Bank of Japan Working Paper Series

Output Composition of the Monetary Policy Transmission Mechanism in Japan

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No.03-E-9
November 2003

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Abstract

In this paper, I investigate the output composition of the monetary policy transmission mechanism in Japan. The predominant channel via which monetary policy affects output in Japan is usually thought to be the investment channel, namely the process whereby a change in the interest rate alters the cost of capital and therefore investment. In the United States, however, the consumption channel, which works through intertemporal substitution, is commonly considered the more significant of the two.

The aim of this paper is twofold: 1) based on analysis using VAR and DSGE models, to understand which of the two channels; the consumption channel or the investment channel, plays the more important role in the transmission of Japanese monetary policy; and 2) to contribute to the research on what Angeloni, Kashyap, Mojon and Terlizzese (2003) term the "Output Composition Puzzle," referring to the fact that whereas in the United States the predominant driver of output changes is the consumption channel, in the Euro area it is the investment channel.

The results obtained from the Japanese models are consistent with our intuition that the investment channel is more important.

JEL Classification: C33; E50
Key words: VAR; DSGE; Monetary Policy Transmission; Output Composition Puzzle

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†The author would like to thank Ed Nelson (FRB St.Louis) for sharing the code for the DSGE model used to evaluate the VAR impulse responses. Helpful comments were also received from Kosuke Aoki (Universitat Pompeu Fabra), Kanemi Ban (Osaka University), Shigeru Fujita (University of California, San Diego), Munehisa Kasuya (Bank of Japan), Ryo Kato (Bank of Japan), Ryuzo Miyao (Kobe University), Kazuo Momma (Bank of Japan), Toshitaka Sekine (Bank of Japan) and seminar participants at Osaka University and the Bank of Japan. Importantly, the views expressed in this paper should not be taken to those of the Bank of Japan nor any of its respective monetary policy or other decision making bodies. Any errors remain soley the responsibilibily of the author.

1 Introduction

In this paper, I research the output composition of the monetary policy transmission mechanism in Japan. It is generally observed that raising interest rates leads to decreases in both output and eventually the price level. However, although intuition and experience may suggest that it is fairly self-explanatory, the channel via which this mechanism achieves its effect is not so readily observable. The standard assumption holds that the predominant channel is the so-called "investment channel", namely the process whereby an interest rate change implemented by the central bank alters the cost of capital and hence affects investment.[1] Yet, for the United States, it is commonly argued that the consumption channel, which works via intertemporal substitution, plays a more significant role than the investment channel. Recent research by Angeloni, Kashyap, Mojon and Terlizzese (2003) makes use of analysis from VAR (Vector AutoRegression), DSGE (Dynamic Stochastic General Equilibrium) and Large Macroeconometric Models employed in central banks to conclude that whereas in the United States it is the consumption channel that is the main transmission channel, in the Euro area, this channel plays only a minor role in monetary transmission. The authors state that, for plausible parameter calibrations, the DSGE model is unable to account theoretically for this U.S. phenomenon, a fact which they refer to as the "Output Composition Puzzle."

The aim of this paper is twofold: 1) based on analysis using VAR and DSGE models, to understand which of the two channels; the consumption channel or the investment channel, plays the more important role in the transmission of Japanese monetary policy; and 2) to contribute the research on the "Output Composition Puzzle." The results are consistent with our intuition that the investment channel is more significant in transmitting monetary policy in Japan.

This paper is structured as follows. First, I construct four VAR models, each of which is identified differently, to account for the respective responses of consumption and investment to a nominal interest rate shock. The results from these VAR models are then compared with those obtained from a DSGE model, for which parameters are estimated, or established from other sources, and then calibrated so as to explain the macroeconomic dynamics underlying the Japanese macroeconomic data. Lastly, the conclusion summarizes the findings of the paper.

2 VAR Models

There is a vast amount of research on the monetary policy transmission mechanism using VARs. Indeed monetary transmission provides the subject matter for Sims' seminal paper on identified VAR [Sims (1980)], which is well-known for its critique of traditional large macro models for their implausible identifications (the "Sims critique"). Since Sims' paper, a considerable amount of

[1] Of course, there may exist other channels of monetary policy than mentioned in this paper.

research, making use of various identification schemes has been published. In this literature, it is popular to identify the system for contemporaneous relationships between macroeconomic variables. To this end, some authors, such as Christiano, Eichenbaum and Evans (1999), make use of the Choleski decomposition, which assumes that the system is recursive and hence allows identification. Others, such as Leeper, Sims and Zha (1996), employ a non-recursive framework for identifying monetary policy shocks.

Turning to research that specifically deals with Japanese monetary policy, Iwabuchi (1990) represents the first attempt to investigate the monetary transmission mechanism in Japan using an identified VAR, employing a non-recursive structure for the analysis. Since then, a number of papers similar to Iwabuchi (1990) but slightly different in aim have been published, making use of various identification methodologies. Miyao (2000), Kimura, Kobayashi, Muranaga and Ugai (2002), and Fujiwara (2003a) examine the stability of the monetary transmission mechanism within an identified VAR framework. Kasa and Popper (1997) and Shioji (2000) construct monetary VAR models with reserve markets that enable them to embed the actual scheme for implementation of monetary policy. Sugihara, Mihira, Takahashi and Takeda (2000) try to obtain robust conclusions with regard to the monetary transmission mechanism by making use of a variety of different identification schemes for their VAR models, employing both recursive and non recursive frameworks, as well as including the long-run restrictions introduced by Blanchard and Quah (1989). They also estimate the model using both non-differenced and differenced series. Teruyama (2001) provides an overall survey of recent developments in VAR studies of the monetary transmission mechanism in Japan.

However, when it comes to the output composition of the monetary transmission mechanism, which is the focus of investigation in this paper, previous research has paid little attention to the detailed structure of the transmission channel. In other words it has not fully engaged with the question of whether the output changes that follow a monetary policy shock are driven more by the consumption channel (via intertemporal substitution) or by the investment channel (via the cost of capital). As prior research in this field in Japan tends to include only one output variable, usually industrial production,[2] a clear picture has yet to emerge as to whether changes in the output and price levels are brought about mainly through consumption or investment.

Even for the United States and the Euro area, research looking to explain the output composition has been limited. One example can be found in Christiano, Eichenbaum and Evans (2001). This paper carries out VAR estimation using ten variables: consumption, investment, GDP, the GDP deflator, real wages, labor productivity, corporate profits, the federal funds rate, M2 and the S&P 500 stock price index. The authors examine whether the results obtained from a DSGE model with time-varying capital utilization may be used to reproduce realistic impulse responses, where by “realistic” is meant similar to those obtained from

[2]This may be due to the fact that VAR analysis of the monetary policy transmission is normally carried out using monthly data in order to maximize the number of possible observations for estimation.

their VAR models. Once again, however, understanding the output composition of the monetary transmission mechanism lies outside the main focus of the paper.

The seminal research underlining the importance of understanding output composition is a recent paper by Angeloni, Kashyap, Mojon and Terlizzese. The authors employ a number of VAR models, obtaining four separate sets of estimates for both the United States and the Euro area, with a view to scrutinizing the differences in monetary transmission mechanisms between them. For the United States, they construct VAR models based on Christiano, Eichenbaum and Evans (1999); Gorden and Leeper (1994), extended to include GDP components; Christiano, Eichenbaum and Evans (2001); and Erceg and Levin (2002). For the Euro area, they make use of the VAR models of Peersman and Smets (2003), both with and without M3; Gali (1992), extended to include GDP components; and Christiano, Eichenbaum and Evans (2001), where the latter is modified to suit the Euro data. As mentioned above, the authors conclude that whereas the predominant driver of output changes in the United States is the consumption channel, in the Euro area it is the investment channel. This phenomenon is christened the "Output Composition Puzzle."

As VAR analyses that deal with the monetary transmission mechanism from the point of view of output decomposition in a Japanese context are few and far between,[3] I construct four separate VAR models. These are based, respectively, on: (1) Gorden and Leeper (1994), (2) Christiano, Eichenbaum and Evans (2001), (3) Erceg and Levin (2002) and (4) Leeper, Sims and Zha (1996).[4] While contemporaneous relations are assumed to conform to a recursive structure in the first three, in the last case a non-recursive structure is applied, the methodology for which is established in Bernanke (1996), Blanchard and Watson (1986) and Sims (1986). After a brief explanation of the VAR methodology employed here,[5] outlines are given for the models specified above. Finally, the results from the VAR models are used to shed light on the output composition of monetary transmission in Japan.

[3]The only research I could find was Morsink and Bayoumi (2000), but this estimates the VAR separately for each GDP component.

[4]Detailed information on the data employed in these VAR models may be summarized as follows. For investment, consumption and the other GDP components, data are seasonally adjusted series at 1995 prices, obtained from the SNA (Cabinet Office). For the CPI, I make use of the seasonally adjusted Consumer Price Index at 2000 prices (Ministry of Public Management, Home Affairs, Posts and Telecomunications); and for commodity prices, the Nikkei Shohin Sisuu (Nikkei Shimbun). The call rate is quoted with collateral bases before 1995 and without collateral bases after 1995 (Bank of Japan). The money supply is seasonally adjusted M2+CD, where the discontinuity caused by the adoption of a new definition is solved by using the quartely growth rate (Bank of Japan). Stock prices are illustrated by TOPIX (Tokyo Stock Exchange); the bond yield is that on newly issued 10 years government bonds (The Japan Bond Trading Co.); the profit to sales ratio is computed from "Financial Statements Statistics of Corporations by Industry, Quarterly" (Ministry of Finance); and labour productivity from the SNA and the "Labour Force Survey" (Ministry of Public Management, Home Affairs, Posts and Telecommunications)

[5]My discussion follows Vigfusson (2002).

2.1 VAR Primer

Estimation and identification of the VAR models in this paper takes place as follows.

2.1.1 Estimation

The basic building block consists of a vector time series Z_t. The vector Z_t evolves over time according to:

$$Z_t = B_0 + B_1 Z_{t-1} + B_2 Z_{t-2} + ... + B_q Z_{t-q} + u_t$$

where $\mathrm{E} u_t u_t' = V$. The vector u_t is assumed to be uncorrelated with past values of Z_t.

Estimation of the VAR's coefficients $\{B_j\}_{j=0}^{q}$ can be carried out equation by equation using OLS. The matrix V can then be estimated from the sample residuals $(1/T) \sum \hat{u}_t \hat{u}_t'$.

In this paper, VAR models are estimated for two periods. Miyao (2000) and Fujiwara (2003a) conclude that there is a high probability that a structural break occurred around 1995. For this reason, two estimating periods, from 1980/Q1 to 2002/Q3 and from 1980/Q1 to 1996/Q1, are adopted in order to ensure that the results on the output composition of the monetary transmission mechanism are robust.

As for the lag length, the number of lags, q, is determined optimally in accordance with two different information criteria: the Akaike Information Criterion (AIC) and the Schwarz Bayesian Information Criterion (SBIC). According to the SBIC, the optimal lag length is always one, while the AIC suggests a lag length of two at the most. Results are therefore shown for both the one and two lag cases. Impulse responses, however, are shown only for the longer of the lag lengths recommended by the two information criteria. This is because there are no major changes in impulse responses for reasonable lag lengths.

2.1.2 Fundamental Shocks and the Structural VAR

The next step is to calculate the structural matrix A_0. The values of u_t are not the standard structural shocks, since the latter are usually auto-correlated. Instead, we assume that the relationship between the VAR disturbances u_t and the fundamental economic shocks ε_t is given by

$$A_0 u_t = \varepsilon_t,$$

$$\begin{aligned} A_0 Z_t &= A_0 B_1 Z_{t-1} + A_0 B_2 Z_{t-2} + A_0 u_t \\ &= A_0 B_1 Z_{t-1} + A_0 B_2 Z_{t-2} + \varepsilon_t. \end{aligned}$$

We need to know the value of A_0 in order to calculate impulse responses. To find a unique A_0 however requires further assumptions. Many matrices might solve the equation

$$A_0^{-1}\left(A_0'\right)^{-1} = V.$$

In general, one can choose between two different approaches. The simpler and more common is the recursiveness assumption. One implements this assumption by defining the matrix A_0^{-1} to be the lower Choleski decomposition of V.

The other approach is not to assume recursiveness but rather to assume that enough entries are zero or otherwise constrained that there is only one unique A_0 that both solves the above equation and satisfies these further assumptions. Following the methodology established by Bernanke (1986), Blanchard and Watson (1986) and Sims (1986), this unique matrix A_0 is determined as the matrix that maximizes the likelihood function below.[6]

$$L\left(A_0, V\right) = -\frac{T}{2}\log\left(2\pi\right) + \frac{T}{2}\log\left|A_0\right|^2 - \frac{T}{2}\text{trace}(A_0 V A_o')$$

2.1.3 Impulse Responses

Having found the A_0 matrix, the next step is to calculate the impulse responses to a fundamental shock. The basic idea is the following. Suppose that the VAR has the following form.

$$Z_t = B_1 Z_{t-1} + B_2 Z_{t-2} + A_0^{-1}\varepsilon_t$$

We suppose that the j-th fundamental error takes on the value one while the other fundamental errors are set equal to zero. The impulse response is how the variables in the VAR respond to this shock. The impulse response in the first period is

$$\Gamma_j(1) = A_0^{-1} e_j$$

where the j-th element of e_j is equal to one and all other elements are zero. The vector $\Gamma_j(1)$ has length being equal to the number of endogenous variables with the same ordering as Z_t. The second period impulse response is

$$\Gamma_j(2) = B_1 A_0^{-1} e_j.$$

The third is

$$\Gamma_j(3) = B_1 B_1 A_0^{-1} e_j + B_2 A_0^{-1} e_j.$$

Note that if the matrix A_0 were the identity matrix, then the impulse response functions for all shocks would be the moving average representation of the VAR.

[6]However, the uniqueness of this A_0 can be difficult to establish.

2.1.4 Constructing Confidence Intervals for Impulse Responses

The procedures uses simulation to calculate confidence intervals around the impulse response functions. These confidence intervals are pointwise confidence intervals.

Each confidence interval is constructed using the following steps. The first step is to generate artificial data under the null hypothesis that the estimated model correctly represents the data. This artificial data is created using the estimated coefficients along with some error terms. Here, these error terms are generated via the bootstrapping method, in which error terms are generated by sampling randomly with replacement from the residuals of the original vector autoregression.

Having generated the artificial data, the next step is to carry out VAR estimation on this data. Using the estimated variance covariance matrix, a new A_0 matrix is estimated. The impulse response is calculated using these new estimates.

The above steps are repeated 100 times to generate a large sample of impulse responses. The procedure then establishes confidence intervals using the 5 and 95 percentile values of the sample to obtain the lower and upper bounds.

2.2 VAR Based on Gordon and Leeper (1994)

The model consists of eight variables: consumption c, investment i, other GDP components y, the CPI p, commodity prices com, the bond yield rl, the call rate r and M2+CDs m. All variables except for interest rate are logs of their actual values.[7] Although in the original paper [Gorden and Leeper (1994)] the information set available to the central bank when setting the short-term interest rate is restricted by excluding contemporaneous data on output and its components, as these would not have been accessible, in the model examined here this data is deemed of influence on the central bank's interest-rate setting decision. In addition, commodity prices are added to avoid the price puzzle.[8]

When deriving the impulse responses, the order of the variables is set as above and a simple recursive framework is employed for identification. The change in the call rate can only have a contemporaneous effect on the money supply and it is assumed that the central bank exploits all information except for the current money supply when determining the call rate.

2.2.1 Impulse Responses to a Nominal Interest Rate Shock

Chart 1 shows the impulse responses to a nominal interest rate shock for the estimation period from 1980/Q1 to 2002/Q3, while Chart 2 presents those for

[7]VAR models are estimated in levels in this paper. Sims, Stock and Watson (1992) claim that even if variables are non-stationary, the VAR should be estimated in levels as differencing throws away important information.

[8]The "price puzzle" is the name given to the tendency for the price level to rise after a positive interest rate shock. For discussion of price puzzle, see Hanson (2000).

1980/Q1 to 1996/Q1.[9]

Almost the same impulse responses are obtained in both cases. A rise in the nominal interest rate by the central bank lowers the level of the money supply and together these combine to reduce consumption, investment and the remaining GDP components. The price level and commodity prices also decrease eventually reflecting these developments, although there is initially a temporary increase in the price level. This is indeed the price puzzle. Notably, this price puzzle almost disappears in the estimation for the 1980/Q1 to 1996/Q1 period.[10] As a result, the long-term bond yield also becomes lower.

When we look at output composition, which will be analysed in more detail later, it seems that it is the investment channel which predominates. As for the significance of the responses of each component, confidence intervals suggest that the responses of consumption and investment may basically be considered significantly negative in the estimation for the period up to 1996/Q1.

2.3 VAR Based on Christiano, Eichenbaum and Evans (2001)

The model consists of ten variables: consumption c, investment i, other GDP components y, the CPI p, real wages w, labor productivity q, the call rate r, the profit to sales ratio π, M2+CDs m, and the TOPIX share price index s. All the variables except for r and π are logs of their actual values. In the original paper, Christiano, Eichenbaum and Evans (2001) employ aggregate real corporate profits, but it is the profit ratio that is employed. This is due to discontinuities in the aggregate profit data in Japan following the bankruptcies of a number of large companies and other institutions during the 1990s.

Impulse responses are derived for each variable in turn, following the order established in the preceding paragraph and a simple recursive framework is employed for identification. Changes in the call rate could only have a contemporaneous effect on corporate profits, the money supply, and stock prices, and it is assumed that central bank has complete information on all current non-financial variables when determining the call rate.

2.3.1 Impulse Responses to a Nominal Interest Rate Shock

Chart 3 shows impulse responses to a nominal interest rate shock for the estimation period from 1980/Q1 to 2002/Q3, while Chart 4 presents equivalent results for the period from 1980/Q1 to 1996/Q1.[11]

The impulse responses in the two charts are almost the same. A positive shock to the call rate reduces corporate profits and the money supply, and this

[9] The AIC suggests that the optimal lag length for the estimation period 1980/Q1 to 2002/Q3 is two. For this period, therefore, impulse responses are shown for a lag length of two.

[10] Fujiwara (2003a) suggests that one of the causes of the price puzzle may be the coexistence of equilibrium dynamics and dis-equilibrium dynamics in economic time series.

[11] In both cases, the lag length is one.

causes stock prices to fall. These developments in financial variables induce lower levels not only in consumption and investment but also in the other GDP components. The price level and real wages initially increase but then begin to decrease soon after.[12] These developments result in lower labor productivity.

Once again, when we look at output composition, it is the investment channel that seems to be more important. Confidence intervals suggest that the responses of consumption and investment may basically be considered large and negative for the estimation conducted up to 1996/Q1.

2.4 VAR Based on Erceg and Levin (2002)

The model consists of six variables: consumption c, investment i, other GDP components y, the CPI p, commodity prices com, and the call rate r. All variables except for r are logs of their actual values.

Impulse responses are derived for each variable in turn, in the order established above and a simple recursive framework is employed for identification. The change in the call rate has no contemporaneous effect on other variables but current information on all the macroeconomic variables are used by the central bank to set the interest rate.

2.4.1 Impulse Responses to a Nominal Interest Rate Shock

Chart 5 shows the impulse responses to a nominal interest rate shock for the estimation period from 1980/Q1 to 2002/Q3, while Chart 6 presents equivalent results for the 1980/Q1 to 1996/Q1 period.[13]

Once again, the impulse responses obtained in the two cases are nearly the same. A positive shock to the call rate decreases consumption, investment and other GDP components and this causes commodity prices to fall. Although initially increasing, the price level eventually decreases, reflecting these developments.[14]

As for the output composition, investment is likely to be the predominant driver of GDP changes. The response of investment may basically be considered large and negative for the 1980/Q1 to 1996/Q1 estimation.

2.5 VAR Based on Leeper, Sims and Zha (1996)

Leeper, Sims and Zha (1996)[15] claim that it is unrealistic to include contemporaneous information about demand and the price level within the information

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[12] The extent of the price puzzle is less significant for the estimation period from 1980/Q1 to 1996/Q1. The price puzzle is explained in Christiano, Eichenbaum and Evans (2001) by appealing to the cost channel of monetary policy, as advocated by Barth and Ramey (2001).

[13] The AIC suggests that the optimal lag length for both estimation periods is two. Impulse responses are therefore shown for the two lag case.

[14] The price puzzle is more significant for the 1980/Q1 to 2002/Q3 estimation period.

[15] The largest of the models introduced in Leeper, Sims and Zha (1996) consists of thirteen variables. It includes consumption but not investment.

set to which the central bank has access at the time it changes the nominal interest rate. Instead, they think it appropriate to restrict this information set to include only a leading indicator of the price level, commodity prices in this case, and the money supply. Furthermore, to retain consistency with the definition of a leading indicator, it is assumed that all variables may have contemporaneous effects on commodity prices.

Based on this identification scheme, the model for application to the Japanese data is constructed as follows. The model consists of seven variables: CPI p, consumption c, investment i, other GDP components y, commodity prices com, the call rate r and M2+CDs m. All variables except for r are logs of their actual value.

The structural matrix A_0 is then constructed as follows.

$$A_0 = \begin{pmatrix} a_1 & a_2 & a_3 & a_4 & 0 & 0 & 0 \\ a_5 & a_6 & 0 & 0 & 0 & 0 & 0 \\ a_7 & o & a_8 & 0 & 0 & 0 & 0 \\ a_9 & a_{10} & a_{11} & a_{12} & 0 & 0 & 0 \\ a_{13} & a_{14} & a_{15} & a_{16} & a_{17} & a_{18} & a_{19} \\ 0 & 0 & 0 & 0 & a_{20} & a_{21} & a_{22} \\ a_{23} & a_{24} & a_{25} & a_{26} & 0 & a_{27} & a_{28} \end{pmatrix} \begin{matrix} u_p \\ u_c \\ u_i \\ u_y \\ u_{com} \\ u_r \\ u_m \end{matrix}$$

The matrix above is obtained by non-recursive identification. As for the parameters, no restrictions have been made as to the sign of any of the components of the structural matrix.

The concept behind this matrix is as follows. The top row shows that the price level is susceptible to contemporaneous effects from GDP components. The second to fourth rows show that while consumption and investment are affected only by the current price level, the other GDP components are affected to some extent by consumption and investment as well as the price level. This is because other GDP components include imports and exports, and these are likely to have a high degree of contemporaneous correlation with consumption and investment. The logic behind the fifth and sixth rows is explained in the opening paragraph of the current section. The last row relates to money demand. It describes potential contemporaneous effects on money demand arising from the price level, GDP and the call rate.

Changes in the call rate can only have simultaneous effects on the money supply and commodity prices.

2.5.1 Impulse Responses to a Nominal Interest Rate Shock

Chart 7 shows impulse responses to a nominal interest rate shock for the estimation period from 1980/Q1 to 2002/Q3, while Chart 8 presents those for the 1980/Q1 to 1996/Q1 period.[16] The two charts reveal almost the same impulse

[16]The AIC suggests that the optimal lag length for the 1980/Q1 to 2002/Q3 estimation period is two. Impulse responses are therefore shown for the two lag case.

responses.

A positive shock to the call rate reduces consumption, investment, and the money supply. Initial increases in other GDP components, the price level and commodity prices are somewhat puzzling, but the dampening effect of the tighter monetary policy eventually kicks in and they begin to decrease as expected.

As in the above three models, the investment channel looks to be playing a more important role in monetary transmission.

2.6 Output Composition of the Monetary Transmission

In this subsection, the results obtained above are first summarized in terms of *contributions,* thus allowing us to measure the output composition of the monetary transmission mechanism in Japan. Contributions are termed by Angeloni, Kashyap, Mojon and Terlizzese (2003), which describes "the ratio of changes in the components of GDP to the overall movements in GDP." Since VAR models are estimated in logs for GDP components, this is computed as follows: first the cumulative response[17] of each component is described in the form of a ratio relative to the GDP response, where each response is measured relative to the relevant component baseline; then component movements are weighted by their shares in GDP. The weight accorded to each GDP component is set in line with its historical average since 1980/Q1, as follows: consumption 0.55; investment 0.15; other GDP components 0.3.

Contributions of consumption and investment for both the one and two lag cases are described below.

[17] Cumulative responses are used so as to eliminate the distortion from temporal noise.

- Consumption

model	lag	estimated period	4q	8q	12q
GL	1	1980:1-2002:3	0.14	0.20	0.24
CEE	1	1980:1-2002:3	0.43	0.40	0.36
EL	1	1980:1-2002:3	0.15	0.20	0.24
LSZ	1	1980:1-2002:3	0.50	0.47	0.47
GL	1	1980:1-1996:1	0.10	0.25	0.28
CEE	1	1980:1-1996:1	0.50	0.43	0.39
EL	1	1980:1-1996:1	0.27	0.29	0.30
LSZ	1	1980:1-1996:1	0.57	0.47	0.43
GL	2	1980:1-2002:3	0.20	0.21	0.21
CEE	2	1980:1-2002:3	0.40	0.41	0.36
EL	2	1980:1-2002:3	0.06	0.17	0.22
LSZ	2	1980:1-2002:3	-0.01	0.68	0.44
GL	2	1980:1-1996:1	-0.16	0.13	0.17
CEE	2	1980:1-1996:1	0.46	0.46	0.42
EL	2	1980:1-1996:1	0.24	0.30	0.31
LSZ	2	1980:1-1996:1	0.18	0.23	0.21
		average	0.25	0.33	0.32

- Investment

model	lag	estimated period	4q	8q	12q
GL	1	1980:2-2002:3	0.53	0.69	0.70
CEE	1	1980:2-2002:3	0.18	0.54	0.67
EL	1	1980:2-2002:3	0.67	0.72	0.71
LSZ	1	1980:2-2002:3	0.62	0.57	0.54
GL	1	1980:2-1996:1	0.58	0.64	0.65
CEE	1	1980:2-1996:1	-0.11	0.35	0.51
EL	1	1980:2-1996:1	0.56	0.61	0.64
LSZ	1	1980:2-1996:1	0.49	0.49	0.53
GL	2	1980:2-2002:3	0.39	0.74	0.88
CEE	2	1980:2-2002:3	0.08	0.48	0.61
EL	2	1980:2-2002:3	0.57	0.95	0.94
LSZ	2	1980:2-2002:3	0.42	0.53	0.58
GL	2	1980:2-1996:1	0.40	0.65	0.76
CEE	2	1980:2-1996:1	-0.12	0.24	0.38
EL	2	1980:2-1996:1	0.35	0.54	0.60
LSZ	2	1980:2-1996:1	0.29	0.56	0.70
		average	0.37	0.58	0.65

Overall, as is expected from the impulse response analysis, contributions of investment are larger than those of consumption. The average contribution of consumption (where the average is taken over the 16 VAR models) is 0.25 at the end of the first year after the shock, and 0.33 and 0.32 at the end of the second and third years, respectively. On the other hand, of the equivalent figures of investment are 0.37, 0.58 and 0.65. This is consistent with our original intuition about the monetary transmission mechanism in Japan.

3 DSGE Model

Inspired by real business cycle (RBC) models such as those of Kydland and Prescott (1982) and King, Plosser and Rebello (1988), analysing macroeconomic phenomena within a small general equilibrium framework has become very popular in the field of monetary economics. Usually, sticky prices as in Calvo (1982) and a Taylor-type policy rule [Taylor (1993)] are added to the standard RBC models referred to above in order to enable investigation of the role of monetary policy. This analytical framework[18] is often described as a dynamic stochastic general equilibrium (DSGE) framework.[19] It would not be any exaggeration to say that this DSGE framework is now one of the central analytical tools in modern macroeconomics.[20]

Applications of DSGE models to Japan, however, have been more limited than those making use of VARs. Only a few such research papers can be found dealing with the Japanese economy, including Orphanides and Wieland (2000), Kimura and Kurozumi (2002), Fukunaga (2002), Hayashi and Prescott (2002), and Jung, Teranishi and Watanabe (2002). Furthermore, most of these models do not paid explicit attention to stock variables and therefore do not endogenize investment.[21] They are not, therefore, usually well-suited to analysis on the output composition of monetary transmission, and instead a new DSGE model for the Japanese economy needs to be constructed here. This model represents a slight modification and re-calibration of the model laid out in Nelson (2002). As the aim of constructing the DSGE model here is to judge whether the impulse responses obtained in the above VAR models can be considered realistic from a theoretical perspective, the model should be based on standard macroeconomic theory.[22] Nelson (2002) takes an entirely standard approach to modelling. He incorporates equations derived from the utility maximization of consumers and the profit maximization of firms, and includes habit formation,

[18] Goodfriend and King (1997) name this analytical framework the "New Neo-Classical Synthesis".

[19] Several solution methods are now available, for example Uhlig (1999) and Klein (2002). All, however, are based on the seminal research by Blanchard and Kahn (1981).

[20] Taylor (1999) assembles and provides an overview of the early stages of research making use of this technique.

[21] Fukunaga (2002) includes investment in the system. However, the focus in Fukunaga (2002) is more on the effect of incomplete financial markets than on simply obtaining impulse responses for the Japanese economy.

[22] It may not be appropriate to use the word "standard" in the context of economics. Here, by "standard", I mean a robust theory which has been widely employed. Research such as the financial accelerator model of Bernanke, Gertler and Gilchrist (1999), the model of the credit cycle by Kiyotaki and Moore (1997), the limited participation model of Christiano and Eichenbaum (1995), and the model of "search and match" in the labour market produced by Mortensen and Pissarides (1994) would, for example, be excluded as candidates since they may be deemed too topic-specific.

capital adjustment costs, and an estimated policy rule, as in Rotemberg and Woodford (1997), as well as a New Keynesian Phillips curve, as in Calvo (1983) and Fuhrer and Moore (1995).

3.1 The Model

The DSGE model examined in this paper consists of the thirteen equations detailed below. All equations are expressed as log deviations from steady state values.[23]

3.1.1 Structural Equations derived from Optimizing Behaviour

Consumption

$$\frac{\beta h(\sigma-1)}{\sigma(1-\beta h)}E_t c_{t+1} = \frac{\beta h^2\sigma - \beta h^2 + \sigma\beta h - 1}{\sigma(1-\beta h)}c_t - \frac{h(\sigma-1)}{\sigma(1-\beta h)}c_{t-1} - \psi_t + \frac{1-\beta h\rho_\lambda}{1-\beta h}\lambda_t$$

variables: c consumption; ψ Lagrange multiplier on consumer budget constraint; λ demand shock[24]

parameters: β subjective discount rate; h parameter for habit formation; σ intertemporal elasticity of substitution for consumption; ρ_λ AR(1) parameter on demand shock

Labor Market Equilibrium

$$0 = (1-\chi)y_t - (1-\chi)n_t - \mu_t + \psi_t$$

variables: y GDP; n labor; μ gross markup

parameters: χ elasticity of substitution between labor and the capital stock

Money Demand

$$0 = -\frac{1}{\varepsilon}\psi_t - rm_t - \frac{1}{\varepsilon R^{SS}}R_t$$

variables: rm real money balance; R net nominal interest rate[25]

parameter: ε reciprocal of intertemporal elasticity of substitution for real money balances

Euler Equation

$$\mathrm{E}_t\psi_{t+1} = \psi_t - r_t$$

variable: r net real interest rate

[23]A detailed explanation of the derivation of these equations, by solving agents' optimizing problems and carrying out log-linearisation, may be found in Fujiwara (2003b). This is available upon request.

[24]To be exact, this is a shock to consumer preferences.

[25]Capital letters with superscript SS denotes the steady state level of a variable.

Fisher Equation

$$R_t = r_t + E_t \pi_{t+1}$$

variable π inflation rate

Quasi-Investment

$$\beta(1-\delta)\,\mathrm{E}_t x_{t+1} + \beta \frac{\rho(1-\alpha)\frac{Y^{SS}}{K^{SS}}}{(\eta-1)\beta\phi\eta\left(X^{SS}\right)^{\eta-1}} \mathrm{E}_t\left[(1-\chi)\,y_{t+1} - (1-\chi)\,k_{t+1} - \mu_{t+1}\right]$$
$$= x_t + \frac{1}{(\eta-1)\phi\eta\left(X^{SS}\right)^{\eta-1}} r_t$$

variables: x quasi investment;[26] k capital stock

parameters: δ depreciation rate; α labor share; ρ reciprocal of steady state markup; ϕ, η: parameters capturing capital adjustment costs[27]

Law of Motion for Capital

$$k_{t+1} = \delta x_t + (1-\delta)\,k_t$$

Resource Constraint

$$y_t = \frac{C^{SS}}{Y^{SS}} c_t + \frac{X^{SS} + \eta\phi\left(X^{SS}\right)^{\eta}}{Y^{SS}} x_t$$

Production Function

$$y_t = \alpha\left(\frac{A^{SS}N^{SS}}{Y^{SS}}\right)^{\chi} a_t + \alpha\left(\frac{A^{SS}N^{SS}}{Y^{SS}}\right)^{\chi} n_t + (1-\alpha)\left(\frac{K^{SS}}{Y^{SS}}\right)^{\chi} k_t$$

variable: a technology shock

3.1.2 AR Shocks

Aside from the structural equation above, the disturbances mentioned above are assumed to follow an AR(1) process:

Demand Shock

$$\lambda_t = \rho_\lambda \lambda_{t-1} + e_{\lambda t}$$

innovation: e_λ white noise innovation for demand shock

[26] Quasi investment describes the investment excluding capital adjustment costs.

[27] In this paper, capital adjustment costs are defined as ϕX_t^{η}.

Technology Shock

$$a_t = \rho_a a_{t-1} + e_{at}$$

innovation e_a white noise innovation for technology shock

3.1.3 Policy Rule

Although there are several available formulas for this (for example the Taylor rule), here estimation of the Bank of Japan's empirical policy rule is carried out using the method introduced in Rotemberg and Woodford (1997).[28]

$$\begin{aligned} R_t = {} & 1.2926 * R_{t-1} - 0.4728 * R_{t-2} + 0.0296 * R_{t-3} \\ & + 0.0624 * \pi_t + 0.0179 * \pi_{t-1} + 0.1205 * \pi_{t-2} \\ & + 0.3227/4 * y_t - 0.2132/4 * y_{t-1} - 0.0986/4 * y_{t-2} \\ & + e_{Rt} \end{aligned}$$

innovation: e_R white noise innovation for policy shock

3.1.4 Phillips Curve

Two pricing equations based on optimizing behaviour are utilized in this paper. Their results will be shown later. The first one is widely used in monetary economics and is generally referred to as the New Keynesian Phillips curve, following the terminology of Roberts (1995). It is based on the staggered price setting described in Calvo (1983), where only a limited number of firms have the chance to change their prices. The other, the Hybrid New Keynesian Phillips curve, is based on Fuhrer and Moore (1995) and has a similar setting to Calvo (1983), except that past information on inflation is also utilized when setting new prices.[29]

Calvo (1983) The parameter α_μ is determined by the frequency with which firms can change their prices.

$$\beta \mathrm{E}_t \pi_{t+1} = \pi_t - \alpha_\mu \mu_t$$

Fuhrer and Moore (1995) Weights on leads and lags are set in line with the estimation results for Japanese data obtained by Kimura and Kurozumi (2002).[30]

[28] Rotemberg and Woodford (1997) first estimates the VAR with R_t, π_{t+1} and y_{t+1} and then derive a monetary policy reaction function by assuming that the monetary policy shock has no contemporaneous effect on the other variables.

[29] Although including lagged inflation substantially improves performance in terms of mimicking movements in actual business cycles, it must be admitted that its inclusion is somewhat ad hoc.

[30] Note that the sum of the parameters on leads and lags is one. This implicitly assumes that the subjective discount rate is approximately one, which may contradict assumptions made in the model so far. However, the effect from this approximation is minuscule.

$$0.65 * \mathrm{E}_t \pi_{t+1} = \pi_t - 0.35 * \pi_{t-1} + \alpha_\mu \mu_t$$

3.2 Setting Deep Parameters

The table below describes the model calibration.

- Model Calibration

Parameters	Description	Quarterly Value
α	labor share	0.65
β	subjective discount factor	0.99
σ	intertemporal elasticity of substitution for consumption	0.66
h	habit formation parameter	0.8
δ	rate of depreciation	0.021
$1/\sigma\epsilon$	steady state consumption elasticity of money demand	1.00
ϕ	capital adjustment cost parameter 1	0.75
η	capital adjustment cost parameter 2	2.00
$1/\rho$, μ	steady state markup	1.25
ρ_λ	AR(1) parameter for demand shock	0.22
ρ_a	AR(1) parameter for technology shock	0.87
α_μ	price stickiness	0.087
N^{SS}	steady state fraction of time in employment	0.33
Z^{SS}	steady state level of technology	1.00
π^{SS}	steady state inflation rate	0.025

The grounds for these parameter calibrations are as follows.

Labor Share The labor share is set in line with Fukunaga (2002), who computes the historical average of nominal labor income relative to nominal GDP.

Discount Factor The subjective discount factor is the reciprocal of the gross equilibrium real interest rate[31] and the equilibrium real interest rate is set at 1 % per year.

Intertemporal Elasticity of Substitution for Consumption Estimating the intertemporal elasticity of substitution σ is an intensively researched area, as seen in Hayashi and Sims (1983), Hall (1988), Patterson and Pesaran (1992), Atkeson and Ogaki (1996), and Ogaki and Reinhart (1998). However, even

[31] Note that overlapping generations models, as employed in Yaari (1965), Blanchard (1985), Buiter (1988) and Weil (1989), which are well summarized in Frenkel and Razin (1992), are not employed here. This means that a steady state exists when the subjective discount factor equals the reciprocal of the real steady state gross interest rate. Futher, when this condition is satisfied, any level of consumption may be a candidate for the steady state value, since the consumption Euler condition always holds.

though sophisticated econometric techniques are used, the results are not necessarily either sensible or consistent. Here, I simply use GMM to estimate σ for the IS curve as shown in McCallum and Nelson (1999), where the IS curve is derived from the same representative consumer's optimization problem as in the model above.

$$y_t = b_0 + \mathrm{E}_t y_{t+1} - \sigma \frac{C^{SS}}{Y^{SS}} \left(R_t - \mathrm{E}_t \Delta p_{t+1}\right) + \frac{C^{SS}}{Y^{SS}} \nu_t$$

This equation is estimated for the period from 1980/Q1 to 1996/Q1.[32] Instrumental variables are a time trend, constant, and both one and two lags of government expenditure. Estimation results are as follows, where the steady state ratio of consumption against GDP is simply set at 0.55, its historical average since 1980.

	b_0	σ
Estimated Value	-0.360648	0.655399
(Standard Error)	(0.260995)	(0.484557)

The estimated intertemporal elasticity of substitution is thus about 0.66.

Habit Formation Parameter As it is difficult to find any previous research that estimates the degree of habit formation in Japan, the parameter is initially set at the value obtained for the U.S. in Fuhrer (2000).[33] As there is no guarantee that this value is valid for the Japanese economy, results with quite different settings, namely a very high habit formation case (h=0.99) and a very low habit formation case (h=0.4) are also shown, as a check on the robustness of the results.

Depreciation Rate The capital depreciation rate is set in line with previous research on Japan, specifically Hayashi and Prescott (2002), and Fukunaga (2002).

Steady State Consumption Elasticity of Money Demand A unitary elasticity of substitution between consumption and real balance is assumed.

Capital Adjustment Cost Parameters ϕ and η are set based on Cassaras and McCallum (2000). Like the habit formation parameter, parameter values for this particular capital adjustment cost function cannot be found for the

[32]Fujiwara (2003a) hints that since the introduction of de-facto zero nominal interest rate in 1996 the Japanese economy may possibly be in a state that is difficult to explain using standard macroeconomic theory. Hence, the estimation is conducted for the period before 1996.

[33]It would be possible to obtain the parameter for habit formation by applying the estimation method advocated by Fuhrer (2000) to Japanese data. This, however, is beyond the scope of the current paper.

Japanese economy case and are extremely challenging to estimate.[34] For this reason, results from quite different settings, namely a very high adjustment cost case (ϕ=1.5) and a very low adjustment cost case (η=0.25) are also shown, as a check on the robustness of the results.

Steady State Markup The steady state markup is set at around the historical average of the markups computed from corporate profit in the SNA statistics.

AR(1) Parameter for Demand Shock This is estimated from the errors in the IS curve estimation for obtaining the intertemporal elasticity of substitution described above.

AR(1) Parameter for Technology Shock This is set at the value employed in Fukunaga (2002).

Price Stickiness Price stickiness is set in line with the estimate obtained by Fuchi and Watanabe (2001), which is also that used in Fukunaga (2002).

Steady state fraction of time in employment This is set so to ensure an average eight-hour working day.

Steady State Level of Technology This determines the consumption/GDP ratio in steady state. Therefore, it is fixed at the value which makes this ratio roughly equal to its historical average.

Steady State Inflation Rate One percent annual inflation is assumed, reflecting recent price developments in Japan.[35]

3.3 Impulse Responses to a Nominal Interest Rate Shock

Chart 9 shows impulse responses to a nominal interest rate shock when the New Keynesian Phillips Curve is employed, while Chart 10 presents equivalent results for the Hybrid New Keynesian Phillips Curve.

Although there exist minor differences caused by differences in specification, the monetary policy transmission mechanisms are all alike. A positive shock to the call rate lowers investment[36] through a rise in the cost of capital, consumption through intertemporal substitution, and therefore aggregate GDP. In response to these developments on the demand side, the inflation rate falls.

[34] Neri (2003) employs dynamic general equilibrium models with several forms of capital adjustment cost, carrying out maximum likelihood estimation on U.S. data. However, estimation of the capital adjustment parameters is beyond the scope of this paper.

[35] This setting has only a marginal effect on the results, merely altering the steady state nominal interest rate.

[36] Note that investment here is quasi-investment. Contributions are also calculated for quasi-investment.

3.4 Output Composition of the Monetary Transmission

Contributions, defined above, are also used here to measure the output composition of monetary transmission in Japan as depicted in a DSGE model.

- Consumption

model	ϕ	h	NKP	4q	8q	12q
BASE	0.75	0.80	Calvo	0.25	0.29	0.32
High AC	1.5	0.80	Calvo	0.32	0.36	0.38
Low AC	0.25	0.80	Calvo	0.07	0.13	0.18
High H	0.75	0.99	Calvo	0.07	0.14	0.18
Low H	0.75	0.40	Calvo	0.28	0.30	0.33
BASE	0.75	0.80	FM	0.14	0.20	0.24
High AC	1.5	0.80	FM	0.20	0.25	0.28
Low AC	0.25	0.80	FM	0.07	0.14	0.20
High H	0.75	0.99	FM	0.04	0.09	0.14
Low H	0.75	0.40	FM	0.17	0.22	0.25
	average			0.16	0.21	0.25

- Investment

model	ϕ	h	NKP	4q	8q	12q
BASE	0.75	0.80	Calvo	0.39	0.35	0.33
High AC	1.5	0.80	Calvo	0.27	0.25	0.24
Low AC	0.25	0.80	Calvo	0.67	0.61	0.54
High H	0.75	0.99	Calvo	0.53	0.48	0.44
Low H	0.75	0.40	Calvo	0.36	0.34	0.32
BASE	0.75	0.80	FM	0.55	0.49	0.45
High AC	1.5	0.80	FM	0.46	0.41	0.38
Low AC	0.25	0.80	FM	0.67	0.59	0.53
High H	0.75	0.99	FM	0.65	0.59	0.55
Low H	0.75	0.40	FM	0.52	0.47	0.44
	average			0.51	0.46	0.42

Results suggest that the investment channel is the predominant driver of GDP changes. The average contribution of consumption from the 10 DSGE models is 0.16 at the end of first year after the shock, 0.21 at the end of second year, and 0.25 at the end of third year. Equivalent figures of investment, on the other hand, are 0.51, 0.46 and 0.42.

Angeloni, Kashyap, Mojon and Terlizzese (2003) conclude that the high response of consumption to nominal interest rate shocks in the United States cannot be explained by a theoretical model with reasonable calibration.[37] The

[37] Inclusion of liquidity constrained households, of which one manifestation is the "rule of thumb" consumer, may enable the model to explain the superiority of the consumption channel in the U.S. monetary transmission mechanism. The construction of a DSGE model capable of explaining this phenomenon in the U.S. is left as a topic for future research.

same is not true for the Japanese results produced here. With no major caveats, we can safely say that the output composition obtained from VAR models identified using a variety of schemes may be considered within the range of theoretical explanation, although it is true that in the theoretical DSGE model the responses of investment are somewhat smaller.[38]

4 Conclusion

This paper has shown empirically, using VAR models, that the investment channel is the predominant monetary transmission channel. The same result is also obtained from a theoretical DSGE model of the Japanese economy. Therefore, it would be appropriate to conclude that the output composition of the response to a nominal interest rate shock in Japan presents no particular puzzle. Indeed our conclusion with regard to the output composition may be considered entirely reasonable, since the VAR results are basically consistent with those obtained from the DSGE model.

So, what makes the output composition so different in Japan from that in the United States? Angeloni, Kashyap, Mojon and Terlizzese (2003) identify three possible explanations for the difference in consumption reactions between the Euro area and the U.S.: 1) lower adjustment costs on investment in the Euro area due to higher labor adjustment costs; 2) the greater sensitivity of U.S. consumers to interest rate changes due to differences in financial asset composition; and 3) government insurance mechanisms which cushion income against interest rate shocks. These explanations are naturally also valid for explaining the difference between Japan and the U.S. However, we may add to these two further explanations: the high relative risk aversion[39] and the saving behaviour of Japanese consumers. The former directly implies a low intertemporal elasticity of substitution. With respect to the latter, it should be pointed out that the amount outstanding of financial assets owned by households is much larger in Japan than in the U.S. This implies that the downward pressure from the interest rate rise caused by the substitution effect is somewhat mitigated by upward pressure from the income effect, although overall it is the substitution effect that dominates.

Probably, it is a combination of these five features that makes the consumption response to nominal interest rate shocks less critical in Japan. However, there is the prospect of some of these features becoming less influential in future. Prolonged recession since the beginning of 1990s has been transforming the labor market in Japan. Conventional life-time employment can no longer be

[38]This may be due to the fact that investment here is quasi-investment, which excludes adjustment costs. There are also difficulties in obtaining a hump-shaped investment response, such as in the VAR impulse responses, from a DSGE model, because capital adjustment costs only apply to the capital stock and not to investment.

[39]The estimate of the intertemporal elasticity of substitution is not significantly lower than the value generally assumed for the U.S. However, if we concentrate on the difference in the impulse responses, the intertemporal elasticity of substitution may be deduced to be higher in the U.S. than in Japan.

fully guaranteed and this may result in lower labor adjustment costs. Government debt has risen substantially, with the result that future cuts in government spending are expected. At the same time the conspicuous aging of the Japanese population will bring about a rise in the propensity to consume, leading to decreased holdings of financial assets. It might, therefore, be possible for the output composition in Japan become more similar to that of the U.S. in the near future.

In this regard, checking the output composition of responses to nominal interest rate shocks may be considered useful not only for understanding the transmission mechanism in order to discover the optimal policy mix for stimulating the economy, but also for raising awareness of potential structural breaks. Although formal testing to explain the difference in output composition between Japan and the U.S. is left for future research,[40] it is always of importance for the central bank to understand the detailed monetary transmission mechanism.

Last but not least, the output of the VAR models reported in this paper reinforces the results of Miyao (2000), Kimura, Kobayashi, Muranaga and Ugai (2002) and Fujiwara (2003a), in that the models seem to imply that monetary policy has become less effective since the introduction of the de-facto zero nominal interest rate in 1996. For the VAR estimated from 1980/Q1 to 2002/Q3, which includes the periods during which there was a de-facto zero nominal interest rate, the upper bounds of confidence intervals for investment and consumption tend to be above zero. This suggests that the effects of monetary policy have been weakening recently.

[40] In this paper, I present results from quite different settings for capital adjustment costs and habit formation parameters in order to check the robustness of the results. However obtaining convincing values for these parameters would also enhance the credibility of the outcomes from the DSGE model.

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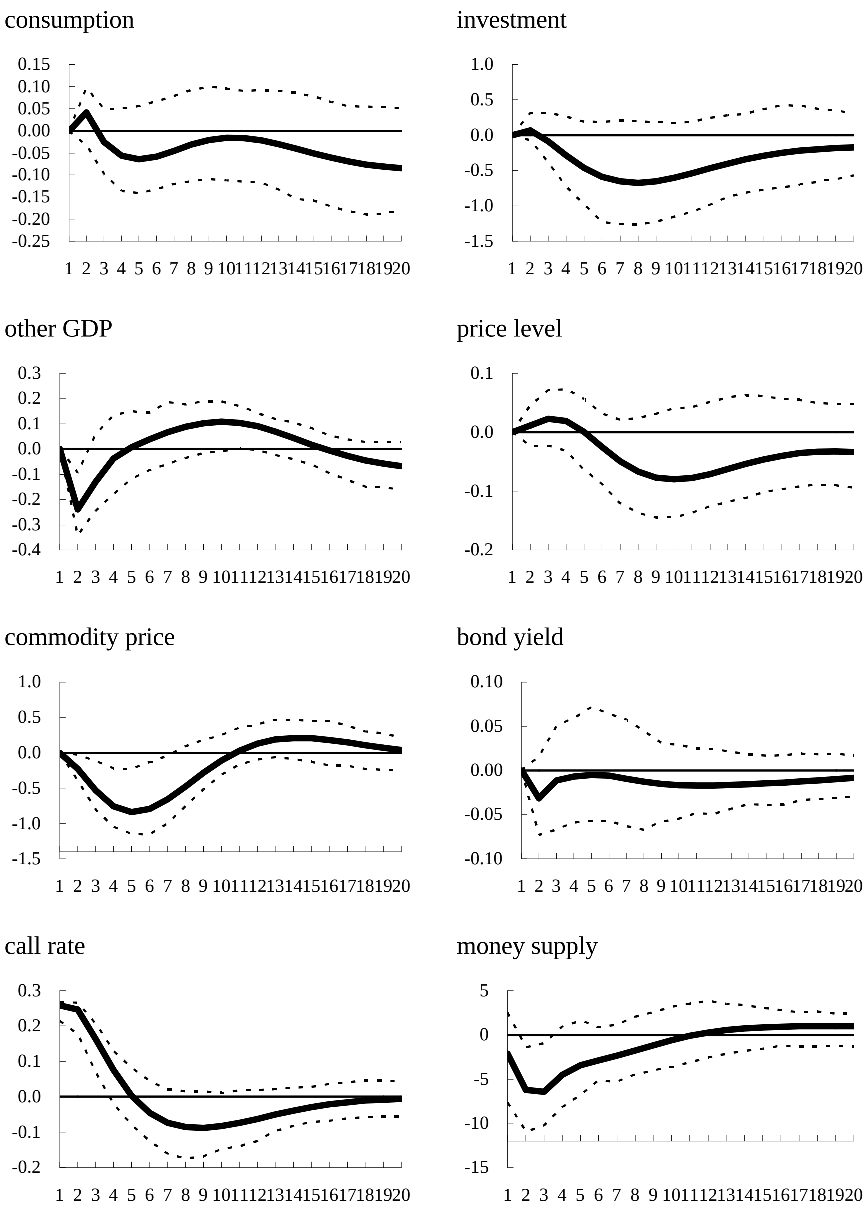
chart 1

VAR based on Gordon and Leeper (1994): 1980/Q1-2002/Q3



VAR based on Gordon and Leeper (1994): 1980/Q1-1996/Q1

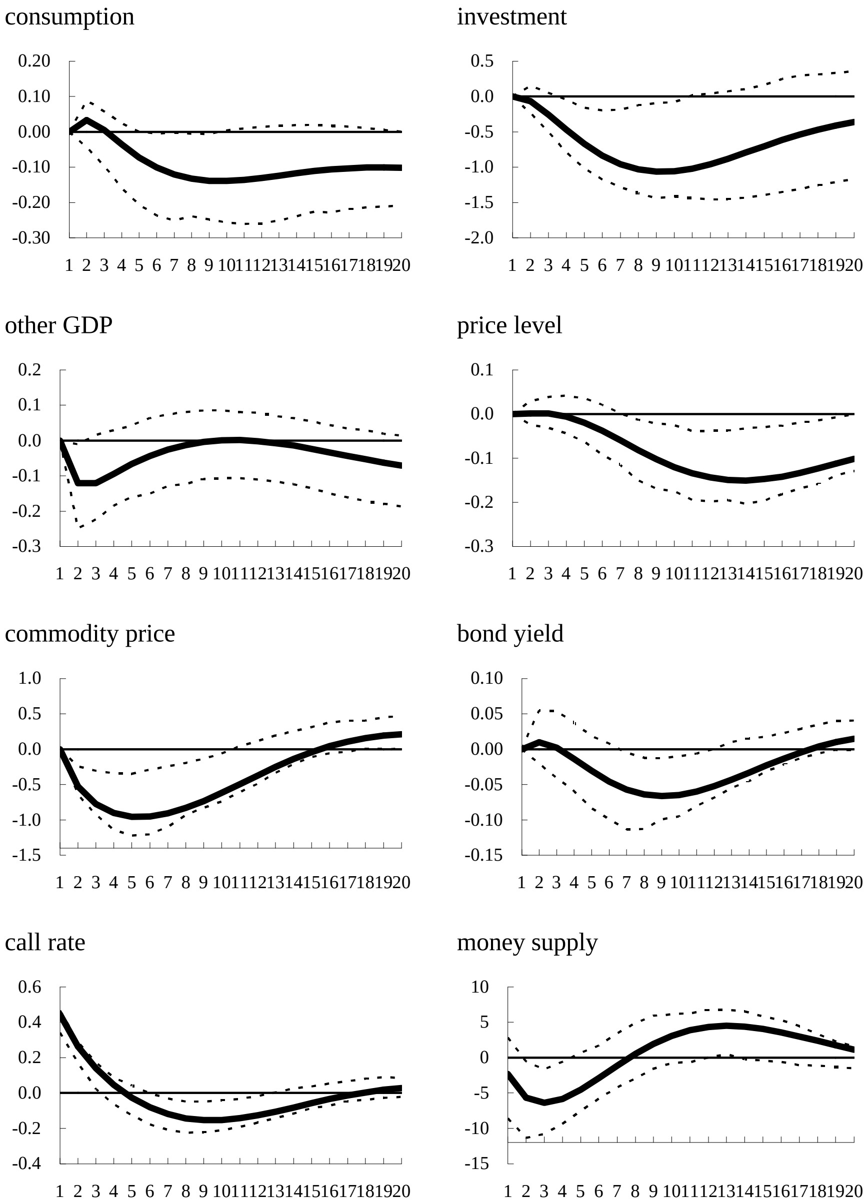


chart 3

VAR based on Christiano, Eichenbaum and Evans (2001): 1980/Q1-2002/Q3

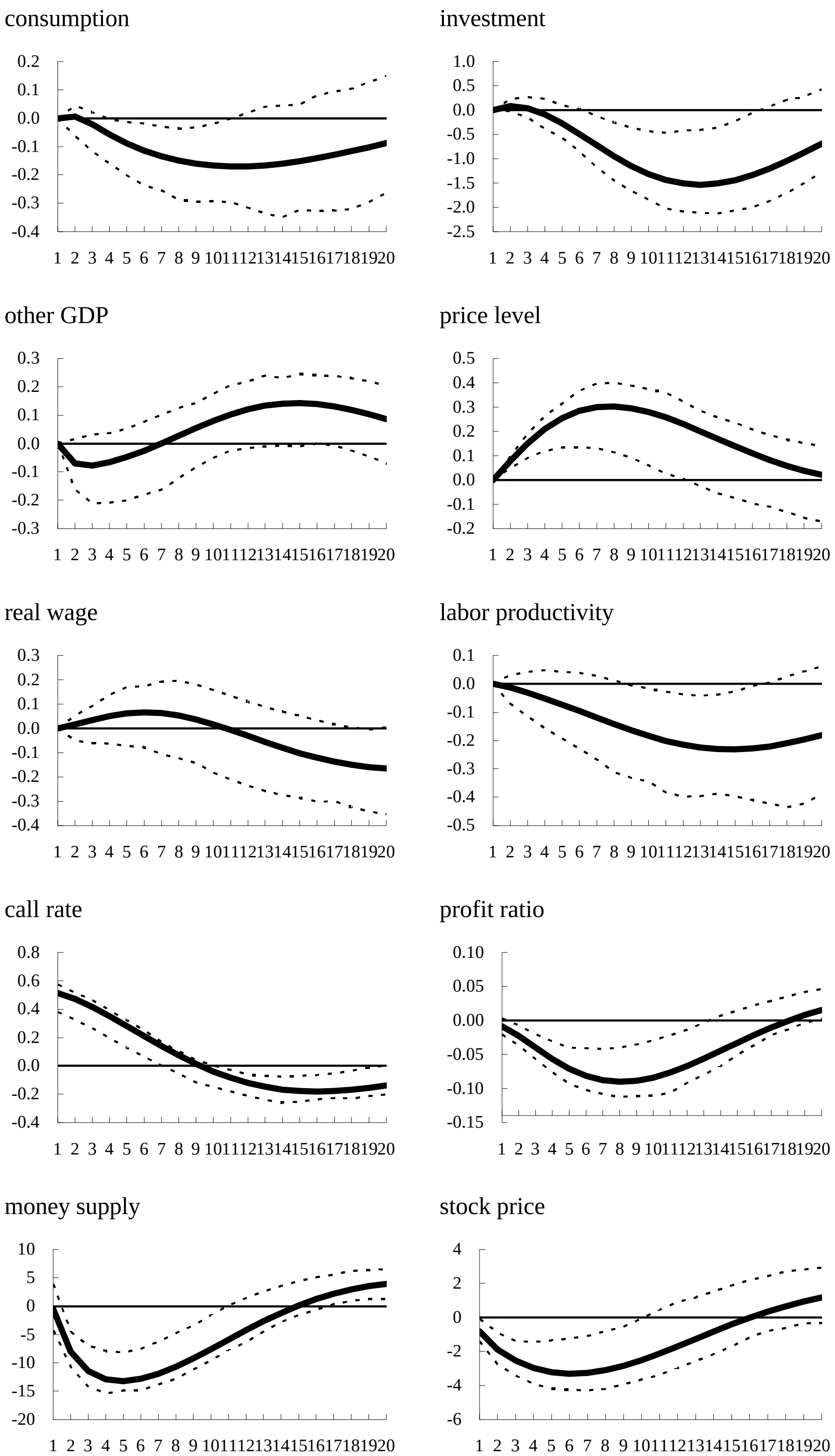


chart 4

VAR based on Christiano, Eichenbaum and Evans (2001): 1980/Q1-1996/Q1

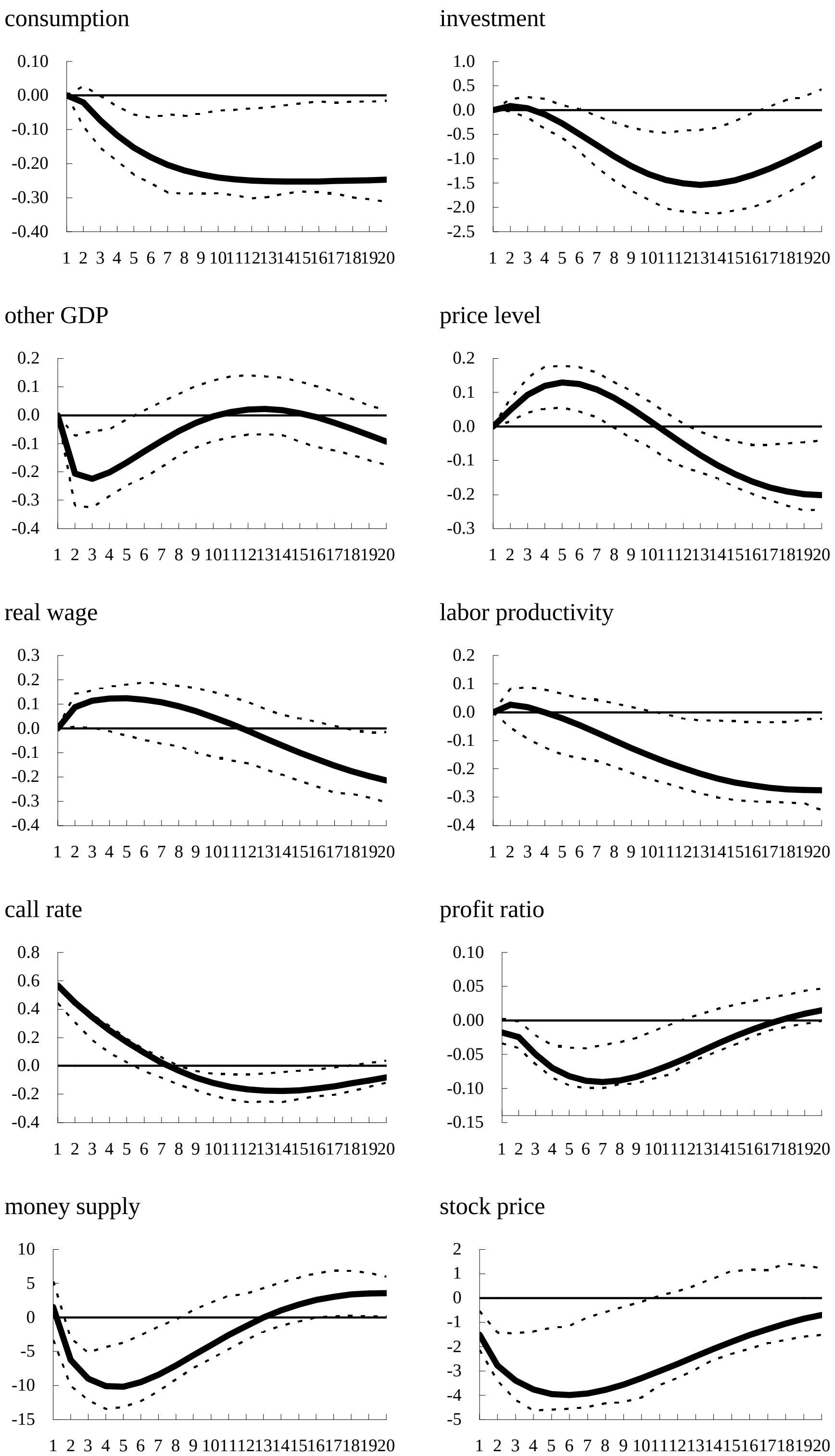


chart 5

VAR based on Erceg and Levin (2002): 1980/Q1-2002/Q3

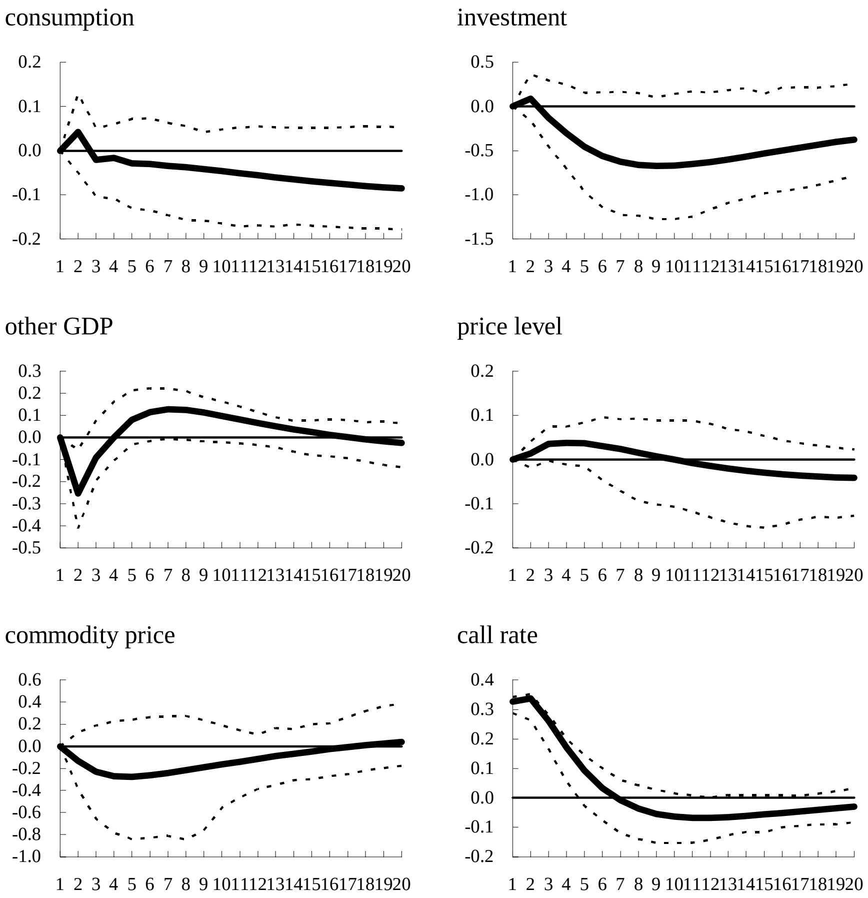


chart 6

VAR based on Erceg and Levin (2002): 1980/Q1-1996/Q1

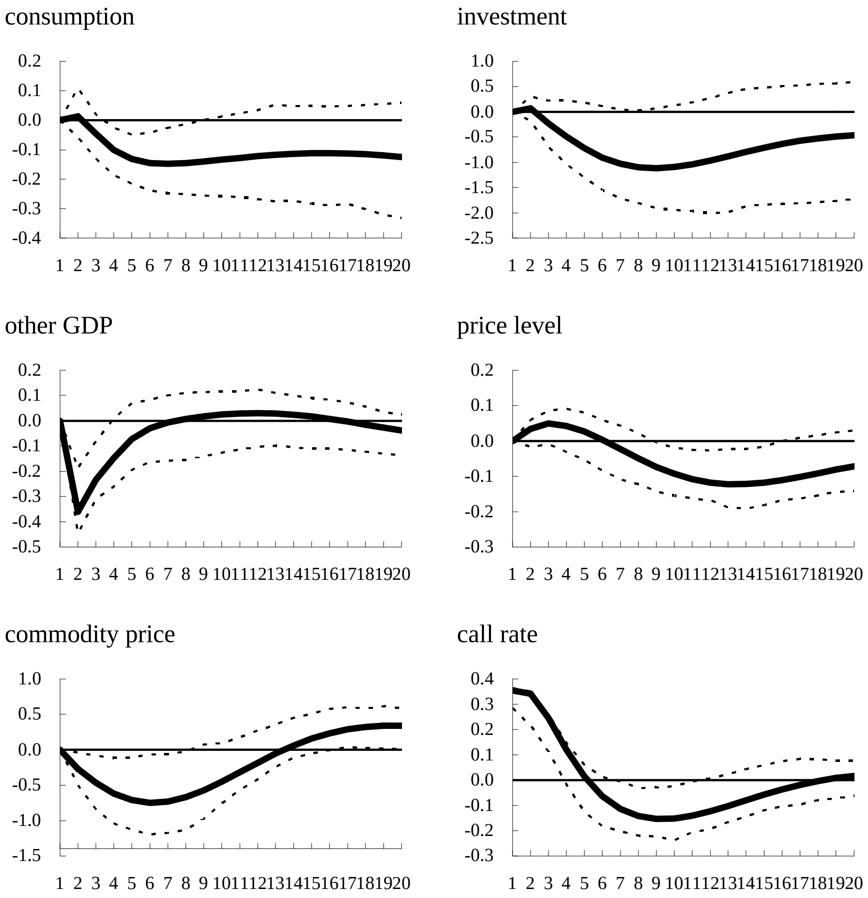


chart 7

VAR based on Leeper, Sims and Zha (1996): 1980/Q1-2002/Q3

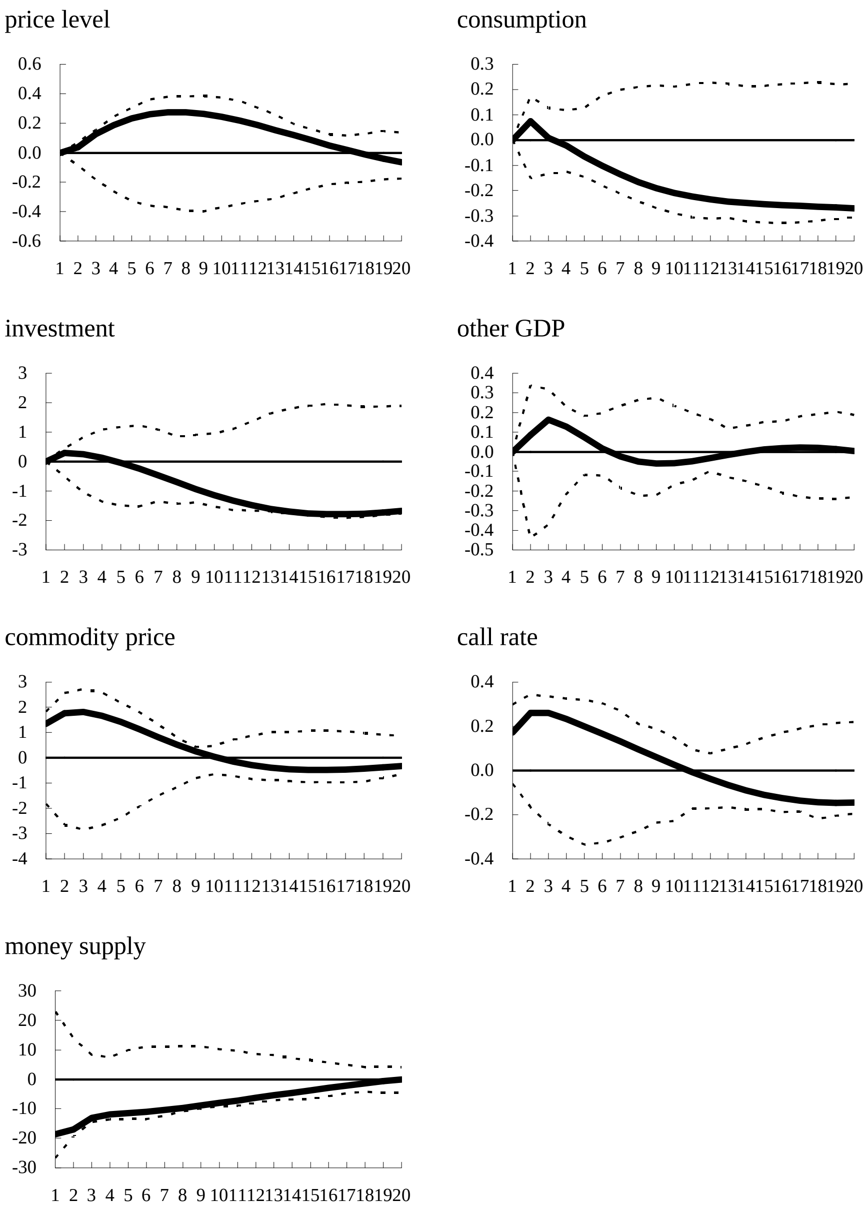
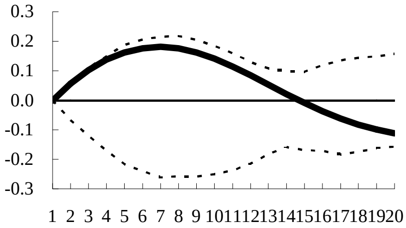


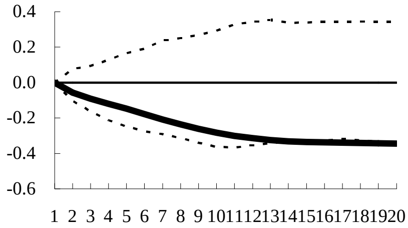
chart 8

VAR based on Leeper, Sims and Zha (2002): 1980/Q1-1996/Q1

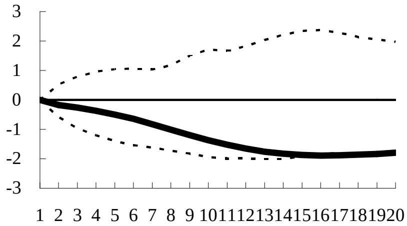
price level



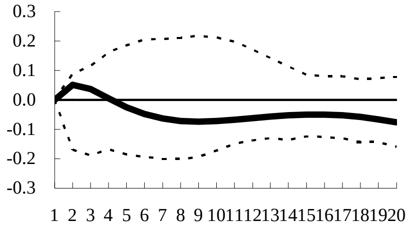
consumption



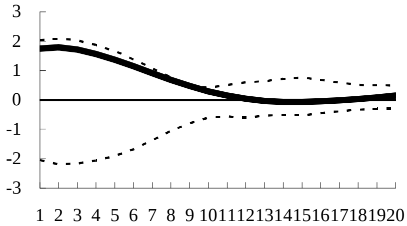
investment



other GDP



commodity price



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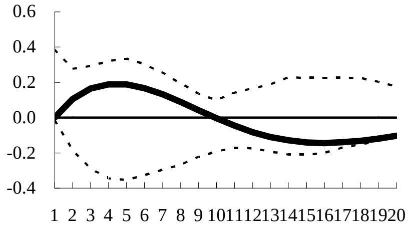


money supply

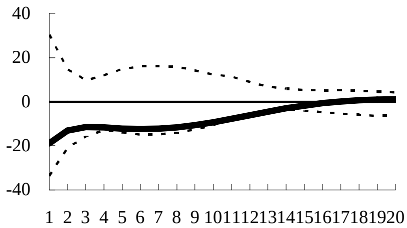


chart 9

DSGE based on Calvo (1983)

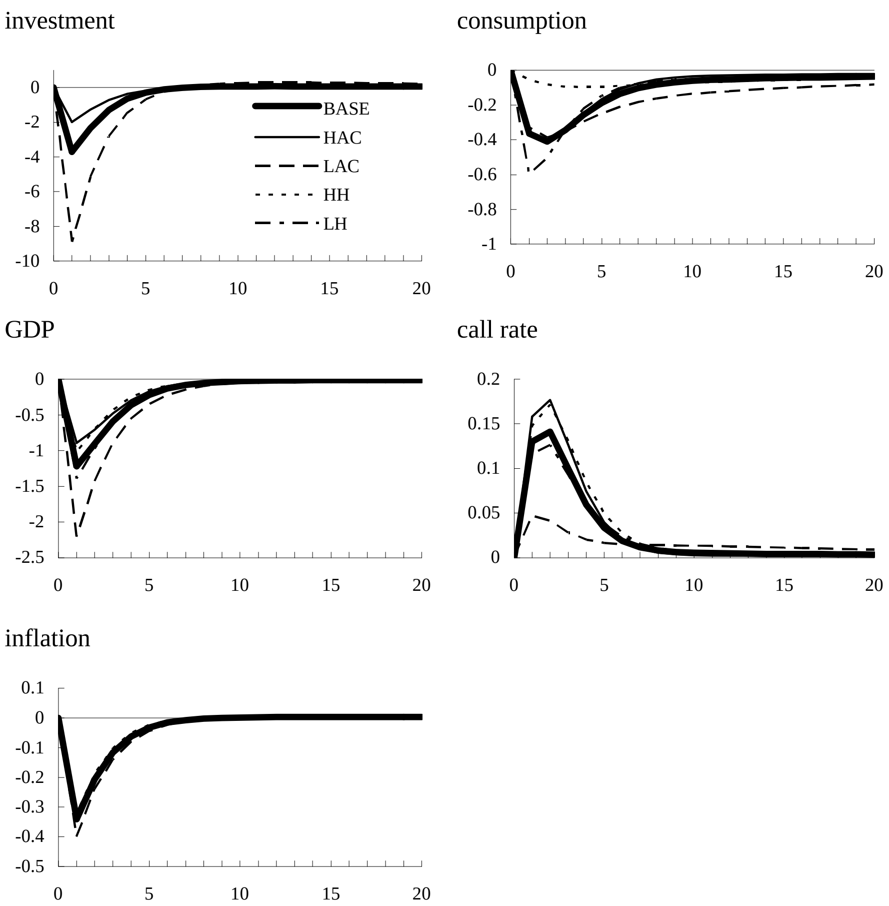
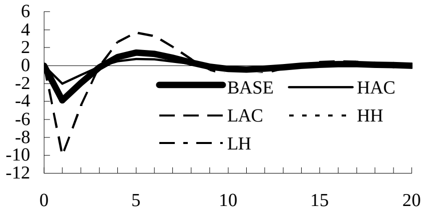


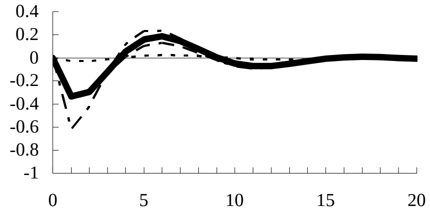
chart 10

DSGE based on Fuhrer and Moore (1995)

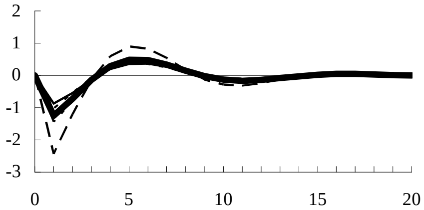
investment



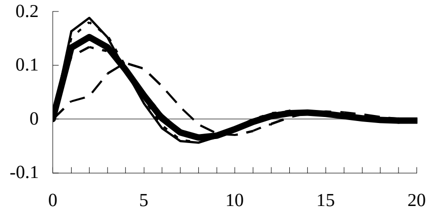
consumption



GDP



call rate



inflation