Using Models for Monetary Policy Analysis*

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Modern policy analysis makes extensive use of dynamic stochastic general equilibrium (DSGE) models. These models differ significantly from earlier generations of large-scale econometric models. I review what I see as major progress in the ability of economists to conduct model-based policy analysis. This progress has come through the evolution in the types of models being used and in a refinement of the types of questions asked of these models.[1]

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1. Models for Policy Analysis

Economists use both simple theoretical models and empirical models designed to match data to address questions of policy relevance. Our intuition about the roles of policy actions in affecting the economy, the nature of the linkages between policy and macro variables, and the consequences of commitment and transparency often come from simple, highly stylized theoretical models. However, my focus here will be on empirical models, by which I mean models that are estimated from time-series data or calibrated to match data and that are then used for policy analysis.

Estimated economic models have long been used for policy analysis. One of the major figures in the development of large-scale econometric models for policy analysis during the 1960s and 1970s was Lawrence Klein, who received the 1980 Nobel Prize in Economics. In a 1981 paper, prepared for the Federal Reserve Bank of Kansas City's

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[1]See Faust (2009) for an excellent discussion of some of the strengths and weaknesses of modern DSGE models as tools for policy analysis.

symposium and entitled "The Value of Models in Policy Analysis," Klein presented a general discussion of models designed for policy evaluation and provided some examples of how these models could be used to assess both monetary and fiscal policies.[2] It is interesting to contrast and compare his views, representing the views common in the 1970s on this subject, with the current thinking on the same issues—for example, as exemplified by Adolfson et al. (2009) or by the papers presented in this session. Doing so helps to illustrate the progress that the profession has made over the past thirty years in constructing economic models that can offer valuable insights to policymakers.

I should note, however, that the views expressed by Klein in 1981 did not represent a consensus among model builders or model users at the time. In fact, one should probably think of it as reflecting the consensus of the late 1960s or early 1970s. However, it represents a useful starting point from which to assess the progress that has been made.

1.1 Klein (1981)

In re-reading Klein (1981), one is struck by the fact that much of the language he uses to discuss policy evaluation and model usage is still in use today. He draws the distinction between endogenous and exogenous variables, between targets and instruments. However, from a modern perspective, there are significant differences in the way he characterizes the formal model used for policy analysis and in the way he divides variables between the categories of exogenous and endogenous, targets and instruments.

1.2 The Formal Model

In representing a model formally, Klein writes

$$F\left(y_t', y_{t-1}', \ldots, x_t', x_{t-1}', \ldots, z_t', z_{t-1}', \ldots, w_t', w_{t-1}', \ldots, \theta'\right) = e_t', \quad (1)$$

[2] The Federal Reserve Bank of Kansas City's 1981 symposium was the last one held in Kansas City and was the last with a focus on agricultural economics. In 1982, the symposium moved to Jackson Hole, WY, and took on a broader monetary policy focus.

where y is a vector of targeted endogenous variables, x is a vector of non-targeted endogenous variables, z is a vector of exogenous instruments, w is a vector of non-instrument exogenous variables, θ is a vector of parameters, and e is a vector of random (presumably exogenous) variables.

While Klein carefully distinguishes in his discussion between the four categories of variables appearing on the left side of (1), there is virtually no discussion of the nature of the equations represented by $F(.)$ nor of the nature and source of the stochastic variables e'.

Klein was very clear on the ultimate test of an economic model—its forecasting ability. And while he does not discuss the estimation procedure in this particular paper, he does mention the role of add factors—i.e., non-model information—used to adjust equations to incorporate information available to the model analyst that is not formally present in the model itself.

While $F(.)$ could include non-linear equations, assume for simplicity that we are dealing with a linear system. If we also assume that the system is sufficiently well behaved, we can solve for the time t endogenous variables as functions of the exogenous variables (policy instruments, non-policy instruments, and shocks), yielding

$$\begin{bmatrix} y'_t \\ x'_t \end{bmatrix} = B_1 \begin{bmatrix} y'_{t-1} \\ x'_{t-1} \end{bmatrix} + B_2 z'_t + B_3 w'_t + B_5 e'_t, \tag{2}$$

where, rather than introduce additional notation, vectors such as y' should now be interpreted as augmented to incorporate lags so that (2) is the state-space representation of the solution and the elements of the matrices B_i are functions of the parameter vector θ'.

1.2.1 Representing Policy

When it comes to using the model in policy analysis, the exercises Klein has in mind involve solving the model under alternative paths for the exogenous policy instrument variables appearing in (2). The list of such policy instruments was quite large. For example, in the exercise Klein (1981) reports, instruments include both defense and non-defense government spending, personal federal taxes, guidelines for capital depreciation, and growth-rate targets for $M1$ and $M2$.

The model was used to generate forecasts (projections in the current parlance) under alternative scenarios for policy, with policy alternatives meaning alternative paths for the instrument variables (the path for z'_{t+i}). Thus, policy analysis involved comparing the forecast paths implied by the system for alternative *exogenous* paths for the instrument variables z'_t. Suppose $\bar{z}'_{t+i}$ represents the baseline path for the exogenous policy instrument, and let $\tilde{z}'_{t+i}$ represent the alternative policy path. Define $\Delta z'_{t+i} \equiv \tilde{z}'_{t+i} - \bar{z}'_{t+i}$ as the deviation of $\tilde{z}'$ from the baseline path. Then the effect of the policy experiment for future date $t+i$ is given from (2) by

$$\begin{bmatrix} \Delta y'_{t+i} \\ \Delta x'_{t+i} \end{bmatrix} = \sum_{j=0}^{i} B_1^j B_2 \Delta z'_{t+i-j}. \tag{3}$$

While it was recognized that the model was potentially misspecified and the forecasts of the non-policy exogenous variables that feed into the forecast were subject to error, the impact of policy could be assessed by comparing the forecast with a baseline forecast. In the case of a linear model, (3) shows that the non-instrument exogenous variables and the stochastic shocks do not appear, as they are the same in both the baseline and the alternative scenarios.

Using different paths for $\Delta z'_{t+i}$, alternative paths for the target endogenous variables $\Delta y'_{t+i}$ could be obtained. Then, Klein describes the choice of policy as follows: "When policymakers find combinations of input values that lead to desirable model solutions, they choose the configuration that they like" (pp. 5–6). Klein does not provide a formal metric with which to evaluate the alternative paths of the target variables associated with different assumptions about the exogenous paths of the instrument variables. He does not rule out the use of a more formal optimal control approach that would, of necessity, require the specification of an objective function that could be used to rank the outcomes for the target variables. But, he concludes that "there is a feeling that public authorities are not yet ready for the automatic approach of control theory and prefer to proceed with models, among other devices, by search and experimentation" (p. 5).

Two aspects of Klein's specification of policy differ from the approach adopted in modern treatments. First, he includes policy instruments as among the exogenous variables of the model. I will discuss in more detail below the significance of this classification, but it is among the most important differences between Klein's view of policy analysis and the modern approach. Second, he views the range of potential targets for macroeconomic policy as quite large, stating that "at the macro level, comprehension, appreciation, meaningfulness for the electorate, and manageability are criteria that limit the number of targets, certainly fewer than ten magnitudes, and possibly no more than five are practical limits *at the present time*" (p. 3, emphasis added). Rather than an expansion of the number of feasible targets, as Klein appears to have expected would be the case, the number of targets that is viewed as reasonable, at least for central banks, has declined since he wrote. Many central banks today view inflation as their single target, and debate is active over whether some measure of financial stability should be added to the responsibilities of flexible inflation targeters. Doing so would bring the number up to three (inflation, the output gap, and a financial gap), so even five targets seems ambitious.

1.3 Using Policy Models in 2009

The past decade has witnessed the rapid development of structural general equilibrium models incorporating stochastic and dynamic elements. The current generation of models is based on the combination of optimizing behavior by economic agents and nominal price and wage rigidities.[3] These DSGE models now typically employ Bayesian techniques to combine elements of calibration with the estimation of structural parameters.[4] DSGE models are employed in the policy process at several central banks (e.g., the Federal Reserve, the Bank of England, the Reserve Bank of New Zealand, the Bank of Canada, and the Riksbank), and the active development of DSGE models is a major task of research departments in many central banks.

In general, these models can be expressed in the form

$$A_1 \begin{bmatrix} Z_{t+1} \\ \mathrm{E}_t z_{t+1} \end{bmatrix} = A_2 \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + A_3 i_t + A_4 \begin{bmatrix} e_{t+1} \\ 0 \end{bmatrix}, \tag{4}$$

[3]Early models with these properties include Yun (1996), Goodfriend and King (1997), and Rotemberg and Woodford (1997).

[4]The first example of a New Keynesian DSGE model that was estimated was due to Rotemberg and Woodford (1997). The Bayesian approach to estimating DSGE models was pioneered by Smets and Wouters (2003).

where Z is a vector of predetermined variables, z is a vector of endogenous non-predetermined variables, i is the policy instrument, and e is a vector of exogenous stochastic innovations.

In comparing (1) with (4), the most important difference is the presence of expectations in (4)—specifically, expectations of forward-looking endogenous variables. As is well known, the presence of these variables has important implications for policy design. Expectations appear because the equilibrium conditions summarized in (4) include first-order conditions derived from the decision problems of the households and firms that populate the model economy. This leads to a second key difference between (4) and (1): the behavioral relationships in modern models are based on the decision problems agents face. That is, the components of the model meant to capture the behavior of economic agents are not specified in a reduced-form manner, with the decision variable expressed as a function of relevant state variables. Instead, the objectives of the agent and the constraints under which decisions are made are first specified, and then the first-order conditions from the resulting decision problem are used to characterize the agent's behavior.

While the model in (4) is linear, it is derived directly from an underlying non-linear model. Thus, the elements of the matrices A_i are obtained by taking a linear approximation to the underlying equilibrium conditions of the theoretical model that describes the economy. This implies that the parameters in the resulting equilibrium conditions represent properties of either the agents' objectives or of the constraints they face. The A_i matrices are then functions of the structural parameters that characterize the model. The attempt to ensure that parameters are structural reflects the desire of model builders to address the Lucas critique (Lucas 1976) by distinguishing between parameters—or, more generally, aspects of the model structure—that remain invariant to alternative policies, and reduced-form parameters that may change under alternative policies. In addition, because the mapping from the model's structure and the elements of the linear approximation is explicit, the manner in which alternative assumptions about the model's structure affect the coefficient matrices in (4) and the behavior of the model's solution can be analyzed.

In using a model such as (4) for policy analysis, the policy variable i_t is not treated as a purely exogenous process. Instead, it is treated either as an endogenous variable, determined by an instrument rule that relates the policy variable to other endogenous variables, or it is assumed to be set optimally on the basis of a policy objective function that is part of the model's specification.

Dating from the important work of Smets and Wouters (2003), Bayesian techniques have become standard for estimating structural DSGE models. Thus, non-model information is incorporated formally as part of the estimation procedure (although some parameters are calibrated).[5]

An excellent recent example of the way a modern DSGE model can be employed for policy analysis is provided by Adolfson et al. (2009), henceforth ALLS. They show how the model, estimated with Bayesian methods using Swedish data, can be used to construct projections of endogenous variables under alternative assumptions about monetary policy, including the assumption that the Riksbank had followed an optimal commitment policy.

ALLS estimate the model under two different assumptions about monetary policy. Under the first assumption, policy is represented by a simple instrument rule. Such a rule can be written as

$$i_t = F \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + v_t$$

so that the model to be estimated is

$$A_1 \begin{bmatrix} Z_{t+1} \\ \mathrm{E}_t z_{t+1} \end{bmatrix} = (A_2 + A_3 F) \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + A_3 v_t + A_4 \begin{bmatrix} e_{t+1} \\ 0 \end{bmatrix},$$

showing how the coefficients of the model's reduced form will depend on the elements of F. The alternative specification for policy assumes that the Riksbank implemented the optimal precommitment policy during the sample period. In this case, the weights appearing in a quadratic loss function involving the target variables are estimated along with the other parameters of the model. The vector of target

[5]As Chris Sims pointed out at the conference, add factors are also incorporated into DSGE models when used for forecasting. Their role, in earlier generations of models and in current DSGE modes, often is to incorporate new information contained in high-frequency data. For example, the model may be estimated using quarterly data, and add factors can be employed to reflect information in data available at a monthly frequency.

variables is of low dimension, consisting of inflation, a measure of the output gap, and the nominal interest rate. Note that under either the assumption of a simple instrument rule or the assumption of optimal policy, the policy instrument becomes an endogenous variable. When the objective function includes stabilizing interest rate volatility, the policy instrument appears as both an endogenous variable and as a target variable.

1.4 Areas of Agreement and Disagreement

Let me briefly review some of the major points of agreement and disagreement between the approach to model-based policy analysis of Klein and that of ALLS.

1.4.1 Agreement

Perhaps the most obvious similarity between the views expressed by Klein and the modern approach to policy analysis exhibited by ALLS is that they both employ formal models. Formal models impose a discipline by forcing forecast paths of endogenous variables to be consistent with the model. Klein, for example, stresses the internal consistency of the model forecasts in criticizing U.S. administration forecasts for 1981–83 that projected higher real growth and lower inflation than the model forecasts. The distinction between targets and instruments is also one made by both Klein and ALLS.

Both Klein and ALLS also emphasize trade-offs: alternative policies lead to different outcomes for the target variables. These trade-offs are evaluated more formally in the analysis of ALLS since they include an explicit loss function as part of the specification of their model.

1.4.2 Disagreement

There are several important points of disagreement between the model-based analyses of Klein and ALLS. Let me list five.

First, and most importantly, is the difference in the treatment of policy itself. In Klein's discussion, policy is modeled as exogenously specified paths for policy instruments; in ALLS's discussion, the chief focus is on the systematic behavior of the policy instrument. This difference is central to the modern approach to policy analysis.

Rather than assessing outcomes under alternative exogenous paths for the policy instruments, with policymakers then choosing the path for the instrument that they view as yielding the best path for the target variables, policy is endogenous, responding to developments in the economy. The way this endogeneity is modeled can vary. ALLS consider a simple instrument estimated jointly with the rest of the model, and they also employ an explicit loss function to derive projections under the assumption that the policymaker is implementing an optimal precommitment policy.

Second, the nature of the trade-offs that are emphasized differ. For Klein, these are trade-offs between the level of GDP growth and the level of inflation. For ALLS, they are trade-offs involving variances.

Third, ALLS incorporate a more limited set of policy instruments. Specifically, they only focus on the central bank's policy interest rate; fiscal policy variables are treated as exogenous to the rest of the model, with lump-sum taxes implicitly adjusting to ensure a period-by-period balanced fiscal budget.

Fourth, ALLS are concerned with the Lucas (1976) critique, an issue Klein does not mention. Thus, the equations of their model represent equilibrium conditions that include first-order conditions implied by the households' and firms' decision problems.[6] Thus, many of the model parameters have structural interpretations in terms of utility functions or production functions. When ALLS estimate their model under different assumptions about the determination of historical policy (simple instrument rule versus optimal precommitment), they focus on whether the parameter estimates seem to be invariant to the different ways policy is modeled.

Of course, the particular microfoundations in the model of ALLS contain many aspects that one would not consider structural in the same way economists typically assume utility functions and production functions are structural. For example, the Calvo parameter governing the frequency with which prices are adjusted is not based on a plausible model of price stickiness. Instead, it is designed to capture in a simple manner the staggered adjustment of prices that seems to

[6]In a related point made at the conference, Doug Laxton characterized older models as constructed around variables, such as consumption or investment, while modern models are constructed around agents, such as household and firms.

characterize the data. In an environment of low and stable inflation, it is not unreasonable to treat this frequency measure as invariant to the types of policy alternatives normally analyzed. It would be unreasonable to treat it as fixed if the exercise being studied with the model involved major shifts in average inflation. Similarly, the Riksbank's RAMSES model used by ALLS assumes that firms index prices to a weighted average of past inflation and an exogenous target inflation rate. The relative weight on these two components cannot be given a structural interpretation, nor is it likely to be invariant to major shifts in monetary policy. The same argument applies to parameters that capture deviations from uncovered interest parity.

Fifth, the treatment of the disturbance terms differs. The stochastic errors in (1) are not integrated into the model specification. In contrast, ALLS incorporate various structural shocks as part of the specification of the firm and household decision problems. This means that disturbances may appear in several of the model's equilibrium conditions with coefficients that depend on the structural parameters of the model. Of course, as Chari, Kehoe, and McGrattan (2009) argue, the models are often unable to distinguish between shocks that call for a policy response and those that do not.

2. Conclusions

The type of model and the way models are used in policy analysis have evolved significantly. Modern models, because they are based on a more careful specification of the economic environment within which the agents of the model must operate, address, at least in principle, the Lucas critique. The strength of the modern approach to using models for policy analysis is the wider range of policy-relevant questions that can be put to the models. These questions include the following: How do systematic policies affect the behavior of the economy? What are the projections for target variables under optimal policies? How do changes in the economic structure affect parameters of the model, and how do these changes affect the design of an optimal policy? The ability to address these questions reflects an evolution over the past thirty years from the view of policy as an exogenous path for instrument variables to the view that policy is endogenous and responds to economic conditions.

Of course, the current generation of DSGE models also have their weaknesses. Many of the key parameters of the structure are not really "structural." The Calvo parameter is a good example. This means that the model is unlikely to be invariant to major changes in the economy. And while DSGE models can address many interesting questions, there are many others that they cannot. What will be the effects of a major shock of a type not seen in the historical data used to estimate the model, for example? Or, if policy is endogenous, how can we infer what policymakers will do in unforeseen situations? In addition, many of the structural parameters of these models may only be weakly identified (Canova and Sala 2009). So there is always a need for new work designed to improve the usefulness of models for policy analysis, but the current shortcomings of the modern class of models should not prevent us from recognizing that the state of the art has advanced markedly in recent years.

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