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Practical Use of Macroeconomic Models at Central Banks

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Macroeconomic models are effective tools for central banks in economic projection, including risk assessment. In recent years, a multiple-model approach called the "Suite of Models" has become popular with central banks. This approach advocates the use of multiple models for several purposes, including checks of the robustness of projections. This idea has encouraged major central banks to use different types of models. These include hybrid-type models, which pursue short-run empirical coherence and long-run theoretical consistency, and Dynamic Stochastic General Equilibrium (DSGE) models, which place greater emphasis on theory. At the Bank of Japan, a new hybrid-type model named Q-JEM (Quarterly-Japanese Economic Model) has been recently added to the Bank's suite of models. A suite of models is useful for forecasting and for policy analysis. The use of models, however, requires sufficient understanding on the properties and limitations of each model.

1. Introduction: Role of Macroeconomic Models at Central Banks

Because of the considerable lag in the effect of monetary policy on an economy, monetary policy is conducted in a forward-looking manner. Hence, economic projections build foundations for decision-making concerning monetary policy.

Central bankers, including the Board members, form their projections based on numerous kinds of information, such as macroeconomic statistics, corporate activity, and developments in financial markets. Macroeconomic models are effective tools in the projection process because they can illustrate economic relationships based on a given framework.

Because macroeconomic models simplify the complex interactions among a huge number of economic variables, no model can perfectly describe reality. But models have advantages, such as: (1) simplification facilitates further understanding of economic mechanisms, (2) models provide a common language for discussion, and (3) models can be used for simulation on different assumptions for risk assessment. In recent years, macroeconomic models have been playing a more significant role in monetary policy conduct, because (1) publishing longer-term forecasts and assessing risks in a well-balanced manner have become more important for central banks attempting to improve communications with the public, and (2) recent advances in economic theory and computer technology have helped those in macroeconomic modeling. In these circumstances, central banks have started to use DSGE (Dynamic Stochastic General Equilibrium) models, which place greater emphasis on theoretical coherence.

Regarding this matter, Chairman Bernanke of the FRB (Board of Governors of the Federal Reserve System) claimed the rising importance of models in his 2007 speech saying that "Indeed, considerable progress has been made in recent years, at the Board and elsewhere, in developing dynamic stochastic general equilibrium (DSGE) models detailed enough for policy application. These models have become increasingly useful for policy analysis for the simulation of alternative scenarios. They are likely to play a more significant role in the forecasting process over time as well, though, like other formal methods, they are unlikely to displace expert judgment." [1]

This article is organized as follows. Section 2 introduces the developments and current uses of macroeconomic models at central banks. Section 3 sheds light on the utilization of models at the Bank of

Japan, and introduces its new model. In Section 4, we revisit limitations on macroeconomic models, and provide future possible directions for model developments.

2. *Use of Macroeconomic Models at Central Banks*

(1) Development of models

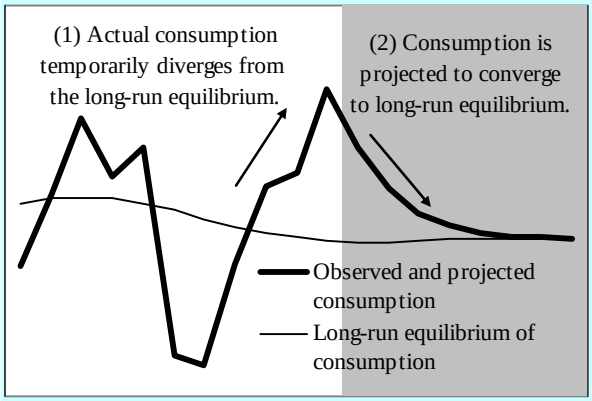
Conventional Keynesian-type large-scale models—which heavily focus on empirical coherence—used to be key tools for macroeconomic analysis at central banks, but ran into strong criticism from academics started in the 1970s.

The critics, represented by the Lucas critique, argue that those models are irrelevant for policy analysis.[2] The Lucas critique points out that observed economic relationships should reflect the rational behavior of households and firms under the policy of that time. Lucas argues that policy changes would affect those relationships through changing each agent's behavior. Hence, to analyze the policy effect, monetary policy authorities should not simply estimate past economic relationships. Rather, they should model expectations and behavior of economic agents based on economic theory.[3] Since then, model developments have been shifted toward more theory-based models.

Error-correction models represent the models developed in the early stages following the Lucas critique. Those models assume that an economy moves along its theory-based equilibrium path in the long-run, while it can deviate from that path in the short-run. The wedge between the data and the equilibrium captures factors that theories cannot explain. In this way, error-correction models contain higher theoretical coherence than conventional Keynesian models do.[4]

Suppose, for example, we model private consumption with the error-correction mechanism. The long-run equilibrium of consumption is generally modeled to depend upon income in accordance with theory. Actual developments in private consumption cannot be fully explained by the theory-based equilibrium and can deviate from the equilibrium in the short-run. It is reasonable that, however, such deviation will eventually diminish; actual consumption will converge to the equilibrium in the long-run. Chart 1 illustrates how private consumption is projected under the error-correction mechanism.

Chart 1 Error-correction mechanism



Note: Shaded area indicates projection period.

Models incorporating the idea of error-correction are often called hybrid-type models, since they combine theory-based dynamics with data-matching properties. The FRB, ECB (European Central Bank), and other major central banks have used hybrid-type models as their main macroeconomic models even in recent years.

Furthermore, central banks have actively developed and started to use DSGE models, which place stress on theoretical coherence even in short-run dynamics.[5]

It has been pointed out that DSGE models would be useful for monetary policy practice as well as for academic research because of their following advantages: (1) their firm theoretical foundations, such as optimization by economic agents, are unlikely to lead to illogical explanation, (2) a decent result can be obtained by using theory even when data is insufficient, and (3) the theory-based models contribute to avoiding the Lucas critique. In addition, monetary economics has significantly progressed over the last decade, partly because of increasing studies in that area by economists at central banks. That has been further stimulating the practical use of DSGE models at central banks in conjunction with improvements in computational power.

Nevertheless, DSGE models have not been playing any dominant role in monetary policy practice in many countries. For instance, a hybrid-type model has remained the main tool at the FRB even recently.

This is because even contemporary DSGE models entail various drawbacks. For example, (1) the theoretical discipline makes it difficult to expand those models to simultaneously analyze key variables such as overseas economies, oil prices, financial variables, and demographic changes, (2) DSGE models partly rely on the theories rejected by empirical studies, since theoretical consistency takes priority,[6] and (3) it is difficult to implement nonlinear relationships among variables into DSGE models.[7]

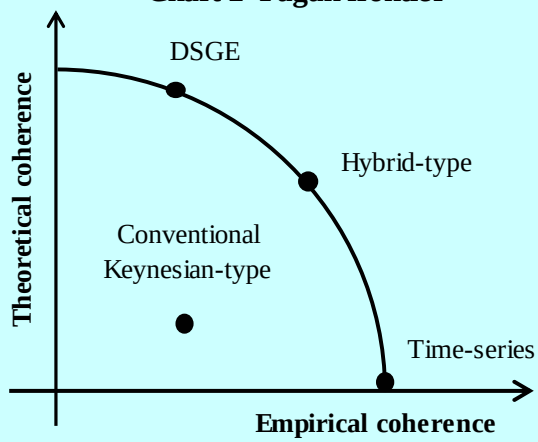
In contrast, hybrid-type models are inferior to DSGE models in theoretical coherence. However, for conducting monetary policy that requires a certain answer within a limited time, the following advantages of hybrid-type models continue to be highly evaluated: (1) models can be modified or enlarged relatively easily according to the problem, (2) various simulations can be done in one model, and (3) they fit well with the data.

(2) Benefits of the use of multiple models

As mentioned earlier, no sole model can answer all questions. Even a DSGE model, which is a symbol of recent model developments, does not sufficiently meet the practical needs at central banks. In this situation, a practical approach is the use of various models that have different characteristics and complement one another. A multiple-model approach called the "Suite of Models" has been recognized as an effective strategy among central banks. A suite of models is used to examine the robustness of projections, and each model in the suite can be also used separately according to purpose. For example, the FRB and ECB own both hybrid-type and DSGE models. This can be interpreted as a sort of suites of models. Moreover, many central banks also use purely statistical time-series models in their suites of models.

Chart 2 illustrates an aspect of the "Suite of Models." The diagram depicts an intrinsic trade-off between theoretical coherence (vertical axis) and empirical coherence (horizontal axis). The curve in the chart, called the Pagan frontier,[8] shows a set of models that can be developed by the current modeling technology. On the current frontier, hybrid-type models locate between DSGE models, on the upper-left, and time-series models including VAR (Vector Auto-Regression) models,[9] on the horizontal axis.

Chart 2 Pagan frontier



Central banks should aim: (1) to improve modeling techniques so that the frontier expands to the upper right hand, and (2) to develop and use a set of different types of models located on the frontier. Furthermore, it is desirable to use multiple models of the same type.[10]

(3) Models and judgments

Although models are efficient tools for projections in monetary policy conduct, they cannot fully describe reality. Hence, shaping projections also benefits from judgments based on expertise. Judgments can provide a broad range of information that models cannot. The balanced use of models and judgments is essential to make projections.

Projections by central banks consist of the following two parts: (1) the main scenario, and (2) risk assessment (analyzing alternative scenarios, etc).

Either of the following two strategies is generally employed for balancing models against judgments when the main scenario is constructed. The first strategy relies only on judgments. Model forecasts are compared with the main scenario to check its relevance. The second strategy is that model forecast constitutes a preliminary version of the main scenario. Judgments are used to modify this version to make the final version. By relying on either of these approaches, central banks utilize both models and judgments. Near-term forecasts place greater stress on judgments, whereas mid- to long-term forecasts are

more likely to depend on models.[11]

Central banks also utilize both models and judgments in risk assessment, while models play a more significant role than they do in constructing the main scenario. An example of risk assessment is to forecast under a specific scenario such as a further slowdown in overseas economies. In this case, models make forecasts under a set of alternative assumptions determined by judgments based on past similar events. Another example is to use fan charts, which depict a range of possible paths of future economic developments. Models compute these paths by referring to past average fluctuations in the economy. Taking the model-based fan charts as a benchmark, judgments characterize the current uncertainty by examining how it differs from that in the past and whether upward or downward risk is larger.

3. Utilization of Macroeconomic Models at the Bank of Japan and "Q-JEM"[12]

(1) Model developments at the Bank of Japan

At the Bank of Japan, macroeconomic models are used for various purposes of analysis. One example is the contribution to the *Outlook for Economic Activity and Prices* (Outlook Report).

The Bank of Japan has been enhancing transparency. Since October 2000, the Bank has been releasing the Outlook Report biannually in April and October. The Outlook Report contains an economic outlook and risk assessments as well as the figures of the Policy Board members' forecast regarding GDP growth rates and inflation rates. Since the April 2008 Outlook Report, the Bank has provided Risk Balance Charts, which depict the Policy Board member's views on uncertainty around the outlook in the Outlook Report. Since July 2008, the Bank has released the forecast figures and the Risk Balance Charts also in January and July, at the time of interim evaluation of the Outlook Report.[13]

When making their projections, the Board members receive a bulk of information on the domestic and overseas economies, developments in financial markets, and financial institutions' activity from the staff. Departments of the Bank provide different types of information defined by their responsibility within the Bank. For example, the Research and Statistics Department reports its projections on domestic economic activity and prices. The main and risk scenarios prepared by the staff are indispensable for the Board members to formulate and quantify their own views.[14]

The Bank of Japan's macroeconomic models are used both in the process of the staff projection and in that of the Board members' outlook. In the staff projection process, the staff uses its models to check the relevance of their main scenario and evaluate risks surrounding it. In the process of the Board's outlook, the staff uses its models to produce forecasts under alternative assumptions upon request of the Policy Board members. For instance, a Board member who has his/her own views on overseas economies and oil prices may request model simulations based on such views. These model simulations facilitate the discussion between the Board and the staff.

At the early stage of its long history of model development, the Bank of Japan employed conventional Keynesian models. For example, the Bank published a paper on its Keynesian model in 1972, which substantially incorporated the role of monetary factors.[15]

In recent years, the Bank of Japan has constructed various types of models to refine its "Suite of Models." The Suite covers a broad range of models including theory-based DSGE models and empirically coherent models. JEM (Japanese Economic Model), developed in 2003, is one of the Bank's DSGE models. JEM has contributed to policy analysis at the Bank, part of which has been published in several papers.[16] Several DSGE models have been developed at the Bank after JEM, with recent advances in economic theory. Many studies using those models have been published in the Bank of Japan Working Paper Series and academic journals.[17] As for more empirically coherent large models, the Bank of Japan has recently developed a hybrid-type model named Q-JEM (Quarterly-Japanese Economic Model). We provide an overview of Q-JEM below.

(2) Overview of Q-JEM

Q-JEM, like other hybrid-type models, is designed

to describe the error-correction of the Japanese economy converging toward its long-run equilibrium determined based on economic theory. The hybrid structure of this model can contribute to stabilizing long-term projections and capture short-term fluctuations. Hence, Q-JEM can provide relatively realistic projections over both short-term and long-term horizons.

Q-JEM is a large-scale model with approximately 200 equations, among which about 70 are estimated. It has key variables to analyze recent economic developments such as overseas economies, crude oil prices, and financial variables. Q-JEM explicitly models monetary policy and private sector expectations. The monetary policy in this model depends on a rule that employs the call rate as the policy instrument, and responds to the output gap and CPI inflation rates. At the same time, the private sector in Q-JEM predicts future monetary policy based on this rule. These expectations influence the current economy mainly by changing long-term interest rates (see BOX). Having these characteristics, Q-JEM can be used for various purposes. Next we will introduce how Q-JEM describes the economy with examples of real investment by firms and private consumption.

Investment by firms

The theoretically coherent long-run equilibrium of real investment by firms is defined using real GDP, potential growth rates, the relative price of capital goods to produced goods (business fixed investment deflator / GDP deflator), and real lending rates. Real GDP and potential growth rates correspond to demand for goods produced by using the invested goods, and the expectations for its trend, respectively. On the other hand, the relative price of capital goods and real lending rates correspond to the profitability of the investment.

Q-JEM formulates the short-run dynamics of the investment by firms on a more empirical basis. In detail, it depends on the lending attitude DI, exports, and the error-correction process to the long-run equilibrium. The lending attitude DI captures the financial environment. Exports capture volatile developments in private investment of the manufacturing sector, which exports actively. With this property, Q-JEM expresses impacts of overseas economies and foreign exchange rates on domestic investment, since exports are modeled to depend on these variables.

Private consumption

The long-run equilibrium of private consumption depends mainly on disposable income, financial assets/liabilities, potential growth rates, and the ratio of the elderly. The first two correspond to consumers' purchasing power, and potential growth rates to its trend. Here, we impose the theoretical constraint that private consumption and disposable income share a trend in the long-run. The ratio of the elderly is used so that the propensity to consume rises along with population aging as the lifecycle hypothesis suggests. The short-run dynamics of private consumption are mainly explained by the error-correction process, since private consumption fluctuates less in the short-run.

Impulse responses of the economy demonstrate how far economic variables diverge from the main scenario after a shock occurs. These are helpful to understand the properties of Q-JEM. Chart 3 illustrates impulse responses to two types of shocks: a temporary slowdown in overseas economies, and a fall in crude oil prices.

A temporary slowdown in overseas economies[18] leads to the following three results shown as solid lines in Chart 3: (1) exports decline due to the slowdown in overseas economies and the subsequent yen's appreciation, and this reduces GDP both directly and indirectly through declined business fixed investment; (2) CPI inflation rates decline as the output gap worsens and import prices fall because of the yen's appreciation; and (3) expectations of lower call rates based on the policy rule lead to an earlier decrease in long-term interest rates.[19]

A fall in crude oil prices[20] leads to the following three results, shown as broken lines in Chart 3: (1) GDP increases as the shock stimulates domestic demand such as private consumption through increasing real purchasing power; (2) CPI inflation initially declines because a fall in energy prices dominates in the short-run, but eventually rises as the output gap improves; and (3) long-term interest rates

BOX: Expectations and the Monetary Policy Rule in Q-JEM

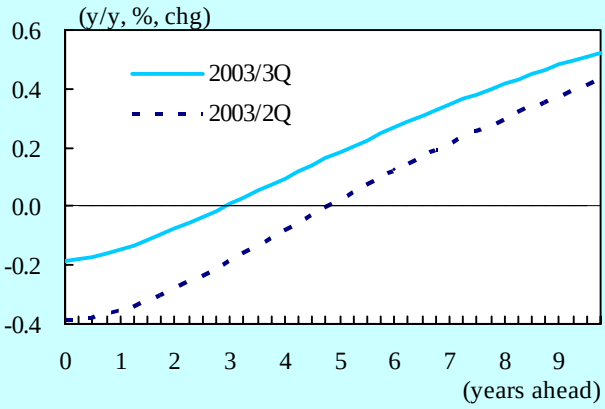
For macroeconomic analysis, it is quite important to consider how expectations influence an economy. Even if monetary policy is unchanged, changes in expectations of future events influence the current economy, for instance, through long-term interest rates and asset prices. Q-JEM explicitly takes this mechanism into account. To be specific, this model incorporates expectations of the future output gap, CPI inflation, and call rate (note 1). Expectations of the future call rate are formed on the basis of those of the future inflation and output gap with a monetary policy rule.

A detailed example of the significant role of expectations would be the upsurge in long-term interest rates in 2003/Q3. In 2003/Q2, the call rate was fixed at about zero percent, the inflation rate was -0.4 percent, and the output gap was far below zero. This situation contributed to maintaining low expected levels of future call rates. Under these circumstances, long-term interest rates were historically low. In 2003/Q3, however, a shift in the inflation rate from -0.4 to -0.2 percent caused bond market participants to expect sooner ends of deflation and the zero interest rate. The changes in expectations resulted in a rise in long-term interest rates, although the call rate was unchanged.

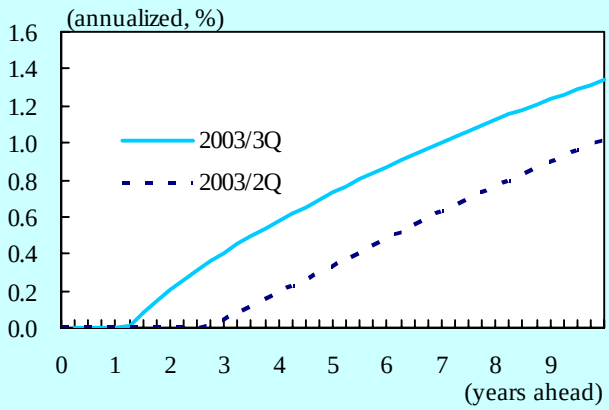
Q-JEM can illustrate how expectations had changed over these periods. According to its estimation, in 2003/Q2 the call rate was expected to be zero for two and a half years, as shown in the right panel of BOX Chart. As a result, an average of expected future call rates up to ten years ahead registered only about 0.4 percent, which contributed to maintaining low long-term interest rates. In 2003/Q3, the expected duration of the zero interest rate was reduced to just over one year. Accordingly, long-term interest rates rose (notes 2 and 3).

BOX CHART: Future inflation rates and overnight call rates expected by private sector

(1) Inflation rate



(2) Overnight call rate



Notes: 1. In Q-JEM, the private sector forms its expectations of inflation and output gap simply by estimating the relationship between these variables. Therefore, private expectations in this model are not necessarily equal to the Q-JEM's forecasts based on its complex structure. This type of expectations is known as adaptive expectations in economics. On the other hand, expectations that equal the model's forecast are known as rational expectations. The FRB's hybrid-type model FRB/US can be used with alternative assumptions of these two types of expectations. Implementing rational expectations into Q-JEM remains one of our future works.

2. The article below points out that a fall in long-term interest rates in the first half of 2003 and their subsequent upsurge basically reflected changes in the outlook for Japan's economy.

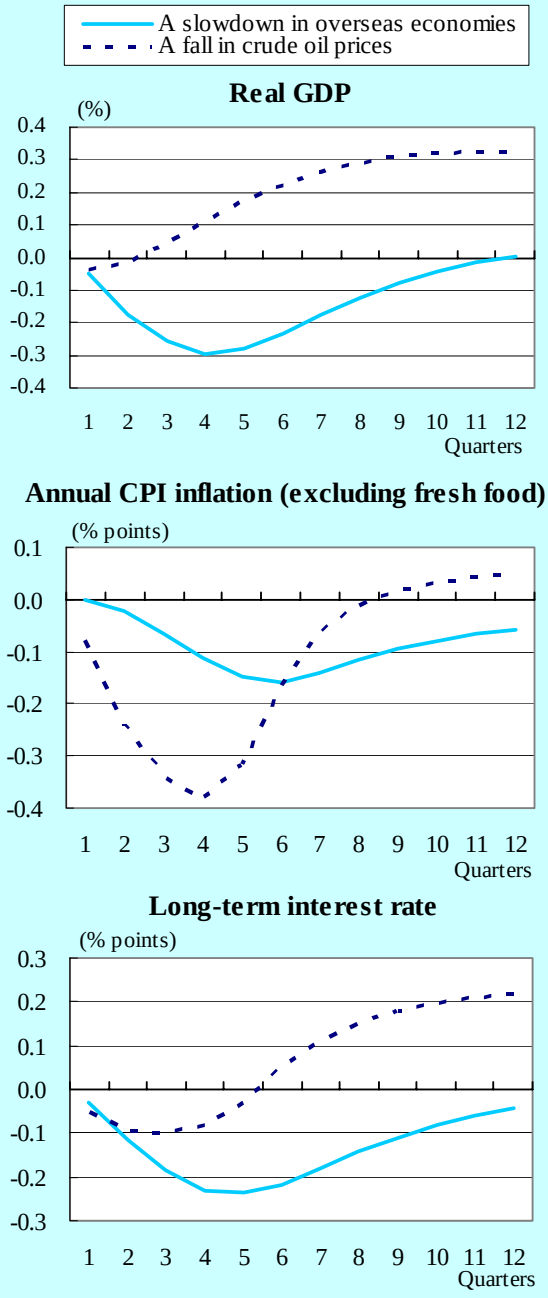
Takashi Nakayama, Naohiko Baba, and Tatsushi Kurihara (2004), "Price Developments of Japanese Government Bonds in 2003," *Bank of Japan, Market Review E-Series* 2004-E-2.

3. The following paper estimates the term structure model of interest rates taking account of the zero interest rate bound. This paper reports that, from 2003/Q2 through Q3, the expected duration of the zero interest rate was reduced to around 1.4 years from about 2.1 years.

Hibiki Ichiue and Yoichi Ueno (2007), "Equilibrium Interest Rate and the Yield Curve in a Low Interest Rate Environment," *Bank of Japan Working Paper Series* 2007-E-18.

marginally decline at the early stage reflecting an initial fall in inflation, and then turn upward, slightly ahead of the increases in the GDP and CPI inflation.[21]

Chart 3 Response to different types of shocks



4. Conclusion

We have overviewed the recent developments and current use of macroeconomic models at central banks. Hybrid-type models have been widely employed for economic projections, and DSGE models have started to be used at many central banks. The idea of the "Suite of Models," which advocates a harmonious use of multiple models for analysis, has become more popular. The Bank of Japan is not an exception; the Bank has developed various types of macroeconomic models according to the purpose of analysis. The Bank has recently developed a new hybrid-type model, "Q-JEM," introduced in Section 3.

Revisiting the role and usefulness of macroeconomic models, we suggest the following three main advantages: (1) models can facilitate understanding on the economic mechanism by reducing the number of complex interactions among economic variables to a simplified system; (2) such simplification can provide a common basis for discussion; and (3) models can be easily adapted to carry out risk simulation.

It is important to note that every model has its own advantages and disadvantages because models necessarily simplify reality—which is complex far beyond what any model can describe—by imposing certain assumptions. There are four key points on using models at central banks. First, multiple models should be used to compare results and to check robustness. Second, the results of models should be regarded as one of many interpretations of the actual economy, rather than as an absolute one. Third, using models requires deep understanding about each model's concept, structure, properties, and limitations. Finally, it is indispensable to constantly make efforts on model improvements that reflect new practical issues, developments in economics, and an accumulation of empirical research.[22]

The models used by central banks today leave many questions unanswered. One example is how to implement the financial sector into macroeconomic models. The recent turmoil in financial markets has been motivating more researchers to model interaction between the financial system and the real economy via asset prices. Nevertheless, no model is fully ready for practical use at the current stage.[23] Another example is how to model economic agents. The mainstream at present is a model called the representative household model which assumes the homogeneity of economic agents. However, we actually observe the heterogeneity of economic agents, for instance, the coexistence of workers and the unemployed. Because the majority of models currently used do not incorporate that heterogeneity,

central banks lack tools to analyze how the heterogeneity of economic agents influences the economy.[24] Further research on these issues is desirable.

Finally, we would like to make a few remarks on the future directions of model developments in Japan. To date, a large part of research using DSGE models is based on U.S. data. This means that, including academic work, there are only a limited number of DSGE models that capture characteristics unique to the Japanese economy. The construction of DSGE models at the Bank of Japan substantially relies on preceding research describing the U.S. economy.

While economic globalization has progressed, each country has its own economic structure and unique behavioral patterns of economic agents. Japan has encountered unusual situations such as the bubble and the subsequent lost decade, a range of large-scale fiscal stimulus packages, zero-interest rates, and the rapid and ongoing population aging. Although macroeconomic models that properly explain Japan's experience are difficult to construct, they are indispensable to analyze the Japanese economy. It cannot be successful without the further accumulation of high-quality research based on Japanese data.

Importing the idea of the most-advanced research from abroad helps to model the Japanese economy. It is also important to constantly examine the relevance of its application to Japan, and modify the idea if necessary. Using reliable statistics should be among top priorities for more accurate empirical studies. Further progress in Japanese economic statistics is also desirable.[25]

Q-JEM was developed with the help of Satoshi Ito, Takushi Kurozumi, and Takeki Sunakawa, especially at the early stage. We thank Chikako Wakasa for her help with the English translation.

[1] Ben S. Bernanke (2007), "Inflation Expectations and Inflation Forecasting," Remarks at the Monetary Economics Workshop of the National Bureau of Economic Research Summer Institute, Cambridge, Massachusetts (from the FRB website).

[2] The Lucas critique was introduced in the following paper:

Robert E. Lucas Jr. (1976), "Econometric Policy Evaluation: A Critique," in K. Brunner and A. H. Meltzer eds., *The Phillips Curve and Labor Markets*, Amsterdam: North Holland, pp. 19-46.

[3] This does not argue that any theoretical model works. Rather, only models that properly capture the actual economy are relevant for policy analysis.

[4] See the following paper for error correction models:

Tomoo Yoshida (1990), "On the Stability of the Japanese Money Demand Function: Estimation Results Using the Error Correction Model, " *Monetary and Economic Studies* Vol. 8 No. 1, January 1990, pp. 1-48.

[5] The FRB introduced a hybrid-type model "FRB/US" as the main model in 1996, and a DSGE model "FRB/EDO" as a supplementary model recently. Meanwhile, the ECB has regularly used a hybrid-type model "AWM" in forecasting and simulation tasks. The ECB also uses several DSGE models in accordance with the intended use.

[6] For instance, open economy models generally assume the theory "uncovered interest parity" on foreign exchange rates. This theory projects the depreciation of high interest currencies, but a large number of empirical studies reject its validity at least for near-term projections up to one year ahead.

[7] Fixed gasoline excise is a good example of generating a nonlinear relationship in an economy. As gasoline excise is set at about 50 yen per liter in Japan, a rise in crude oil prices reduces the ratio of fixed gasoline excise to gasoline prices. Consequently, it increases the elasticity of gasoline prices to crude oil prices, because a larger part of gasoline prices becomes elastic to crude oil prices. This changeable elasticity is important to analyze the Japanese CPI, while it is difficult to incorporate this nonlinearity into a standard DSGE model.

[8] See the following paper for the Pagan frontier:

Adrian Pagan (2003), "Report on Modelling and Forecasting at the Bank of England," *Bank of England Quarterly Bulletin*, Spring, pp. 60-88.

[9] The VAR model is frequently used for macroeconomic research and practical analyses. However, the VAR model is less satisfactory for central banks monitoring a wide range of dataset, since it cannot handle many variables at once. To overcome this shortcoming, the FAVAR (Factor-Augmented VAR) model has been developed, which enables analysis using many variables simultaneously.

[10] To develop a variety of useful models, a large number of highly skilled staff is indispensable. In fact, major central banks have recruited many economists with PhDs and have come to possess their suites of models.

[11] The following speech simply explains the roles of models and judgments at the FRB as well as their interactions:

Laurence H. Meyer (1997), "The Role for Structural Macroeconomic Models," Remarks at the AEA Panel on Monetary and Fiscal Policy, New Orleans, Louisiana (from the FRB website).

[12] Details on Q-JEM will be released in a separate paper.

[13] For reference, see the following article for central banks' strategies regarding uncertainty around their economic outlook including the Bank of Japan's Risk Balance Chart:

Koji Nakamura and Shinichiro Nagae (2008), "The Uncertainty of the Economic Outlook and Central Banks' Communications," *Bank of Japan Review*, 2008-E-1.

[14] The following speech is useful to gain an insight of the preparation process of forecast figures by the Bank of Japan's Policy Board members:

Sakuya Fujiwara (2000), "'*Bukka no Antei' ni tsuite kangaeru* (thinking about price stability; available in

Japanese only)—speech given by Sakuya Fujiwara, Deputy Governor of the Bank of Japan, at the Chunichi meeting held on November 8, 2000" (from the BOJ website).

[15] Research Department and Statistics Department, Bank of Japan (1972), "*Nihonginkou keiryokeizai moderu—sono shiten to kousei—*" (Bank of Japan econometric model; available in Japanese only), *Chousa geppou*, September 1972 issue, 1-38.

[16] Ippei Fujiwara, Naoko Hara, Yasuo Hirose and Yuki Teranishi (2005), "The Japanese Economic Model (JEM), " *Monetary and Economic Studies* 23 (2), pp. 61-142

[17] For an example, see the following paper:

Tomohiro Sugo and Kozo Ueda (2008), "Estimating a Dynamic Stochastic General Equilibrium Model for Japan," *Journal of the Japanese and International Economies* 22(4), pp. 476-502.

[18] The size of shock is determined based on one standard error calculated from past data. Here, a shock is given so that the annualized growth rate of overseas economy recovers gradually after having dropped by about 1.5 percent in the initial quarter.

[19] As seen in past movements of the overnight call rate, central banks usually do not rapidly change the policy interest rate in response to changes in the output gap and inflation. It is pointed out that such moderate adjustments in monetary policy are aimed at avoiding unnecessary fluctuations in financial markets caused by rapid changes in short-term interest rates, and while maintaining its effect on the economy via long-term interest rates, which reflect the expectations for future developments in short-term interest rates.

[20] This simulation assumes a decrease in crude oil prices by one standard error of past fluctuations. Crude oil prices drop by about 11 percent in the initial quarter and subsequently fall at a slower pace. They finally reach a level of about 14 percent lower than the main scenario.

[21] In this simulation, inflation expectations are assumed to be formed based on the inflation rate of CPI, which excludes fresh food but includes energy. Thus, a drop in crude oil prices decreases the CPI inflation of this definition, the inflation expectations and long-term interest rates. However, if inflation expectations are assumed to be formed based on the CPI excluding food and energy, the initial fall in long-term interest rates will be mitigated, since inflation expectations do not directly respond to energy prices. This example shows that simulation results produced by a model may differ under different assumptions. Thus, on interpreting the results computed by a model, it is important to know which assumptions contribute to these results.

[22] According to the following paper, the FRB has modified numerous parts in FRB/US every year since its introduction in 1996.

Robert J. Tetlow and Brian Ironside (2007), "Real-time Model Uncertainty in the United States: The Fed, 1996-2003," *Journal of Money, Credit, and Banking* 39 (7), pp. 1533-1561.

[23] At a panel discussion at the 2008 International Conference organized by the Institute for Monetary and Economic Studies of the Bank of Japan, Professor Christiano of Northwestern University stated that "the current financial turmoil in the United States was going to place financial frictions front and center on everyone's research agenda for at least a decade." Details on this conference are available in the paper below:

Ippei Fujiwara, Kazuo Fukuda, Ichiro Muto, Yosuke Shigemi, and Wataru Takahashi (2008), "Frontiers in Monetary Theory and Policy: Summary of the 2008 International Conference Organized by the Institute for Monetary and Economic Studies of the Bank of Japan," *IMES Discussion Paper Series* 2008-E-18.

In a recent speech, Vice Chairman Kohn of the FRB indicated that contemporary macroeconomic models cannot capture recent economic developments, including those in risk premium. He expresses that economists at central banks and in academia will head to devote much effort to overcoming these deficiencies in coming years:

Donald L. Kohn (2008), "Productivity and Innovation in Financial Services," Speech at the Official Celebration of the 10th Anniversary of the Banque Centrale du Luxembourg, Luxembourg, Luxembourg (from the FRB website).

[24] Standard DSGE models assume the homogeneity of households to simplify household behavior. In these models, no household is unemployed and firms adjust labor input not by number of workers but by hours worked. With recent advances in modeling technology, DSGE models incorporating unemployment have become more popular at central banks. In these models, firms also adjust labor input by the number of workers, as observed in the actual economy. See the following paper for an application of such models to Japan:

Hibiki Ichiue, Takushi Kurozumi and Takeki Sunakawa (2008), "Inflation Dynamics and Labor Adjustment in Japan: A Bayesian DSGE Approach," *Bank of Japan Working Paper Series*, 2008-E-9.

[25] In Japan, official statistics will be substantially revised under the new Statistics Law to be enforced in April 2009. Studies on such statistics revisions have pointed out that these revisions significantly change the perception of economic activity. This type of study is called real-time data analysis, which uses a range of data series available at the time of each release in the past (real-time data). This type of analysis includes an assessment of out-of-sample performance of a model forecast using real-time data. Real-time analysis has been active in the United States and Europe, where large real-time data sets have been open to the public. Collecting and using real-time data for Japan will also improve research on the Japanese economy.

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