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Discussion

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Reflections on macroeconometric modeling

Abstract: I have been doing research in macroeconomics since the late 1960s, almost 50 years. In this paper I pause and take stock. The paper is part personal reflections on macroeconometric modeling, part a road map of the techniques of macroeconometric modeling, and part comments on what I think I have learned about how the macroeconomy works from my research in this area. Section 1 contrasts the methodology of the Cowles Commission approach with that of DSGE modeling. Section 2 presents the general model that I am using; Section 3 discusses theory; and Section 4 discusses estimation and solution. Section 5 then discusses various results from the estimation; Section 6 discusses various properties of the model; and Section 7 uses the model to analyze various economic events. Wealth effects play a large role in the analysis of past events.

Keywords: Cowles Commission; macro modeling; policy properties.

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1 Introduction and methodology

I have been doing research in macroeconomics since the late 1960s, almost 50 years. In this paper I pause and take stock. The paper is part personal reflections on macroeconometric modeling, part a road map of the techniques of macroeconometric modeling, and part comments on what I think I have learned about how the macroeconomy works from my research in this area.

I have gathered my research in macroeconomics in one document, *Macroeconometric Modeling, November 11, 2013* (*MM*), on my website. This document is background material for the present paper. *MM* is written using the current version of my multicountry (MC) model (November 11, 2013), where published

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results using earlier versions of the model have been updated.[1] The present paper contains few references; they are in *MM*. In a number of cases I have indicated in this paper in brackets the relevant sections in *MM* that contain more discussion.

It is clear that macroeconomic methodology has changed since my graduate student days. Macroeconomics began as an empirical discipline. In the early days the data were not very good, and considerable effort was needed to understand the data, both their strengths and weaknesses. The data sharply restricted what could be estimated. There was a pragmatic aspect to this research. The aim was to estimate aggregate relationships and possibly use these estimated relationships to predict the future course of the economy. This research was not always elegant, did not always use consistent estimation techniques, sometimes overreached, possibly at times confused correlation with causation, and possibly data mined. But there was a serious attempt to explain the data, to estimate structural equations that fit well.

The specification of the structural equations to be estimated was constrained by economic theory, but fairly loosely. There was much back and forth movement between empirical results and theory. If something did not work that seemed theoretically plausible, something else was tried. Lagged dependent variables were used freely, and they generally greatly improved the fit of the equations. The use of lagged dependent variables could be justified either as picking up partial adjustment effects or as reflecting adaptive expectations, and there was usually little attempt to distinguish between the two reasons. This style of research is sometimes called the "Cowles Commission" (CC) approach [1.1]. Although it was used by the Cowles Commission beginning in the 1950s, it goes back further. An important early example is the work of Tinbergen (1939). Here are two quotes from Tinbergen (1939) that give a flavor of the approach. The first concerns the choice of lags in an estimated equation, and the second concerns the macroeconomic nature of the analysis.

> The method essentially starts with *a priori* considerations about what explanatory variables are to be included. This choice must be based on economic theory or common sense. If *a priori* knowledge regarding the lags to be taken is available, these may be specified also. In many cases, for example, reactions are so quick that only lags of zero length are acceptable. If no such *a priori* knowledge is available, lags may be tried according to the same principle as coefficients – i.e., by finding what lags give the highest correlation. (p. 10)

1 Users can work with the MC model on line or can download the model and related software to work with it on their own computer. If the model is downloaded, it can be modified and reestimated. Many of the results in *MM* can be duplicated on line. *MM* contains a complete documentation and listing of the model.

> It goes without saying that any regression coefficient found for a market or a group of markets represents only an average for all individuals included, and cannot be applied to problems concerning one individual. (p. 12)

There was what one might consider a general equilibrium feature to this research. Given that the aim was to explain and possibly predict the macroeconomy, many important variables had to be explained. On the aggregate demand side, for example, there are various categories of consumption and of investment, as well as imports, exports, and government spending. Government spending variables and tax rates were usually taken to be exogenous, and exports many times were, but the general aim was not to take as exogenous some variable that seemed clearly endogenous. This obviously led to large models. Disaggregation was also taken seriously. If, for example, expenditures on consumer services behaves differently than expenditures on consumer durables, which is obvious from both theory and the data, separate equations would need to be estimated and generally were. Also, housing investment, plant and equipment investment, an inventory investment behave much differently, and separate equations were generally estimated for each.

Fast forward to the present. Macroeconomic methodology has changed. Theoretical constraints now play a much bigger role, and testing is now different. The models of choice are dynamic stochastic general equilibrium (DSGE) models. Rational expectations are almost always assumed, and explicit maximization problems are postulated. The nature of these models is such that it is hard to make them large, and there is much less disaggregation than existed in models specified using the CC approach. DSGE models tend to be much smaller. At a minimum using the CC approach for the US, consumption would be disaggregated into three categories and investment into three. Government would be disaggregated into federal and state and local. Exports and imports would be in the model. And there would be a number of explanatory stock variables in the equations (stocks of consumer durables, housing, plant and equipment, inventories, and financial wealth). This is a much richer menu than exists in a typical DSGE model.

The care with which the earlier macro dealt with data has not carried over to the newer macro. There is nothing in the DSGE methodology that requires less care, but it is a feature of many DSGE models. Consider a recent paper by Del Negro, Giannoni, and Schorfheide (2013), which uses a DSGE model. The model uses quarterly data on nine variables: output growth, consumption growth, investment growth, real wage growth, hours, inflation, the federal funds rate, the spread between the BAA corporate rate and the 10-year Treasury bond rate, and a 10-year average CPI inflation forecast. The construction of the first six of these variables follows that used in Smets and Wouters (2007), a widely cited paper in the field. Some of this construction, however, is problematic.

First, real consumption is taken to be nominal consumption divided by the GDP deflator, and real investment is taken to be nominal investment divided by the GDP deflator. The relative prices of consumption and investment change over time, and so real consumption and real investment in the model are not the same as in the National Income and Product Accounts. The best estimates of real consumption and real investment are not being used, and the differences between the constructed values and the actual values can be quite large. Second, hours worked is taken to be average weekly hours of all persons in the nonfarm business sector times total civilian employment. This implicitly assumes that government workers have the same average weekly hours as workers in the nonfarm business sector, which is not the case. But more important, civilian employment from the household survey is used instead of jobs from the establishment survey. Some people have two jobs, and so civilian employment underestimates the number of jobs in the economy. This is not just a level difference because the number of people with two jobs is a cyclical variable. (In the MC model an equation is estimated explaining this difference.) So in this model, as well as in the Smets and Wouters (2007) model, consumption growth, investment growth, and hours vary for reasons that have nothing to do with the theory in the model. The correct data are not being used.

There are other recent papers that treat the data in a similar fashion. Schmitt-Grohe and Uribe (2012) deflate nominal nondurable plus service consumption by the GDP deflator and non residential plus residential fixed investment by the GDP deflator. They also deflate nominal government consumption plus gross investment by the GDP deflator. Corsetti, Meier, and Müller (2012) deflate nominal nondurable plus service consumption by the GDP deflator, nominal private investment plus durable goods consumption by the GDP deflator, and nominal government consumption plus gross investment by the GDP deflator. Bils, Klenow, and Malin (2012) (Web appendix) are more careful regarding the deflators used, but they do not handle the issue of establishment versus household data correctly in the construction of their hours variable.

What is remarkable about the macro profession at the moment is that business economists, who generally do not have the prestige of academic economists, would never be caught confusing household survey data with establishment survey data (or using the wrong deflators). On the Friday morning of each month in which the two surveys are simultaneously released, business economists are glued to their computers waiting for the announcements. The data from both surveys are analyzed immediately.

Another important difference between the two macros is how models are tested. Gone is equation-by-equation estimation, where for a given equation the left hand side variable is an endogenous macroeconomic variable and the right hand side variables are variables that theory suggests should affect the left hand side variable. Instead, the entire model is estimated and tested as a unit. Sometimes parameters are calibrated and sometimes estimated by likelihood or Bayesian techniques. The testing criterion is usually how well the predictions and properties of the model match various moments and various impulse responses derived from estimated VAR models. The aim is to see if the theoretical restrictions of the model account for various features of the data. An influential early paper in this area is Rotemberg and Woodford (1998). The last sentence in this paper is an interesting contrast to the above quotes of Tinbergen:

> Our main hope with this paper is precisely to shift the debate over optimal monetary policy so that it will involve different optimizing models, all of which fit the data reasonably well, instead of involving equations which fit well by construction but which have only a tenuous connection to explicit behavioral hypotheses at the microeconomic level.

I have labeled this new macro "macro 2," in contract to the old macro, "macro 1" [1.2]. These two macros are so different that they are essentially different fields. Macro 1 is taught at the introductory level and is used by business economists. Macro 2 dominates research published in professional journals and research done at many central banks. People have strong views about macro 1 versus macro 2. Many in macro 2 feel that macro 1 has been completely replaced by better theory and better techniques. The CC approach is considered ad hoc. On the other hand, some feel that the methodology of macro 2 is so ludicrous that essentially nothing useful has been learned from it, that it has led to a dark age of macro research. And others think that macro overall is so screwed up that it is not worthwhile following and have gone on to other fields.

I am of the dark-age view, but this paper is not a critical review of macro 2. It is instead an attempt to accent the positive aspects of macro 1. The themes are 1) there is much theory behind macro 1, 2) many features of the economy can be analyzed in one model – there is no limit on size and detail, and 3) computer speeds are such that there is essentially no limit on the degree to which macro 1 models can be analyzed and tested. In addition, as noted above, I discuss what I think I have learned about the macroeconomy from working with a macro 1 model. This discussion shows the detailed issues that can be analyzed in macro 1, many of which are not feasible in macro 2.

2 The general model

It will be useful to center the discussion around a general model. The model is dynamic, nonlinear, and simultaneous. The non rational expectations version is:

$$f_i(y_t, y_{t-1}, \ldots, y_{t-p}, x_t, \alpha_i) = u_{it}, \quad i=1, \ldots, n, \quad t=1, \ldots, T, \tag{1}$$

where y_t is an n-dimensional vector of endogenous variables, x_t is a vector of exogenous variables, and α_i is a vector of coefficients. The first m equations are assumed to be stochastic, with the remaining equations identities. The vector of error terms, $u_t = (u_{1t}, \ldots, u_{mt})'$, is assumed to be *iid*. The function f_i may be nonlinear in variables and coefficients.

This specification is fairly general. It includes as a special case the VAR model. It also incorporates autoregressive errors. If the original error term in equation i follows a rth order autoregressive process, say $w_{it} = \rho_{1i} w_{it-1} + \ldots + \rho_{ri} w_{it-r} + u_{it}$, then equation i in the model in (1) can be assumed to have been transformed into one with u_{it} on the right hand side. The autoregressive coefficients $\rho_{1i}, \ldots, \rho_{ri}$ are incorporated into the α_i coefficient vector, and additional lagged variable values are introduced. This transformation makes the equation nonlinear in coefficients if it were not otherwise, but this adds no further complications because the model is already allowed to be nonlinear. The assumption that u_t is *iid* is thus not as restrictive as it would be if the model were required to be linear in coefficients.

The rational expectations (RE) version is

$$\begin{gathered} f_i(y_t, y_{t-1}, \ldots, y_{t-p}, E_{t-1} y_t, E_{t-1} y_{t+1}, \ldots, E_{t-1} y_{t+h}, x_t, \alpha_i) = u_{it} \\ i=1, \ldots, n, \quad t=1, \ldots, T, \end{gathered} \tag{2}$$

where E_{t-1} is the conditional expectations operator based on the model and on information through period t–1. The function f_i may be nonlinear in variables, parameters, and expectations. Although in this version of the model expectations are rational in the sense of being model consistent, the model is not a DSGE model. It is still in the CC tradition of postulating aggregate equations to estimate. The following discussion will focus on the non RE version (1). Comments will be added about the RE version when appropriate.

Although, as noted above, VAR models are special cases of the general model (1), models in the CC tradition are generally not VAR models or various extensions of VAR models. They are structural in the sense that there are right hand side endogenous explanatory variables in many equations. Some of the equations may, of course, have no endogenous explanatory variables and so are like VAR equations.

The MC model, mentioned above, is an example of the model in (1), and it will be used as a reference in some of the following discussion. There are 39 countries in the MC model for which stochastic equations are estimated. There are 25 stochastic equations for the US and up to 13 each for the other countries.

The total number of stochastic equations is 310, and the total number of estimated coefficients is about 1300. In addition, there are 1379 bilateral trade share equations estimated, so the total number of stochastic equations is 1689. The total number of endogenous and exogenous variables, not counting various transformations of the variables and the trade share variables, is about 2000. Trade share data were collected for 59 countries, and so the trade share matrix is 59×59.

The estimation periods begin in 1954 for the US and as soon after 1960 as data permit for the other countries. Data permitting, they end as late as 2013:3. The estimation technique is 2SLS except when there are too few observations to make the technique practical, where ordinary least squares is used. The estimation accounts for possible serial correlation of the error terms. When there is serial correlation, the serial correlation coefficients are estimated along with the structural coefficients. For each estimated equation there are estimated residuals over the estimation period. $\hat{u}_t$ will be used to denote the 1689-dimension vector of the estimated residuals for quarter t.

3 Theory

As noted above, the CC approach uses theory to decide the left hand side and right hand side variables in each equation i in (1). This is clear from the first Tinbergen quote. Theory is taken seriously, and the CC approach is not ad hoc in this sense. As the second quote from Tinbergen suggests, however, the equations are not meant to pertain to one individual. Macroeconomic variables are aggregations of huge numbers of micro variables, and the estimated equations are reflecting average behavior. They are aggregate approximations, if you will. What makes macro 2 seem so loony to some is the precision with which it thinks that aggregate variables can be applied to specific maximization problems and with the use of the assumption of rational expectations for the expectations of these variables.

The theory of household and firm maximization is used to guide the specification of the equations in the MC model [3.2, 3.3]. The equations are taken to be approximations of aggregate decision equations. The theory leads to many exclusion restrictions in each equation, and so lack of identification is rarely an issue. Consider the equations in the above model (1). There are many exogenous and lagged endogenous variables excluded from each equation in this setup, and the equations are generally highly overidentified.

4 Techniques

4.1 Estimation and solution

There are typically endogenous right hand side variables in the equations in (1), where ordinary least squares (OLS) gives inconsistent estimates. Macro 1 has not always been careful in using consistent estimation techniques, and OLS has often been used. It is now, however, computationally easy to obtain consistent estimates even for large nonlinear models. The most straightforward technique is two-stage least squares (2SLS), but also available are two-stage least absolute deviations, three-stage least squares, and full information maximum likelihood [2.3, 2.4]. The same techniques are also available for the RE version, although more computational work is involved [2.12.1, 2.12.3].

Once all the α_i coefficients have been estimated in (1), the model can be solved. There are good numerical algorithms for doing this, the main one being Gauss-Seidel [2.5]. A typical solution uses actual values of the exogenous variables, actual values of the initial conditions up to the beginning of the solution period, and zero values for the error terms. A dynamic simulation is one in which the solution values of the endogenous variables are carried along from period to period as values of the lagged endogenous variables.

What is now easy to do, which was not the case at the beginning of macro 1, is stochastic simulation and bootstrapping (which are essentially the same thing in the present context) [2.6, 2.7]. Consider the MC model. Available after estimation is $\hat{u}_t$, the 1689-dimension vector of the estimated residuals for each quarter *t*. Most of the estimation periods have the 1972:1–2007:4 period – 144 quarters – in common, and consider this period to be the "base" period. These 144 observations on $\hat{u}_t$ can be used for error draws when solving the model. The solution is the same as described above except that the error draws are used instead of zero as the values of the error terms. If the model is solved, say, 1000 times for different error draws, 1000 solution values of each endogenous variable are available, from which measures of variability can be computed. These measures are consistent with historic variability since $\hat{u}_t$ contains historically estimated residuals. Also, since the structural coefficients in an equation and any autoregressive coefficients are jointly estimated (by 2SLS for the MC model), the $\hat{u}_t$ error terms, which are after adjustment for the autoregressive coefficients, can be taken to be *iid* for purposes of the draws. The ease of doing stochastic simulation and bootstrapping opens up many interesting tests and analyzes [3.9, 3.10].

Solution and stochastic simulation is feasible for the RE version, but considerably more computation is needed [2.12.2, 2.12.4]. One has to iterate over solution *paths* to obtain expectations that are consistent with the solution values of the model.

4.2 Testing

Statistical testing has been an important part of the CC approach from the beginning. Statistical tests, for example, are widely used in Tinbergen (1939). A key question, of course, is whether the chosen right hand side variables are statistically significant, and the *t*-test is widely used. After an equation is estimated, one can add other variables, like extra lags or a time trend, to the equation to see if they are significant. χ^2 tests are often used. There are also various stability tests – testing the hypothesis that α_i is constant over time. For the 2SLS technique, there is the standard test of overidentifying restrictions. The rational expectations assumption can be tested by adding variables *led* one or more periods to the equation and using a consistent estimation technique. Testing equation by equation has always been an important feature of the methodology [2.8].

There are a number of techniques for testing complete models [2.9.1]. Stochastic simulation has greatly opened up the types of tests that can be performed. One can compare the variances of one model to those of another, or simply compare the root mean squared errors of one model to those of another. These comparisons, however, are not always straightforward. Models may differ in the number and types of variables that are taken to be exogenous, and this can be problematic. The possibility of data mining is also an issue. Data mining may hide the misspecification of a model. One should compare only outside-sample predictions, but this is not always feasible. Another way to compare models is to examine the information content of their forecasts using encompassing tests [2.9.2].

Stochastic simulation can be used to separate the total variance of a forecast error into that due to the uncertainty of the additive error terms, the uncertainty of the coefficient estimates, the uncertainty of the exogenous variables, and the uncertainty from the possible misspecification of the model [3.10]. A common result that emerges from this kind of exercise is that the additive error terms contribute much more to the overall variance than do the coefficient estimates. Within a given model the sensitivity of the uncertainty estimates to alternative specifications and hypotheses can be examined.

4.3 Optimal control

It is now feasible to solve optimal control problems for large nonlinear models, even models with rational expectations [2.10, 2.12.5, 2.12.6]. The assumption of certainty equivalence is usually used for these problems, which appears to be a good approximation [2.11]. Given model (1), given an assumption about future values of the error terms, given a welfare function, and given a control variable or set of variables, the welfare function can maximized subject to the model. Once the problem is solved for the horizon of interest, the values of the control variables for the first period can be implemented. Then after the first period has passed and the actual values for it are known, the control problem can be solved again beginning in period 2. After this solution, the values of the control variables for the second period can be implemented, and so on. With reoptimization each period, only the first-period values are ever implemented.

Conclusions reached using optimal control analysis are usually heavily dependent on the choice of the welfare function, and so to some extent they are less informative that one might at first think. It is also difficult to know what to assume the policy makers know when they are solving the control problems.

This optimal control setup is different from that used in macro 2, even if the model considered here is the RE version. Say that the policymaker is the Fed, the control variable is the short term interest rate, and the model is the RE version. In this case the equations would be estimated by a consistent estimation technique, say a modification of 2SLS to take account of the led values, a welfare function would be postulated, and the optimal values of the interest rate would be computed, given the model and an assumption about the error terms. The optimization is subject to the requirement that the expectations be model consistent (which requires in this case iterating over solution paths). The Fed in maximizing the welfare function knows how the expectations are formed. It knows, for example, that a change in the current value of the interest rate will affect expectations of future endogenous-variable values (and thus current-period solution values). This is not the macro 2 setup because the equations in the RE version are not derived from the solution of a specific optimization problem. The RE version is in the CC tradition, where theory is used only to pick the left hand side and right hand side variables. The RE assumption merely leads to the use of a different estimation technique than otherwise and to the requirement that in the solution of the overall model the expectations be model consistent.

5 Estimation results from the MC model

Much can be learned about the economy using the CC approach from simply the equation by equation estimates. In this section I will highlight what I think is the case from my estimation of the MC model.

5.1 Age distribution effects

It appears possible in US consumption equations to pick up age distribution effects. The US age distribution has large fluctuations over time, and one might expect that aggregate consumption would, other things being equal, be affected by the distribution. For example, the standard life cycle model would suggest this. The estimates suggest that this is true [3.6.2, 3.6.3]. It is difficult in DSGE models to account for age distribution effects because of the focus on representative agents.

5.2 Testing rational expectations

As noted in Section 4, the assumption that expectations are rational can be tested by adding led values to an equation and testing for their significance. This assumption is generally rejected for the equations of the MC model. Very few of the led values are significant [3.6.11, 3.7.3].

5.3 Physical stock effects

Physical stock variables are important. (The following results are for the US.) A variable measuring excess capital is significant (lagged once) in the nonresidential fixed investment equation, and a variable measuring excess labor is significant (lagged once) in the employment and hours per worker equations. The lagged stock of inventories has a significantly negative effect in the production equation; the lagged stock of durable goods has a significantly negative effect in the consumer durable goods expenditure equation; and and the lagged stock of housing has a significantly negative effect in the residential investment equation [3.6.4].

The existence of these physical stock effects means that there are endogenous features in the model that mitigate business cycles. As physical stocks are drawn down, this has a positive effect on new expenditures, other things being equal, which is expansionary. For example, the smaller is the existing stock of housing, the larger will be future residential investment, other things being equal.

The existence at times of excess labor (firms at times having more jobs than are needed to produce current output) means that measured labor productivity is pro-cyclical. Also, capacity utilization is pro-cyclical because of the existence at times of excess capital (firms at time having more capital than needed to produce current output).

5.4 Wealth effects

A variable measuring the real wealth of the US household sector (both financial and housing), denoted AA, is significant (lagged once) in the three US consumer expenditure equations. It also appears in three of the four labor supply equations, where the estimated effect is negative. More will be said about wealth effects in Sections 6 and 7.

5.5 Nominal versus real interest rates

Interest rates appear in the consumption and investment equations in the MC model for the US and other countries. Consumption and investment are in real terms, and a question is whether the interest rate in the equations should be nominal or real. This can be tested by adding both the nominal interest rate and a measure of expectations of future inflation to an equation and testing whether the coefficient estimate of the nominal interest rate is significantly negative and equal to the negative of the coefficient estimate of the expectations variable. If this is true, it is evidence in favor of the real interest rate. If instead the coefficient estimate of the nominal interest rate is significantly negative and the coefficient estimate of the expectations variable is insignificant, this is evidence in favor of the nominal interest rate. When the two variables are added for various measures of inflation expectations, the results are strongly in favor of the nominal interest rate. The coefficient estimate of the nominal interest rate is usually negative and significant, and the coefficient estimate of the inflation expectations variable is usually insignificant [3.12].

Why this is the case is an interesting question. One possibility is that inflation expectations are simply a constant, so that the nominal interest rate specification is also the real interest rate specification (with the constant inflation expectation absorbed in the constant term of the equation). If, for example, agents think the monetary authority is targeting a fixed inflation rate, this might be a reason for inflation expectations being constant.

5.6 Interest rate rules

Interest rate rules are estimated for the US and many other countries in the MC model, where for a given equation the left hand side variable is the short term interest rate of the country and the primary right hand side variables are measures of inflation and of the real side of the economy. These are "leaning against the wind" equations, where the interest rate is positively affected by inflation and the real side of the economy. These rules are not calibrated policy rules, but estimated ones. The estimation of such rules goes back to at least to 1963, long before calibrated policy rules became popular [3.6.10].

An interesting question in the US is whether Fed policy has changed over time. For example, does the Fed now put more weight on inflation than it did earlier? There was clearly a change in Fed behavior in the 1979:3–1982:4 period, when the Fed announced that it was targeting the money supply. But what about before and after? When the hypothesis that the coefficients in the US interest rate equation are the same in the 1954:1–1979:2 and 1983:1–2008:3 periods, the hypothesis is not rejected at the 95% confidence level. (The last quarter of the estimation for the interest rate rule is taken to be 2008:3, since after that there was likely a zero lower bound constraint.) Fed behavior thus appears to have been stable since 1954, at least up until 2009, except for the 1979:3–1982:4 period.

5.7 Price and wage equations

Early specifications of the price and wage sector had estimated price and wage equations, where prices appeared in the wage equations and vice versa. This fell out of fashion, and price equations began to be estimated without wages in them – reduced form price equations. My results suggest that this was a mistake – better results are obtained by treating price and wage equations together [3.13].

Perhaps of most importance regarding price and wage equations is their dynamics. Consider a price equation by itself, and call the log of the price level the "price level," where the change in the price level is then the rate of inflation. Should the left hand side variable be the price level, the rate of inflation, or the change in the rate of inflation? A typical NAIRU model has the rate of inflation on the left hand side, with the coefficients of the right hand side lagged inflation rates summing to one. The implies that in the long run the left hand side variable is the change in the inflation rate. The different dynamic specifications imply certain coefficient restrictions on lagged price levels, and these restrictions can be tested. My results suggest that the best left hand side variable is the price level, where the lagged price level on the right hand side does not have a coefficient of one. The NAIRU model with the coefficients of the lagged inflation rates summing to one appears to be off by two derivatives.

If the NAIRU specification is rejected, this changes the way one thinks about the relationship between inflation and unemployment. One should not think that there is some unemployment rate below which the price level forever accelerates and above which it forever decelerates. Instead, it appears that the price level depends on the lagged price level with a coefficient less than one. It is probably the case that the relationship between the price level and the unemployment rate is nonlinear at low values of the unemployment rate, where at low values decreases in the unemployment rate have very large effects on the price level. I have experimented with a variety of functional forms to see if the data can pick up nonlinear relationships. Unfortunately, there are so few observations of very low unemployment rates that the data do not appear capable of discriminating among functional forms. A variety of functional forms, including the linear form, lead to very similar results. This does not mean, however, that the true functional form is linear, only that the data are insufficient for estimating the true functional form. It does mean, however, that one should not run experiments using the MC model in which unemployment rates or output gaps are driven to historically low levels. The price equations are unlikely to be reliable in these cases.

6 Properties of the MC model

Once a model has been estimated, various experiments can be run to examine it properties. These examinations are not tests of the model, but simply finding out what the estimated equations and identities imply. Testing is as discussed above – either equation by equation or the entire model. The following are some of the properties of the MC model.

6.1 Effects of a price shock

Experiments show that a positive shock to the US price equation is contractionary even when the nominal interest rate is held constant [4.1]. There are three main reasons for this. First, the percentage increase in nominal household wealth from an increase in the price level is less than the percentage increase in the price level itself, and so there is a fall in real household wealth from a positive price shock. This has, other things being equal, a negative effect on real household expenditures. Second, in the price and wage equations for the US nominal wages lag prices, and so a positive price shock results in an initial fall in the real wage rate and thus real labor income. A fall in real labor income has, other things being equal, a negative effect on real household expenditures. Third, as noted in the previous section, nominal interest rates rather than real interest rates are used as explanatory variables in the various demand equations, and so the fall in the real interest rate does not stimulate demand. In short, the fall in real wealth and real labor income is contractionary, and there is no offsetting rise in demand from the fall in the real interest rate. Not only does the Fed not have to increase the nominal interest rate more than the increase in inflation for there to be a contraction, it does not have to increase the nominal rate at all! The price shock itself will contract the economy through the real wealth and real income effects. This property of the model is in stark contrast to many other models in the literature, where a positive price shock with the nominal interest rate held constant is highly expansionary, sometimes leading to instability.

6.2 Wealth effects

It was mentioned in the previous section that the real wealth variable, *AA*, is significant in the three US consumer expenditure equations. This variable changes when stock prices or housing prices change. Experiments with the model show that the effect of a sustained increase in wealth on consumer expenditures is about 4% per year ignoring feedback effects [5.7]. As discussed in the next section, this wealth effect is important in explaining the boom in the US economy in the last half of the 1990s, the contraction following the boom, and the recession of 2008–2009. It also has implications for macroeconomic forecasting, which is discussed next.

6.3 Macroeconomic forecastability

An important limit to macroeconomic forecasting is the following. If changes in asset prices affect the macroeconomy and if these changes are unpredictable, then fluctuations in the macroeconomy due to changes in asset prices are unpredictable. Asset prices in the MC model are exchange rates, oil prices, and, for the US, housing prices and stock prices (the prices that affect *AA*). The changes in these prices are essentially unpredictable, and they have important effects in the model.

Stochastic simulation can be used to estimate the fraction of the forecast-error variance of an endogenous variable that is due to the variances of the asset-price variables in the model. The results using the MC model suggest that about of the forecast-error variances of output growth and inflation over eight quarters are due to asset-price changes. The inflation results are due to cost shocks from oil prices and exchange rates. The output results are due to stock prices, housing prices, and oil prices [4.3]. There is thus considerable unpredictability of the macro economy if these results are accurate and if asset-price changes are largely unpredictable. If, for example, the recession of 2008–2009 was initiated by the huge fall in housing prices, the recession could not have been predicted to the extent that the fall in housing prices could not have been predicted.

6.4 The effectiveness of monetary policy

Monetary policy for all the major countries is endogenous in the MC model because of the estimated interest rate rules. Interest rates affect affect aggregate demand in the model by appearing as explanatory variables in consumption and investment equations. Using optimal control techniques and stochastic simulation, it is possible to compare the stabilization properties of interest rate rules versus having the monetary authorities solve optimal control problems. It is also possible to see how much of the variability of the endogenous variables can be eliminated by interest rate rules or by solving optimal control problems. I have done this for the Fed with the following results [4.4].

1. The estimated interest rate rule of the Fed substantially reduces output and price variability compared to no rule (i.e. taking the interest rate to be unchanged in response to shocks).
2. Variability is reduced even when the coefficient on inflation in the interest rate rule is set to zero. This is contrary to what would be the case for many models, where such a rule would be destabilizing (as discussed above).
3. Increasing the coefficient on inflation in the interest rate rule lowers price variability, but it comes at a cost of increased interest rate variability.
4. A tax rate rule is a noticeable help to monetary policy in its stabilization effort.
5. When the Fed is assumed to behave by solving an optimal control problem with a higher weight on inflation than on output in a loss function, the results are similar to those obtained using the estimated interest rate rule.
6. Regardless of the interest rate rule used or whether the Fed solves optimal control problems, considerable variance of the endogenous variables remains. Monetary policy does not come close to eliminating the effects of typical historical shocks. This is contrary to most DSGE models, where the Fed can basically sterilize any shocks in the economy.

The last point is important. It says that monetary policy is severely limited in its ability to control the economy. The situation is even worse if there is a zero lower interest rate bound, which was not the case for the above results.

I have also obtained results that show that monetary policy effects depend on the size of the debt/GDP ratio. As this ratio rises, other things being equal, the effects of interest rate increases on aggregate demand become smaller. This is because the larger is the debt/GDP ratio, the more do interest payments of the government change as interest rates change, and some of these payments are part of household income. If interest rates increase, for example, household interest income increases, which has a positive effect on consumption and housing investment, other things being equal. The net negative effect of an interest rate increase on aggregate demand is thus smaller the larger is the household interest income effect [4.7].

6.5 Effects of a yuan appreciation

Some have argued that the yuan is undervalued and that this has a negative effect on US output. An interesting question to analyze using the MC model is thus what would be the effects of a yuan appreciation on US output? The yuan/dollar exchange rate is exogenous in the model, and so this question can be analyzed by simply changing the exchange rate.

The results show that a yuan appreciation has little effect on US output. The main positive effect is that US imports fall – mostly imports from China. But there are two negative effects that roughly offset this positive effect. The first is that the yuan appreciation leads to a decrease in Chinese output, which has a negative effect on Chinese imports, some of which are from the US. The second is that the rise in US import prices (from the rise in Chinese export prices) leads to an increase in US domestic prices. The increase in US domestic prices results in a decrease in real wealth and real wages, which have, other things being equal, a negative effect on US aggregate demand and output (see the discussion in Section 6 regarding the effects of a price shock) [4.5].

6.6 Is fiscal stimulus a good idea?

The MC model has the following property regarding US fiscal stimulus. If the stimulus takes the form of an increase in transfer payments or an increase in tax expenditures and if the increased spending must eventually be paid for, the net effect on output and employment is small. The gain in output and employment on the way up is roughly offset by the loss in output and employment on the way down as the debt from the initial stimulus is paid off.

The experiment that gives this result is one in which there is an initial US fiscal stimulus followed by a de-stimulus after 5 or 9 years with the requirement that the debt/GDP ratio go back to baseline after 14 years. The results are robust to different assumptions about monetary policy (remember that monetary policy is limited in its ability to stabilize the economy). Also, the results are not affected much by discounting. If anything, the argument against stimulating may be a little stronger with discounting. Since there are endogenous cycles in the MC model because of physical stock effects, after de-stimulus has taken place (5 or 9 years out) physical stocks are sometimes lower than baseline, which, other things being equal, leads to increased investment in the future. So for the last few years of the 14-year period, output can be larger than baseline. If these positive values are discounted, the overall gain from the experiment is thus smaller than if they are not discounted [4.6].

7 Analysis of the economy using the MC model

Once a model is estimated, it can also be used to analyze historical episodes. Again, this is not a test of the model, but simply using it for analysis. The following are a few examples.

7.1 Stabilization costs of the EMU

Using the MC model and stochastic simulation, it is possible to estimate the stabilization costs to countries from joining the European Monetary Union (EMU). Variability estimates can be computed for the non EMU and EMU regimes and then compared. A key feature of the MC model that allows this to be done is that there are estimated interest rate rules for each of the European countries prior to 1999:1. In the EMU regime these rules for the joining European countries are replaced with one rule – one interest rate rule for the EMU. There are also estimated exchange rate equations for each of the European countries, and in the EMU regime these equations for the joining European countries are replaced with one equation – the exchange rate equation for the euro. Finally, there are estimated term structure equations for each of the European countries, and in the EMU regime these equations for the joining European countries are replaced with one term structure equation.

The results show that the individual German interest rate rule was fairly stabilizing for Germany, whereas the EMU interest rate rule was less so. For France, on the other hand, the French interest rate rule was not very stabilizing, and so France did not lose much from joining the EMU. (The individual French rule was not very stabilizing for France because the Bank of France was estimated to mostly follow the Bundesbank in setting its interest rate.) The quantitative estimates show that the stabilization costs were largest for Germany and smallest for France, with Italy and the Netherlands in between. In a separate experiment, where it was assumed that the UK joined the EMU, there were estimated to be noticeable stabilization costs for the UK from doing so [5.2].

7.2 A new economy in the 1990s?

There was much talk in the US in the last half of the 1990s about the existence of a new economy or a "new age." One change that was obvious was the huge increase in stock prices relative to earnings beginning in 1995. The mean PE ratio for the S&P 500 index was 14.6 for the 1952:1–1994:4 period and 23.7 for the 1995:1–1999:4 period. This increase appears to have been a major structural change, and an important question is whether there were other such changes? The results of estimating and analyzing the MC model suggest no. Various stability tests of the structure of the US stochastic equations suggest no major changes except for the stock-price equation. An experiment using the MC model was performed in which the stock market boom was turned off shows that were it not for the boom, the behavior of economy would not have been historically unusual. According to the model, the boom in the economy in the last half of the 1990s was driven by the boom in the stock market. This is the wealth effect on consumer expenditures at work. The results are thus consistent with the simple story that the only major structural change in the last half of the 1990s was the huge increase in stock prices relative to earnings [5.3].

This analysis does not provide any hint as to why the stock market began to boom in 1995. In fact, it deepens the puzzle, since there appear to be no major structural changes in the economy except the stock market. There is no obvious fundamental reason for the stock market boom. Put another way, it seems unlikely that any econometric analysis would be able to explain the boom.

7.3 The post boom US economy

The US had in the 2000:4–2004:3 period large expansionary fiscal and monetary policies and yet a recession and fairly slow recovery from the recession. Why was the US economy so sluggish in this period in light of the large expansionary fiscal and monetary policies that took place? The MC model can be used to analyze this question in a manner similar to that discussed above for the last half of the 1990s.

Various stability tests of the structure of the US stochastic equations suggest no major changes in the 2000:4–2004:3 period. There also appear from analyzing the estimated residuals to be no systematic bad shocks in this period. Instead, the main culprits seem to be large negative effects from declines in the stock market and US exports. The wealth effect from the stock market again plays a major role in the story, this time negative rather than positive. Although not tested in this analysis, some of the decline in US exports may have been the result of stock market declines in the rest of the world, in which case most of the explanation is simply the stock market declines themselves through negative wealth effects [5.4].

7.4 The stimulus bill and the deficit

It is straightforward to use the MC model to analyze the effects on the world economy of policy changes like the 2009 US stimulus bill. One simply solves the model with and without the stimulus bill and compares results. The results show that the US output and employment effects over 12 years are positive, with some redistribution of output and employment away from 2012–2015 and with an increase in the federal government debt/GDP ratio. The increase in real output over the 12-year period, 2009–2020, is estimated to be $807 billion in 2009 dollars (0.40% of total output over the period), and the increase in the average level of employment is 532 thousand jobs (0.40%). This assumes no future tax increases or government spending cuts to pay for the stimulus spending. The MC model has the advantage of being able to estimate the increase in the government debt that would result if no future actions are taken. The increase in the federal debt by 2020:4 is estimated to be $616 billion in 2009 dollars, an increase in the debt/GDP ratio of 2.77 percentage points [5.5].

It is also straightforward to use the MC model to analyze various deficit questions. An experiment has been performed that provides estimates of the size of the decrease in transfer payments or tax expenditures that would be needed to stabilize the US debt/GDP ratio. Using the model for this purpose has the advantage of taking into account endogenous effects of spending changes on the economy and the effects of changes in the economy on the deficit. There is clearly some output loss in stabilizing the ratio. Monetary policy helps keep the loss down, but it is not powerful enough in the model to come close to eliminating all of the loss (even if there is no zero lower bound). The results suggest that transfer payments or tax expenditures need to be decreased by about 1% of GDP from a base run in which there are no major fiscal policy changes. The real output loss is about 0.7% of baseline GDP [5.6].

Another approach to estimating output multipliers is what might be called a "reduced form approach." The change in real GDP is regressed on the change in a policy variable of interest and a number of other variables. Since the equation estimated is not a true reduced form equation because many variables are omitted, the coefficient estimate of the policy variable will be biased if the policy variable is correlated with omitted variables. The aim using this approach is to choose a policy variable that seems unlikely to be correlated with the omitted variables. The CC approach does not have the problem of possible omitted variable bias in reduced form equations because reduced form equations are not directly estimated. What is required is that the structural equations in (1) be consistently estimated. The model is then used to estimate multipliers by (implicitly) solving the reduced form equations. This structural approach uses much more information on the economy than does the reduced form approach. For example, the implicit reduced form equation for US output in the MC model is nonlinear and includes hundreds of exogenous and lagged endogenous variables. There are also hundreds of nonlinear restrictions on the reduced form coefficients. Given the complexity of the economy, it seems unlikely that estimating reduced form equations with many omitted variables and no restrictions from theory on the coefficients will produce trustworthy results even if an attempt is made to account for omitted variable bias.

7.5 The financial crisis and the 2008–2009 recession

From 2007:4 to 2009:4 household real wealth (AA) fell by $9.6 trillion, where half was financial wealth and half was housing wealth. The MC model can be used to estimate how much this fall in wealth contributed to the 2008–2009 recession [5.7]. The results suggest that much of this recession was simply due to standard wealth effects on household expenditures.

8 Conclusion

What I have tried to show in Sections 5–7 is that much can be learned about the macroeconomy by following the CC approach. A macro 1 model can easily incorporate the main endogenous features of the economy. Much can be learned from equation-by-equation estimation, and many features of the economy can be analyzed using a complete model, both likely policy effects and historical episodes. In Section 4 I have indicated that the use of techniques like stochastic simulation and optimal control are no longer constrained by computational issues, even for the RE version. As time generates more data and as the data get better for various countries, more and more can be learned about the world economy.

Regarding the use of theory, one should not lose sight of the fact that we are dealing with highly aggregate data, not the kind of data that should be subject to tightly specified optimizing behavior and the rational expectations assumption. Theory should be used to guide the empirical specifications, since equations that make no theoretical sense are not likely to be good approximations. But there is a limit. In many cases in the current macro literature too much faith would appear to be placed on micro foundations. Tightly microfounding aggregate data is problematic.

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