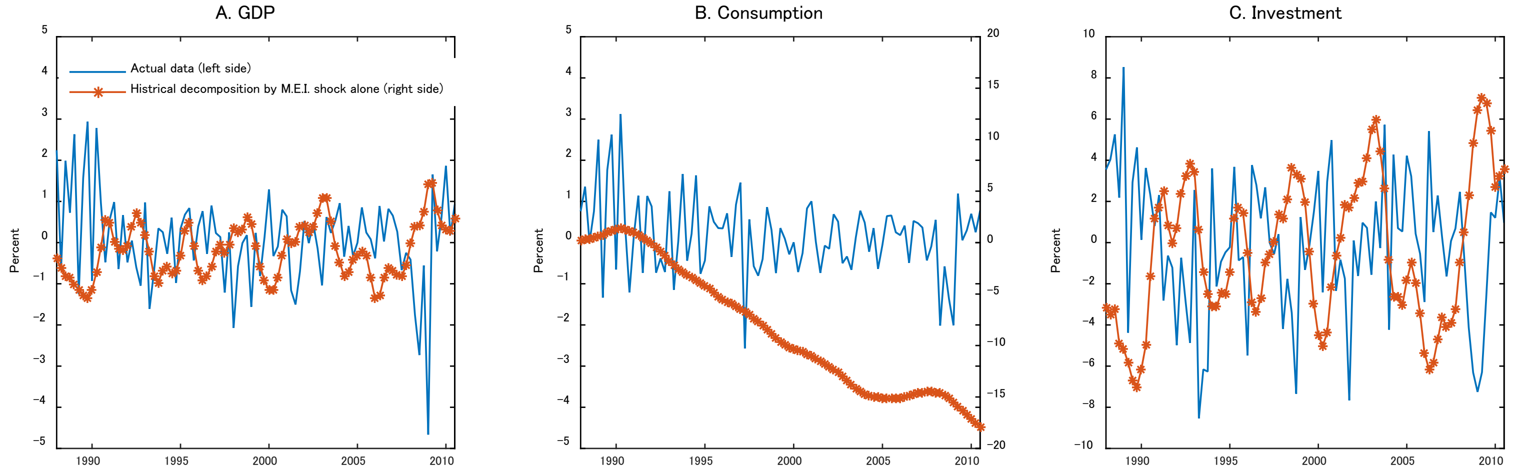


Figure 4: The comparison between time series of the selected data and those of corresponding endogenous variables calculated by the estimated risk shock

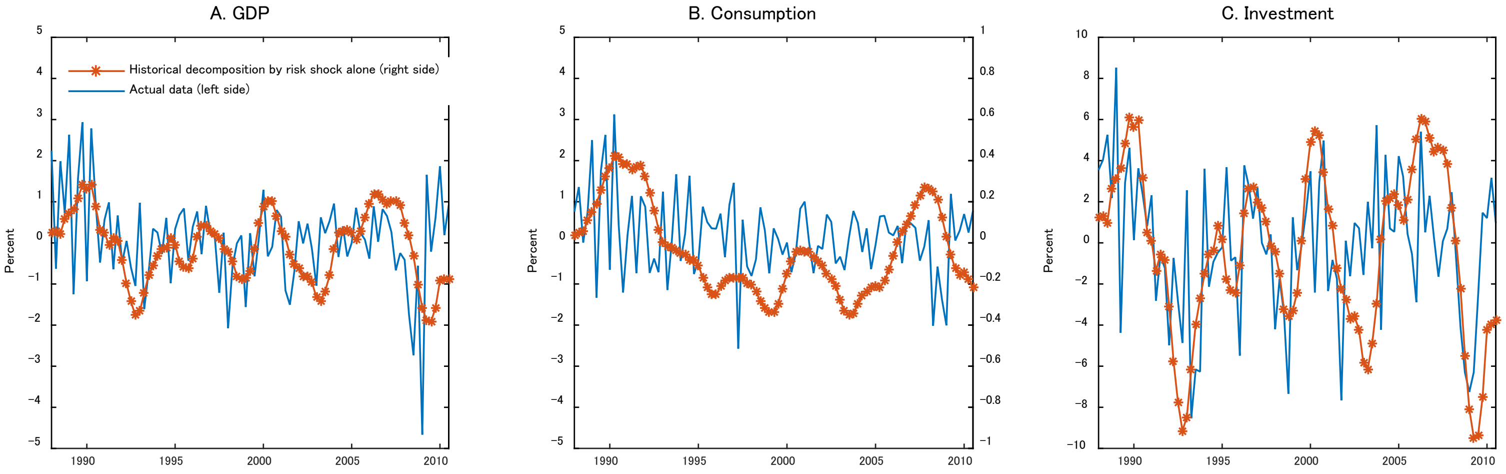
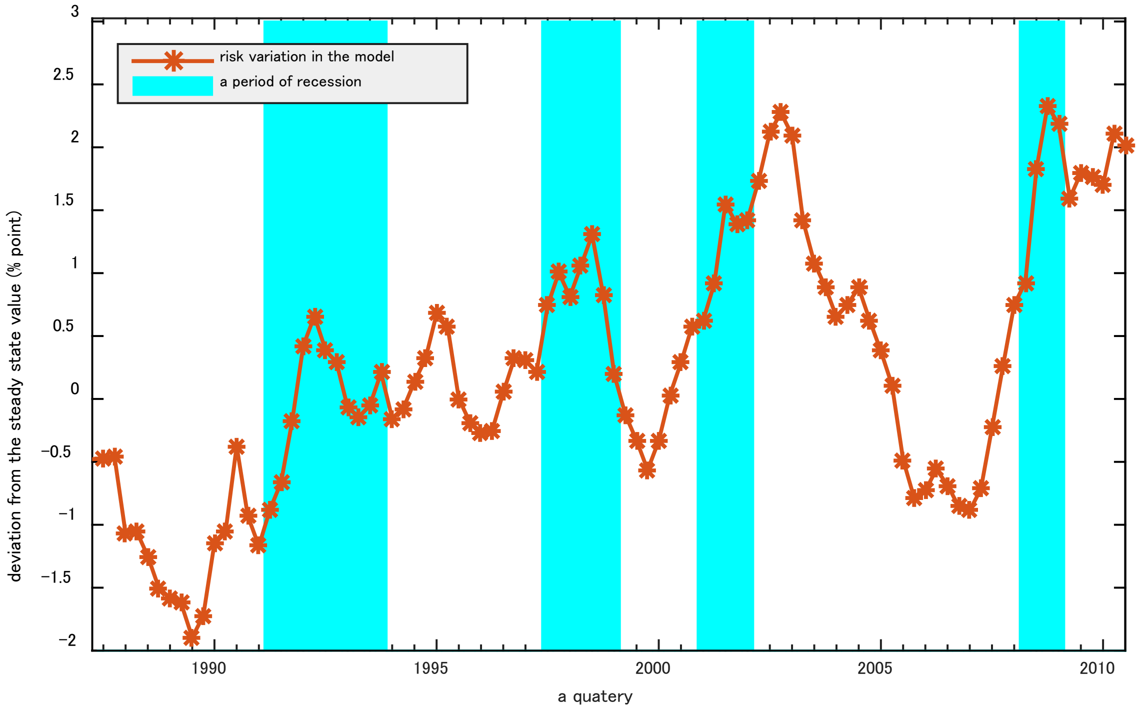


Figure 5: Time path of the estimated risk shock



Note: Shaded areas are recession periods, according to the Reference Dates of Business Cycle, the Cabinet Office of Japan.

Table 4: Correlation coefficient with model out-of-sample indicators

	Correlation coefficient
Coefficient of variation of Nikkei 225	0.22184
SD of DI for business condition	
All industries	-0.34288
Manufacture	-0.26073
Non-Manufacture	-0.39565
DI for business condition	-0.72149
DI for business condition (prediction)	-0.71395
DI for financial position	-0.69687
DI for lending attitude	-0.63490