

Information Technology and Monetary Policy

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I. Introduction

The purpose of this conference is to examine the trend toward a world economy based on knowledge or information technology. In this opening speech, I would like to focus on the monetary policy implications of this trend. In my view, information technology—the use of computers, software, or networks—has two countervailing effects on monetary policy.

First, information technology makes monetary policy decision-making more difficult by increasing uncertainty about the targets and the instruments of monetary policy. The targets of monetary policy—low inflation and stable output, for example—are harder to define and to measure when information goods and services are a large or growing part of the economy. The instruments of monetary policy—in particular, the monetary aggregates—also become harder to define and measure when information technology causes the payments system to undergo rapid transformation. Moreover, information technology increases uncertainty about the relationship between the instruments and the targets, through the development of new financial products or new ways in which goods are traded or prices are formed.

Second, information technology makes monetary policy decision-making easier by improving the processing of information and by permitting greater quantification and handling of uncertainty. Faster computers and computer algorithms allow policy makers to analyze different policies in more realistic settings. Information technology enables the use of modern methods of decision theory and control theory in the formulation of monetary policy.

The first effect is a cost of information technology, while the second effect is a benefit. Both the costs and the benefits are growing as information technology improves. In my view, the benefits are growing faster than the costs. To support this view, I first describe how better information technology has improved research on monetary policy. I then show how this improved research can help policy makers deal with the uncertainties caused by information technology itself.

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II. The Impact of Information Technology on Monetary Policy Research

I focus on the impact that information technology—defined as the development of computers, software, or networks—has had on the evaluation of alternative strategies, plans, or rules for setting the instruments of monetary policy. In its broadest sense, monetary policy research aims at finding ways to improve the design and implementation of monetary policy in order to better achieve the goals of policy. In this sense, monetary policy research is much like any other type of applied economic research that aims to improve decision-making, whether by business firms, investors, or consumers.

Much of monetary policy research is historical and empirical; researchers look for correlations—primarily between the instruments of policy and the outcomes for inflation or employment—that might suggest how the instruments should be set in order to achieve certain goals for the target variables. But good policy research is also theoretical; it uses monetary theory to determine how different policies would work. The monetary policy research of Milton Friedman (1960), for example, which resulted in the proposal that monetary policy keep the growth rate of money constant, was based on both empirical and theoretical considerations.

The formal way to combine monetary theory and empirical observations is through a quantitative model of the economy; because monetary theory involves changes over time, such models are likely to be both dynamic and stochastic. The idea of applying optimal decision theory to monetary policy decisions using a dynamic or stochastic model of the economy goes back to the work of Phillips (1954), Theil (1957), Howrey (1967), and Brainard (1967). Phillips (1954) used dynamic deterministic models to study the effects of different policy rules that described how the instruments of policy reacted to the economy. In looking for a plausible class of policy rules, he borrowed the concepts of proportional, derivative, and integral control from the engineering literature. Theil (1957) added stochastic shocks to the models. Howrey (1967) examined policy rules in models that were both dynamic and stochastic. Brainard (1967) explicitly considered multiplicative uncertainty.

These policy studies focused on the instruments of policy. (Fiscal policy instruments were as often the focus of this earlier literature as monetary policy instruments.) A loss function for the deviations of the target variables from some desired levels was specified. The decision about the instrument was cast as an optimal decision problem in which instruments were set so as to minimize the expected value of the loss function. The expectations were taken across the distribution of the stochastic disturbances and perhaps the parameters of the model, as suggested by the optimal statistical decision theory available at the time (see, for example, Raiffa and Schlaifer [1961]). For the most part, this research could be done without computers: the models were small, linear, and simple.¹ The important analytical research of Poole (1970) on the choice of an interest rate or money supply instrument was conducted within this framework.

1. An exception was the type of optimization problems, considered by Prescott (1972) and Taylor (1974), that tried to deal with the fact that the choice of instrument would affect the flow of information about the parameters. These problems required much greater computing speed and better algorithms; as a consequence, only the most elementary problems could be handled.

The advent of rational expectations in macroeconomics in the 1970s had a radical effect on this decision-theory approach to monetary policy. Of course, it placed more emphasis on credibility and therefore on policy rules or contingency plans for policy; but policy rules were already the focus of the earlier work of Phillips, Howrey, and others. More important for this discussion, rational expectations placed a much greater demand on computers and computer software. The same optimal decision problems that could be performed analytically on the back of an envelope now required supercomputers. In order to deal with the Lucas critique, the models had to be forward-looking. Leads as well as lags of the variables entered the models, either because this was implied by the decision rules, as in Taylor (1979), or because it was implied by the first-order conditions of an individual agent's optimization problems, as in Hansen and Sargent (1980). In sum, rational expectations greatly increased computational complexity. This was true even after algorithms were developed to solve nonlinear rational expectations models. For example, solving a nonlinear rational expectations model using the extended path method required many hundreds of times the computing speed of the pre-rational expectations models. Rational expectations made monetary policy research much more difficult. Few had the time or resources to conduct formal econometric policy evaluation studies.

Fortunately, information technology came to the rescue of monetary policy evaluation research. The same types of computer hardware and software innovations that led to productivity increases and quality improvements throughout the economy also led to productivity and quality improvements in monetary policy research. What was impossible 20 years ago is routine today.

Looking back over the years since the rational expectations revolution, the progress that has been made in computation speed and computer algorithms is striking. Evaluating monetary policy rules in which the instruments of policy react to macroeconomic variables is now routine in the most complex forward-looking model. Econometric policy evaluation methods of the type advocated by Lucas are now used with models consisting of hundreds of equations with estimated numerical parameter values. The same models that took many hours to solve when first developed now take only a few minutes.

The technological breakthrough in research on policy rules is clearly demonstrated by Bryant, Hooper, and Mann (1993). Their project brought together many researchers to evaluate different monetary policy rules using very large multicountry stochastic systems. While no single policy rule obviously emerged from the simulations of many different models, there were some common characteristics. Rules with the interest rate as the instrument performed better than rules with the money supply as the instrument. Rules that reacted strongly *both* to inflation deviations from a target inflation rate and to real output deviations from potential output worked best. Rules that reacted to the exchange rate did not work as well as those that placed little or no emphasis on the exchange rate. These results showed that it is important for policy makers to have a target inflation rate; the task of policy is to keep the fluctuations in inflation around this target small, recognizing that fluctuations in real output around potential output can be affected by monetary policy.

In examining this research, I noted (Taylor [1993]) that there is a simple rule which possesses key characteristics of more complicated rules and which therefore would be expected to work well as a guideline for setting the policy instruments.

The simple rule has the short-term interest rate adjusting to both inflation and to real GDP. The target inflation rate is 2 percent, and the implied real interest rate is 2 percent. The weight on inflation is 1.5, and the weight on real output is 0.5.

Historical analysis supports the findings about the interest rate response to inflation and output found in model simulations as well as in the simple rule. The response of interest rates to inflation and real output in the 1980s and 1990s in the United States is very similar to the simple rule that emerged from the model simulations. Moreover, these responses are much larger than they were during the late 1960s and 1970s. The estimated inflation response coefficient is about 0.8 for the 1960s and 1970s, compared to about 1.5 for the 1980s and 1990s. Because the inflation rate and real output were more stable in the 1980s and 1990s than in the late 1960s and 1970s, this historical comparison provides some evidence that the proposed response coefficients are about right (see Taylor [1998b]).

In sum, information technology made modern econometric policy evaluation research possible. And even though the rules for monetary policy that have emerged from this research are simpler than would be implied by the more complex models, it is unlikely that the simple rules would have appeared without the computer-intensive research with complex models.

III. Dealing with Monetary Policy Uncertainties

As I stated in the introduction, information technology is likely to add uncertainty to the instruments of monetary policy, the target variables of monetary policy, and the relationship between the instruments and the targets. Dealing with the implications of information uncertainty is, therefore, much like dealing with uncertainty in general. I now consider several ways in which modern computer-intensive monetary policy research can deal with this uncertainty.

A. Robustness to Uncertainty about Model Specification

How robust are policy rules to model uncertainty? Monetary models can be specified in different ways. Some of these differences may reflect different information assumptions on the part of agents and thus might be affected by improvements in information technology. For example, if the Internet is used widely to buy, sell, and price goods and services, then the resulting quicker flow of information could cause prices to adjust more quickly. Because some monetary models assume a greater degree of price flexibility than others, the differences between the models could capture this potential effect of information technology. More generally, comparing the performance of policy rules in different models is useful if the differences in the models reflect some of the actual uncertainty in the real world.

There are a number of ways to test for robustness of policy rules across models. Here I report briefly on a very recent robustness study (see Taylor [1998a]) that is illustrative of what can now be done. Nine models were used in this robustness exercise. The models were developed by Laurence Ball, by Andrew Haldane and Nicoletta Batini, by Ben McCallum and Edward Nelson, by Glenn Rudebusch and Lars Svensson, by Julio

Rotemberg and Michael Woodford, and by Jeffrey Fuhrer and George Moore. Two of the nine are models used at the Federal Reserve Board (a small model and a large model) and one of the models is a multicountry model that I developed at Stanford several years ago (TMCM). The models represent a wide variety of approaches. Most are rational expectations models, but others are purely backward-looking. Most of the models are small, but a few are large. Some specify explicit optimization problems for agents, while others assume decision rules. Some are open-economy models, but most are closed-economy models. All the models are dynamic, stochastic, and economy-wide.

A number of different policy rules were part of this robustness study, but a brief description of two of these will be sufficient to illustrate the benefits of this type of approach. I focus on two rules in which the central bank's interest rate decisions respond both to inflation and to real GDP. In both rules, the response to the inflation rate is 1.5: when the inflation rate rises by 100 basis points, the short-term interest rate rises by 150 basis points. The rules differ in the response to real GDP, which equals 0.5 for the less output-responsive rule and 1.0 for the more output-responsive rule.² The rule with the output response coefficient of 0.5 is the rule proposed in Taylor (1993). The other rule has an output response coefficient of 1.0 rather than 0.5 on real output, reflecting the recent views of some researchers that the interest rate should respond more aggressively to output than the 0.5 response coefficient in the simple rule. Of course, there are many other policy rules besides these two, including money supply rules and rules that react to the exchange rate or to inflation forecasts. But these two rules serve as an example of how one can look at different models to assess the robustness of monetary policy rules to some types of uncertainty.

Assessing the robustness to uncertainty by looking at different models is less straightforward than it might at first seem, because some models show that all rules work much better than do other models. Absolute performance measures across models are arbitrary because certain modeling decisions—such as what variables are exogenous—are arbitrary. This arbitrariness also makes comparing estimated variances with historical variances difficult. One can get around this problem by considering rankings between rules. For example, tables 1 and 2 show the standard

Table 1 Macroeconomic Performance with a Rule with Lower Output Response

	Standard deviation of:	
	Inflation	Output
Ball	1.85	1.62
Haldane-Batini	1.38	1.05
McCallum-Nelson	1.96	1.12
Rudebusch-Svensson	3.46	2.25
Rotemberg-Woodford	2.71	1.97
Fuhrer-Moore	2.63	2.68
Small Fed Model	0.70	0.99
Large Fed Model	1.86	2.92
TMCM	2.58	2.89
Average	2.13	1.94

2. Ignoring the constant term, the mathematical form of the two rules is $i_t = g_\pi \pi_t + g_y y_t$, where i_t is the nominal interest rate, π_t is the inflation rate, y_t is real GDP measured as a deviation from potential GDP, and where $g_\pi = 1.5$ and $g_y = 0.5$ or 1.0.

Table 2 Macroeconomic Performance with a Rule with Higher Output Response

	Standard deviation of:	
	Inflation	Output
Ball	2.01	1.36
Haldane-Batini	1.46	0.92
McCallum-Nelson	1.93	1.10
Rudebusch-Svensson	3.52	1.98
Rotemberg-Woodford	2.60	1.34
Fuhrer-Moore	2.84	2.32
Small Fed Model	0.73	0.87
Large Fed Model	2.02	2.21
TMCM	2.36	2.55
Average	2.16	1.63

deviations of the inflation rate and real output for the two rules. Despite the conjectures that the more aggressive of the two rules would work better, neither rule dominates the other across the models. For all models, the more output-responsive rule gives a lower variance of output. However, for six of the nine models this higher output response rule also gives a higher variance of inflation. The change in the average standard deviations across all the models shows a trade-off between inflation variability and output variability. The comparison across models indicates a degree of robustness for both rules in the sense that neither rule results in terrible performance in any model. For none of the models would these rules be likely to lead to another Great Inflation or to a Great Depression with double-digit inflation or a double-digit percentage decline in real GDP below potential. This is not true of all policy rules, as I discuss next.

Another type of policy rule that has frequently been suggested has the interest rate responding to the lagged interest rate, in addition to output and inflation. A comparison of such rules with the two rules that do not respond to the lagged interest rate shows that neither type of rule dominates across all models. However, for a number of models the rules with lagged interest rates perform quite poorly with extraordinarily large variances. These could be Great Depression or Great Inflation scenarios in some models. It turns out, however, that the models that predict very poor performance for the lagged interest rate rules are models without rational expectations, or in which forward-looking effects are not strong in the model. Why? Interest rate rules that respond with a lag exploit people's forward-looking behavior; these rules assume that people will expect later increases in interest rates if such increases are needed to reduce inflation. Models without forward-looking terms clearly cannot describe such behavior. A rule proposed in recent research by Rotemberg and Woodford (1998) has a lagged interest rate coefficient greater than one; it is even less robust than the other rules, because it performs badly when evaluated with models without strong forward-looking behavior.

Although they are just becoming a regular part of research on monetary policy rules, robustness studies like this seem very promising as a means to deal with the effects of

uncertainty on monetary policy. I hope that my brief example hints at what can now be done. I would hope to see many more robustness studies of many more policy rules.

B. Robustness to Uncertainty about the Persistence of Shocks

It is possible to pinpoint more precisely the form of uncertainty to which one would like a policy rule to be robust. This greater precision may be very useful for dealing with uncertainties due to information technology. For example, uncertainty about the trend in potential GDP, or in longer-term movements in the real interest rate, could be due to a shift in productivity in services or some other non-tangible output that is not measured properly. Such uncertainties raise serious problems for policy rules that set the interest rate.

In a recent study, Sargent (1998) has developed a procedure that calculates policy rules which are robust to this form of uncertainty. In particular, he has calculated the parameters of a policy rule that is robust to changes in the serial correlation structure of the model. In other words, the policy maker assumes that there is no serial correlation, while in reality there is some serial correlation of a general variety. This situation could occur if potential GDP or the real interest rate started to drift away from the policy maker's estimate. Sargent focuses on simple interest rate rules such as the ones I discussed earlier. He finds that the robust rule responds more aggressively than either of the simple policy rules. His results depend on the form of the serial correlation, but one calculation is that the interest rate should be increased by 300 basis points for every rise in the inflation rate by 100 basis points, compared with 150 basis points for the simple rule mentioned earlier. For example, if the inflation rate rose in the United States from 2 percent to 4 percent in 1999, then the Federal Reserve Board would increase the interest rate from about 5.5 percent to 11.5 percent, holding the real output gap constant. Sargent (1998) also finds that the interest rate should be much more responsive to real output fluctuations. The response coefficient on real output is 1.6 rather than 0.5 or 1.0 in the other two rules.

It may seem surprising that the robust rule is more aggressive in the face of uncertainty. The reason is that, with the chance of a shock being persistent, the policy maker must guard against the shock having long-lasting effects by reacting to it more aggressively. For example, if there is an inflation shock, then the response will have to be more aggressive if the shock is expected to persist than if it is temporary. The robustness methods applied by Sargent are computationally intensive and at least when applied to larger models require the advances in information technology we have seen in the last 20 years.

C. Robustness to Uncertainty about Key Elasticities

Another specific form of uncertainty that might arise because of information technology concerns the effect of the policy instruments on the target variables. In another recent study, Stock (1998) calculates a policy rule that is robust to this type of uncertainty. In particular, the policy rule calculated by Stock is robust to different values of the slope of the IS curve (the impact of the interest rate on real output) and the speed of adjustment of inflation in a price adjustment equation (the impact of

real output on inflation), rather than to different serial correlation assumptions as in Sargent's robust policy rule. Stock's robust rule is a minimax policy with respect to this parameter uncertainty. In other words, within the class of policies in which the interest rate responds to real output and inflation, he finds a policy rule that minimizes the expected loss (a weighted average of inflation and output variance) for the worst-case scenario (a set of parameters). Stock also finds that the optimal policy should be more aggressive in responding to inflation and output than the two simple rules I mentioned earlier. For example, the interest rate responds by 390 basis points when the inflation rate changes by 100 basis points; if the inflation rate rose from 2 percent to 4 percent in 1999 in the United States, then the Federal Reserve Board would raise the Federal Funds rate to 13.3 percent. This aggressive response is the implication of the minimax strategy because the worst-case scenario has very small coefficients on the interest rate in the IS equation and on output in the inflation equation. In such adverse circumstances, not reacting sufficiently to inflation could cause the inflation rate to fluctuate by a huge amount and in turn lead to large output fluctuations.

D. Uncertainty and the Effects of Learning over Time

Uncertainty raises another type of policy strategy question. In the face of uncertainty about the structure of the model, should the central bank adjust its instruments so as to obtain more information that might reduce the uncertainty? This is the learning and control problem studied in some special cases by Prescott (1972) and Taylor (1974). This problem could simply not have been handled by the type of models needed for monetary policy without the improvements in information technology. In a recent paper, Wieland (1998) has calculated the optimal learning strategy when the uncertainty is due to imprecise estimates of the natural rate of unemployment. Wieland finds that the optimal learning policy—which balances the gains from learning and the costs of deviating from the optimal choice in the current period—is more aggressive than the policy that employs caution in the face of uncertainty (as in Brainard [1967]), but is less aggressive (except in some unusual cases) than the certainty-equivalent policy. The certainty-equivalent policy is assumed in the two simple rules I mentioned earlier. In other words, while learning, along with robustness, may be a reason for greater aggressiveness, it could be offset by the caution due to the parameter uncertainty itself.

E. Simple Monetary Policy Rules versus Complex Monetary Policy Rules

Another recent paper by Levin, Wieland, and Williams (1998) shows that simple rules are more robust to model uncertainty than more complex optimal rules. They find that optimal rules from one model perform worse than simple rules when simulated in other models. The reason for this finding is apparently that the optimal rule exploits certain properties of a model that are specific to that model. If the optimal rule is simulated in another model with different properties, then by exploiting the wrong properties the optimal rule fails.

F. Robustness to Information Lags

Yet another policy question relating to uncertainty is the effect of information lags on monetary decisions and performance. Suppose that policy cannot respond to current quarter values. Would the estimated performance deteriorate? According to simulations in the nine models mentioned earlier, if policy reacted to lagged inflation and lagged output ($i_t = g_\pi \pi_{t-1} + g_y y_{t-1}$) there would be little effect on economic performance. The variances of inflation and output increase by only a small amount when policy must react to lags in this way. Hence, information lags of about one quarter in length do not cause major difficulties for policy rules.

IV. Concluding Remarks: The Importance of Translational Economics

While improvements in monetary policy *research* due to faster computers and better software are impressive, I think it is important to ask whether the improved information technology has actually helped achieve the goals of monetary policy. Has the research improved actual monetary policy? I think the answer is yes, but this answer may pertain more to the United States, about which I am more familiar and on which much of the modeling has focused, than to other countries at this time. Central bankers in the United States have used monetary policy rules as a guide to their decisions; and they discuss specific policy guidelines in speeches. Financial market economists use policy rules to help predict monetary policy decisions. As with the remarkable improvements in information technology, I think it is striking to see how far the practical application of policy rules has come.

However, I think economists need to focus more on the process by which economic research gets applied to solve real-world problems. I hope my opening remarks demonstrate the power of the economic research, such as described in the papers presented at this conference. But if this research is to be useful, we need also to focus more in the future on *translational economics*, the process of translating economic research into practical policy decisions.

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