DSGE Models and Their Use in Monetary Policy*

BY MICHAEL DOTSEY

The past 10 years or so have seen the development of a new class of models that are proving useful for monetary policy: dynamic stochastic general equilibrium (DSGE) models. Many central banks around the world, including the Swedish central bank, the European Central Bank, the Norwegian central bank, and the Federal Reserve, use these models in formulating monetary policy. In this article, Mike Dotsey discusses the major features of DSGE models and why these models are useful to monetary policymakers. He outlines the general way in which they are used in conjunction with other tools commonly employed by monetary policymakers and points out the promise of using these models as well as the pitfalls.

The past 10 years or so have witnessed the development of a new class of models that are proving useful for monetary policy: dynamic stochastic general equilibrium (DSGE) models. The pioneering central bank, in terms of using these models in the formulation of monetary policy, is the Sveriges Riksbank, the central bank of Sweden.[1] Following in the Riksbank's footsteps, a number of other central banks have incorporated DSGE models into the monetary policy process, among them the European Central Bank, the Norge Bank (Norwegian central bank), and the Federal Reserve.[2]

This article will discuss the major features of DSGE models and why these models are useful to monetary policymakers. It will indicate the general way in which they are used in conjunction with other tools commonly employed by monetary policymakers. These other tools include purely statistical models, often not tied to any particular economic theory, but instead are solely based on historical regularities found in the data. Such tools also include large macroeconomic models that contain many sectors of the economy but generally do not place many theoretical restrictions on the interrelationships between the various economic sectors. Other tools include economic surveys of consumers, firms, or forecasters, as well as policymakers' own expertise.

These other tools provide valuable insights into the state of the economy that complement the insights derived from explicit theoretical models, which account for important interactions between sectors of the economy. Together, the various modeling approaches comprise the toolkit that policymakers commonly rely on. This article will concentrate on DSGE models, which share the strengths of many theoretically grounded models but are designed with the intention of providing forecasts and identifying the key drivers of current economic activity. In doing so, I will point out the promise of this modeling strategy as well as its pitfalls.

Economic models, in general, provide valuable guidance when formulating monetary policy. Because the economy is so complex and key economic components are intertwined, it is necessary to develop frameworks that capture these interrelationships. In order to capture, say, the effect that an increase in productivity has on consumption, we must have a model that incorporates the behavior of many

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[1] See the article by Malin Adolfson and coauthors.

[2] Examples of these models can be found in Smets and coauthors; Bruback and Sveen; and Chung, Kiley, and Laforte.

*The views expressed here are those of the author and do not necessarily represent the views of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.

variables, such as income, investment, labor supply, and consumption, if we are to understand this effect. Simply looking at one equation that attempts to only model consumption is likely to produce an incomplete and misleading interpretation. Thus, a model that integrates many economic components is necessary for understanding and predicting economic behavior.

However, because all models are approximations of actual economic behavior, it is often useful to combine the insights from a number of models along with statistical forecasts and the individual experience of policymakers. That is generally what many central banks do, and DSGE models are increasingly becoming a part of policymakers' toolkits.

AN OVERVIEW OF DSGE MODELS

DSGE models are small to medium size economic models that incorporate the major sectors of the economy into a coherent and interrelated whole. They are general equilibrium in nature, meaning that prices and interest rates adjust until supply equals demand in every market. In particular, the demand for goods equals the supply of goods, the demand for assets equals the supply of assets, and the demand for labor equals the supply of labor.

Further, these models include a private sector composed of households and firms, as well as a public sector made up of a government fiscal authority and a central bank. A distinguishing feature of these models is that consumers and firms in the model make decisions that maximize welfare and profits, respectively. Individuals make decisions about consumption and labor supply that maximize their economic well-being subject to constraints based on their wealth. For instance, individuals in the model cannot consume more than they can afford. Firms set prices that maximize profits and demand factors of production, such as labor and capital, in ways that minimize their costs. This depiction of behavior places restrictions on the actions of firms, households, and the government in the model, and the validity of these restrictions can be formally tested. Doing so allows model builders a way of analyzing the strengths and weaknesses of the underlying theory. Model restrictions that are not consistent with economic data indicate a weakness that calls for further development of the model. When various restrictions are consistent with the data, we can have more confidence in the model. It is safe to say that no model has been developed that is consistent with all features of the actual economy, but great strides have been made, and the underlying methodology incorporated into the development of these models makes further improvements likely.

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The models are also stochastic, meaning that they incorporate the random components that play an important role in explaining the cyclical behavior of the economy. Common disturbances include shocks that change consumer demand, shocks that influence the behavior of financial markets, and changes in economic productivity that affect the efficiency of production. What is key to the DSGE paradigm is that these shocks can be estimated as can the proportions of changes in economic activity that are due to a particular disturbance. For instance, we may ask what part of the latest recession was due to financial shocks as opposed to changes in productivity or fiscal policy shocks. The restrictions imposed on the model's economic structure imply that each of these types of shocks has very different implications for the economic predictions of the model, and the estimation of the model places weights on each type of disturbance that allows the model to fit the data as best as possible.

Finally, the models are inherently dynamic. Current behavior does not depend only on the current economic climate but also on anticipation of what the future holds. For example, firms' hiring and investment decisions depend on whether they believe that economic demand will be weak or strong in the future, not just on current demand conditions. This dynamism implies that expectations of the future play an important role, and although such an assumption is not required, most DSGE models assume that the actors in the model — individuals and firms — form expectations that are consistent with the underlying theoretical framework of the model. This does not imply that households and firms perfectly anticipate future outcomes but that, on average, they do not make systematic errors. This type of expectations formation is referred to as "rational expectations," and it is a common feature of a broad set of economic models.

Combining these ingredients — the use of explicit maximizing behavior that is also dynamic in nature and forward-looking rational expectations — makes the output of DSGE models, whether that output is an economic forecast, the results of a policy experiment, or the analysis of the sources of economic fluctuations, readily interpretable in terms of economic theory.

Thus, DSGE models paint a coherent picture with respect to a host of issues that are of interest to policymakers.

MAKING THE MODELS OPERATIONAL

All of the relationships that govern the economic behavior of any DSGE model include parameters, and these parameters must be assigned values before the model can be used. For instance, we need to know how much individuals value current consumption relative to future consumption in order to understand their consumption and saving decisions. The parameter that governs that aspect of behavior is called a discount factor, and it must be given a specific value. Also, we need to understand the costs associated with a firm's adjustment of its capital stock if we are to understand investment behavior, and there are parameters that govern the magnitude of these costs. They too must be either calibrated or estimated. Generally, the models are estimated using historical data because it is not obvious what the appropriate values of many of the parameters are. Furthermore, estimation allows us to establish the uncertainty surrounding any particular parameter value. That, in turn, allows us to better understand the uncertainty inherent in the predictions of the model. Thus, all the mathematical relationships that govern the economic behavior of any DSGE model include parameters that require estimation.

Usually, the estimation is done using a methodology called Bayesian statistics, which allows the user to incorporate prior knowledge of the economy. For example, this information may come from microeconomic studies and thus may contain information that is not formally part of the model but is nonetheless useful for gauging the likely value of the model's parameters. For example, microeconomic evidence on how frequently firms adjust their prices is helpful information in estimating the price-setting parameters of the typical DSGE model.

Estimation also pays dividends. One outgrowth of statistical estimation is that it allows us to characterize the data uncertainty surrounding the parameter estimates. Are we fairly certain of a given parameter's value, or could that parameter take values that span a wide range? The estimation also allows us to capture the uncertainty surrounding the economic forecasts, as well as the uncertainty surrounding the results regarding the likely consequences of using an alternative monetary policy.

Further, using a number of different models allows economists and policymakers to ascertain the extent of model uncertainty, which involves the uncertainty that arises because all economic models are approximations of behavior, and no model accurately captures all facets of economic activity. Thus, different models analyzing the same question will come up with different implications, and as a result, there is uncertainty about those implications. Along with this type of uncertainty, there is uncertainty that characterizes each particular model because the parameters of each model are estimated and not known exactly. Economists are, in general, more uncertain about their models than they are about the parameters of any particular model, making the degree of model uncertainty an important property for policymakers to understand in using economic models for informing particular policy actions.

Therefore, it is useful to look at the implications of a number of models in order to compare the performance of different theories and evaluate which particular ways of thinking about the economy lead to a better understanding of actual behavior. Thus, examining model uncertainty is an important part of analyzing the output of DSGE exercises, since like all economic models, DSGE models are, to some extent, misspecified. Comparing the output of many DSGE models sheds light on the confidence we have in any particular implication of the models as a whole. Hence, looking at a number of different models helps policymakers assess the risk of any particular viewpoint based on a particular model. As indicated in the June 2011 minutes of the Federal Open Market Committee meeting, DSGE models are being studied by staff members at the Board of Governors and at the Federal Reserve Banks of Chicago, New York, and Philadelphia. If models that differ along various dimensions all point to the same conclusion, the policymaker can be more reassured about the outcome of a particular decision.

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A MORE DETAILED DEPICTION OF A BASIC MODEL

The structure of a basic DSGE, namely, the model developed by staff members at the Federal Reserve Bank of Philadelphia, is displayed in the figure.[3] The model is nicknamed PRISM, which stands for Philadelphia Research Intertemporal Stochastic Model. As is true of much of the DSGE modeling framework, the foundations are based on New Keynesian economics, which explicitly models various forms of price and wage rigidity thought to be an integral part of a modern economy's structure. The firms in PRISM employ workers and rent capital in order to produce goods, and they do so in a manner that minimizes the cost of producing output. Production is also subject to productivity shocks. Firms also enjoy some monopoly or pricing power, and they set prices in order to maximize profits over time. The price of each good is adjusted at randomly selected intervals, with only a subset of firms adjusting their prices at any point in time.[4] Thus, the price level is sticky, which means that it does not adjust instantaneously to economic disturbances. The particular pricing behavior that maximizes economic profits over time is one in which firms reset their prices as a markup over a weighted average of current and future marginal costs. Price rigidities are an important feature of the model and are an important element in aligning the model with the data.

While the production function, which indicates the amount of output that can be produced by combining labor and capital, can be viewed as unaffected by changes in monetary policy — independent of the level of interest rates, the same amount of machines and workers produce the same amount of output — it is questionable whether the price-setting mechanism enjoys that property. For example, as inflation changes, we would expect the frequency with which prices are changed to vary as well, but this behavior is not part of the theoretical pricing mechanism in the model.

Along with a productivity shock, firms' decisions are influenced by shocks to the markup of price over marginal cost. We may think of this type of shock as a random variation in a firm's market power, perhaps influenced by the random inflow and outflow of the number of competing firms.

Households in the model own the firms and the capital stock. They choose how much to consume and invest as well as how much labor to supply. Importantly, the function that specifies how consumption is valued involves habit persistence, meaning that consumers value their current level of consumption relative to previous levels of consumption. This implies that consumers value a given level of consumption differently depending on whether that level was less than or greater than the amount of consumption they experienced in the past. If that level of consumption corresponds to a relatively high amount, then the consumer is happier than if it corresponds to a relatively low amount. This aspect of behavior turns out to be a relatively important ingredient for the model's ability to generate the type of economic persistence that is typically found in U.S. economic data.

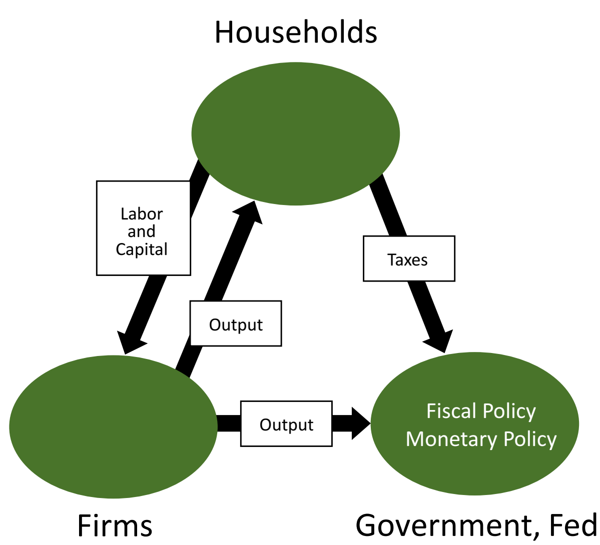
Unlike the choice of consumption, which is fairly standard, the labor supply decision in PRISM is much different than is typically used in basic real business cycle models. These models view labor markets as purely competitive, but in PRISM and most DSGE models, households are viewed as being able to influence wages in much the same fashion that firms set

[3] The features described are fairly similar across first-generation DSGE models. Current model development has proceeded along a number of lines, of which the most important are the addition of more sophisticated financial markets and more detailed depictions of labor markets using search theory. In terms of models employed at various central banks, the model developed by the Federal Reserve Bank of New York and one of the models used by the European Central Bank include separate financial sectors.

[4] This framework is based on Calvo.

FIGURE

PRISM



prices. They then supply all the labor demanded by firms at that wage. As is the case with prices, only a subset of wages is adjusted in any period, and the average wage is thus sticky.

The evolution of the capital stock is also determined by households' investment decisions, and the accumulation of capital is subject to adjustment costs such as those that accompany the installation of new equipment. These costs are also random and affect the efficiency of investment. The more costs associated with adjusting the capital stock, the less new capital is obtained from any particular level of investment. This shock can be given a financial interpretation (see the article by Alejandro Justiniano, Giorgio Primiceri, and Andrea Tambalotti). In particular, when the financial system is not operating efficiently, it is more difficult for firms to purchase investment goods, and the allocation of investment also becomes less efficient. The authors show that a shock to the efficiency with which firms transform investment into increases in the stock of capital is highly negatively correlated with the interest premiums charged to firms, and these premiums are related to financial constraints.

Another common random disturbance that influences households' decisions involves shocks to the rate of time preference. This shock affects the degree to which households are willing to sacrifice current consumption and thereby increase saving, which then allows the household to consume more in the future. As a result, shocks to the rate of time preference can be important in generating differential growth patterns in consumption and investment. Shocks to the value of leisure (which affect labor supply) are also featured in PRISM and most DSGE models. Shocks to leisure are intended to capture any imperfections in labor markets beyond those involving wage rigidity.[5]

As is true with most current DSGE models, PRISM contains a nonproductive government sector that consumes resources, but that is generally the extent to which fiscal policy is incorporated into the model. Monetary policy is modeled as a simple Taylor rule in which interest rates respond to inflation relative to target, an output gap, and the past setting of the interest rate. The output gap in PRISM is the difference between current output and the output that would occur in the absence of any economic disturbances. That is, it is the difference between current output and its trend. In this regard, we find differences across various DSGE models, with some going so far as to construct gaps based on statistical procedures similar to those employed in actual statistical measures of the gap.[6] The Taylor rule also specifies a gradual adjustment of policy to movements in inflation and the gap and is also subject to a random disturbance to monetary policy. In reality, the conduct of monetary policy is more nuanced than the behavior specified in the Taylor rule, with policymakers reacting to more than just output and inflation. The shock reflects these deviations of actual policy from the Taylor rule.

Model development is ongoing, and although many models, including those being studied by staff at various Reserve Banks and the Board, share most of the above features, they do differ along many dimensions. Thus, the field of DSGE modeling provides a rich set of models, which unsurprisingly often present different interpretations of economic events.

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USES OF THE MODELS IN MONETARY POLICY

Once a DSGE model is estimated, it can be used to provide economic forecasts and to identify the disturbances that are driving the forecast. All central banks find it important to forecast economic activity when arriving at a policy decision, and to that extent, these models provide another forecasting platform. Regarding the quality of the forecasts made with DSGE models, they are generally of similar quality to forecasts based on other types of forecasting methods or forecasts that are more judgmental in nature.[7] For example, a 2012 study by Marco Del Negro and Frank Schorfheide indicates that, at short horizons (one quarter), DSGE models do about as well as purely statistical procedures when forecasting output and inflation, but at horizons of one year, they do somewhat better. This

[5] Although shocks to the wage markup are not present in PRISM, most DSGE models feature such shocks, which affect the costliness of labor.

[6] For a detailed discussion of various ways that output gaps are measured, see the *Business Review* article by Roc Armenter and the study by Michael Kiley. A particular DSGE model that calculates a statistically based output gap is the DSGE model being developed by staff at the Chicago Fed (see the article by Charles Evans and coauthors).

[7] However, forecasts that use various model restrictions in forming priors still generally outperform those from DSGE models (see the 2004 study by Del Negro and Schorfheide).

is also the message of the study by Maik Wolters, who additionally shows that taking forecast averages across various DSGE models can improve their forecasting performance.

The models can also be used to benchmark policy, since one of their forecasts is for the behavior of interest rates. Also, standard error bands can be placed around the forecasted path of the interest rate, allowing policymakers to perceive the likelihood of a particular benchmark path. The Riksbank employs its DSGE model for this purpose.

A relative strength of the DSGE framework lies in its ability to identify shocks. For example, many DSGE models identify shocks associated with the impairment of financial markets as being primarily responsible for the most recent recession and the current slow recovery. Identifying the most important shocks in any given economic episode is particularly important for a monetary policymaker, since the optimal response to demand shocks is often much different than the optimal response to supply shocks. Thus, it is important to identify what types of economic disturbances are affecting the economy if a policy decision is to be a fully informed one.

DSGE models are also used to explore the effects of alternative policies. Because all the sectors of the model are formally linked together, along with the assumption that the estimated parameters are invariant to changes in policy, we can carry out policy exercises that are easily interpreted.[8] For example, we can analyze the effects of policies following alternative interest rate paths, paths that differ from the model's forecasted path. Further, we can ask what the models predict if a disturbance was somewhat larger than estimated or if it were to turn out to be more long-lived than usual. Doing so lets policymakers gauge risks associated with particular economic events.

SOME WEAKNESSES OF THE MODELS

My overview would be incomplete if I did not point out some of the inherent weaknesses of the current generation of DSGE models. Perhaps the most important is model misspecification. Currently, many of the restrictions imposed by the various DSGE models are at odds with the data. For example, the models specify that, in the long run, variables such as consumption, output, investment, and wages all grow at the same rate, which is somewhat at odds with the data. One outgrowth of this type of misspecification is that many of the economic disturbances in the model must be very persistent in order to align the model with the data. Incorrect estimation of the disturbances can affect the implications for how the economy would react to a change in monetary policy. In a 2009 paper, Del Negro and Schorfheide show that if the estimated DSGE model attributes too much persistence to productivity shocks, it implies that controlling inflation would involve a monetary policy that responds overly aggressively to departures of inflation from target. That would not be the case if the productivity disturbance was less persistent. Thus, when policymakers are deciding the best way to respond to departures of inflation from target, model misspecification can lead to an incorrectly designed policy.

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Also, because none of the models are literally true, they do not present a totally accurate depiction of the economy. However, looking at the output of various models can help to clarify the extent of that misspecification.

Of greater significance is the fact that some of the behavioral relationships in the models are not really invariant to monetary policy. As mentioned, the price-setting mechanism precludes changes in price-setting behavior at different inflation rates. Thus, policies that affect the behavior of inflation are likely to affect the actual economy in ways that the model cannot capture. Thus, the implications drawn from the model may not be entirely accurate. This problem is less severe if the variation in inflation associated with an alternative policy is not very large, but the model's prediction will be less reliable if the variation in inflation is significant. Thus, when analyzing alternative policies, policymakers should have more confidence in the model's prediction when the alternative is closer to actual policy.

Furthermore, issues concerning the identification of various parameters sometimes arise. By that I mean an occurrence when the data are not particularly informative about the value of a parameter. In that case, the estimated value of the parameter will reflect only the modeler's prior belief about the parameter no matter what that prior belief happened to be. Hence, very little is actually known about the parameter. In cases like this, we need to be particularly careful when assessing predictions of the model, especially if the parameter in question has an important effect on those predictions.

Finally, the models often lack important sectors, such as a sophisticated financial sector, and, as mentioned, the modeling of fiscal policy is quite simplistic. These problems are not

[8] Formally, this means that the models are, in principle, not subject to Lucas's famous critique regarding the inappropriateness of using relationships that are not based on a theoretical structural model to analyze policy changes.

methodological, but they indicate that there is room for continuing evolution in this field of research.

SUMMARY

This article has outlined the basic structure of a new class of models, DSGE models, which are currently being used to aid monetary policymakers in many countries. They have proven useful in forecasting, in identifying key elements that are affecting the economy, and for conducting counterfactual experiments that can help policymakers understand both the likely outcomes and the uncertainty surrounding the outcomes of various policy experiments. Thus, these models are an important element of a policymaker's toolkit. They provide a coherent and internally consistent way of viewing the economy.

The article has also pointed out some of the problems that currently exist within this class of models. It is important to understand that these problems are not methodological, but rather they reflect the current state of the models. Development is ongoing, and many of the problems are currently being addressed in the next generation of models.

Given the relative strengths and weaknesses of current DSGE models, they should be used in conjunction with other forecasting methodologies and other models in combination with other information and expertise that policymakers bring to the table. Indeed, that is the way they are actually being used by central banks around the world.[9]

[9] For an excellent and detailed discussion of how DSGE models are used in the context of monetary policy at the Sveriges Riksbank, see the speech by Irma Rosenberg.

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