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A Comparison of Five Federal Reserve Chairmen: Was Greenspan the Best?

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Abstract

This paper examines the performances of the past five Federal Reserve chairmen using optimal control techniques and a macroeconometric model. Each chairman is evaluated in two ways. The first way is comparing the actual performance of the economy under his term *relative* to what the performance would have been had he behaved optimally. Comparing chairmen only on the basis of the actual performance of the economy is not appropriate because it does not control for different exogenous-variable values and shocks that the Fed has no control over. This comparison is done for a wide range of loss functions. It does not assume that the chairman necessarily behaved by minimizing a loss function; it just compares his actual behavior to what he could have done had he minimized a particular loss function. The second way, on the other hand, assumes that each chairman minimized a loss function, and it backs out an estimate of what this loss function was. A summary evaluation of each chairman is presented in Section 6.

1 Introduction

This paper examines the performances of the past five Federal Reserve chairmen using optimal control techniques and a macroeconometric model. A number of

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people have said that Alan Greenspan was the best Fed chairman ever,[1] and the methodology of this paper can be used to test this. Each chairman is evaluated in two ways. The first way is comparing the actual performance of the economy under his term *relative* to what the performance would have been had he behaved optimally. Comparing chairmen only on the basis of the actual performance of the economy is not appropriate because it does not control for different exogenous-variable values and shocks that the Fed has no control over. This comparison is done for a wide range of loss functions. It does not assume that the chairman necessarily behaved by minimizing a loss function; it just compares his actual behavior to what he could have done had he minimized a particular loss function. The second way, on the other hand, assumes that each chairman minimized a loss function, and it backs out an estimate of what this loss function was.

The methodology of this paper requires the existence of a model and the specification of a loss function. The model used is a version of the multicountry (MC) macroeconometric model in Fair (2004). A number of loss functions are considered. They are specified in terms of inflation and unemployment, with differing weights on the two. The MC model is quite different from the macro model that is primarily used in the current literature, namely the "New Keynesian" (NK) model, and some justification is needed for using a different model. The NK and MC models are briefly compared in Section 3. Some important properties of the MC

[1]For example, Milton Friedman is quoted in *Business Week*, November 7, 2005, p. 42, as saying "It's clear that Greenspan has been the most effective chairman of the Fed since its inception." Blinder and Reis (2005, p. 3) say of Greenspan "While there are some negatives in the record, when the score is toted up, we think he has a legitimate claim to being the greatest central banker who ever lived." And Taylor (2005, p. 1) in his comments on the Blinder and Reis paper agrees with this statement.

model are then discussed in Section 4. The loss functions and optimal control procedure are discussed in Section 5, and the results are presented in Section 6.

Results similar to those in this paper do not appear to be available elsewhere. Romer and Romer (2003) discuss the past Fed chairmen, but they present no measures of performance. Implicit in their discussion is the view that Martin, Volcker, and Greenspan did well relative to Burns and Miller, but no performance estimates are presented. Their view appears to be based mostly on how the economy actually performed during each chairman's term. In Romer and Romer (2002) they argue that Martin did well, but again mostly using actual economic outcomes. Blinder and Reis (2005, pp. 45–48) argue that Greenspan was lucky in probably having smaller shocks than previous Fed chairman had, but this is not pursued further. They simply conclude that Greenspan was great in addition to being lucky. Again, the measure of performance in this paper accounts for the possible luckiness of each Fed chairman. Blanchard and Simon (2001) and Stock and Watson (2003) document that the Greenspan period does appear to be a time of smaller than historically average shocks.

The idea of using optimal control techniques to measure economic performance was presented in Fair (1978). This earlier paper compared different presidents rather than Fed chairmen, under the assumption that presidents control the economy. In the present paper Fed chairmen are assumed to control the economy, which seems a more realistic assumption. Computer speeds have increased enormously since this earlier paper was written, and the optimal control procedure used in the present paper improves upon the procedure used in this earlier paper, which was

Table 1
The Five Fed Chairmen

	Period in Office (Period Used: No. obs.)	Mean Values $\dot{PD}$	UR	RS
William McChesney Martin, Jr.	April 1951–January 1970 (1954:1–1969:4: 64)	1.97	4.89	3.37
Arthur Burns	February 1970–January 1978 (1970:1–1977:4: 32)	6.54	6.26	5.73
G. William Miller	March 1978–August 1979 (1978:1–1979:3: 7)	9.59	5.96	8.18
Paul Volcker	August 1979–August 1987 (1979:4–1987:3: 32)	4.66	7.10	9.42
Alan Greenspan	August 1987–December 2005 (1987:4–2005:4: 73)	2.34	5.53	4.46

- $\dot{PD}$ = percentage change (annual rate) in PD, the price deflator for domestic sales—from NIPA accounts.
- UR = unemployment rate.
- RS = three-month Treasury bill rate.

fairly crude because of computer constraints.[2]

2 Background

Table 1 presents the five Fed chairmen considered, their exact terms in office, the quarterly sample periods chosen to represent the terms, and the average inflation

[2]One issue considered in this earlier paper not considered here is the state of the economy left to one's successor. For example, Volcker left Greenspan a particular state of the economy. Had he optimized, he would have left a different state. Greenspan's optimization problem thus depends on what Volcker did. In evaluating Volcker, actual versus optimal, one should consider how he affected Greenspan's period in addition to how he affected his own. Under the assumption that Greenspan behaves optimally, one could compare how Greenspan could have done given the actual state of the economy that Volcker left him versus how he could have done had Volcker behaved optimally. This difference, which could be either positive or negative, would then be considered in the evaluation of Volcker's overall performance. This issue is not pursued in the present paper.

rate, unemployment rate, and interest rate during each term.[3] Martin began his term in April 1951, but because of data limitations, the first quarter of his sample period is taken to be 1954:1. Miller's sample period consists of just 7 quarters, and so the results for Miller should be interpreted with considerable caution.

If one looks at just the historical averages of inflation and the unemployment rate, Martin does best, followed by Greenspan. Miller had very high inflation. Comparing Burns and Volcker, Volcker had higher unemployment but lower inflation. Martin had the lowest average interest rate, and Volcker had by far the highest. Looking just at these actual values, the view that Martin and Greenspan did well relative to Burns and Miller is clearly supported. Since Volcker had the highest average unemployment rate, he does not look particularly good. The purpose of this paper is to see how this evaluation is affected when the degree of difficulty of controlling the economy is taken into account.

3 The NK and MC Models[4]

3.1 NK Model

Goodfriend and King (1997) lay out what they call the "New Neoclassical Synthesis," which is represented by the NK model. The four features of this synthesis are: 1) intertemporal optimization, 2) rational expectations, 3) imperfect competition, and 4) costly price adjustment. The NK model plays a prominent role in

[3]Data sources and definitions for all the variables used in this paper are listed in Fair (2004) and on the website mentioned in the introductory footnote.

[4]This section is a condensed version of Section 2 in Fair (2007).

Clarida, Gali, and Gertler (1999) in their review of recent research in monetary policy, as it does in Woodford (2003). In the NK model an infinitely lived, representative household maximizes the discounted value of expected future utility. An intertemporal optimality condition relates current consumption to expected future consumption and the real interest rate. Equating consumption to output yields an aggregate demand equation in which current output depends on expected future output and the real interest rate. The price equation, which has come to be called the "new-Keynesian Phillips curve," is a forward-looking Phillips curve in which current inflation depends on expected future inflation and an output gap. It is derived from the optimizing behavior of monopolistically competitive firms, where firms change prices randomly as discussed in Calvo (1983) or face some kind of adjustment costs. An interest rate rule is then sometimes added as a third equation in which the nominal interest rate depends on inflation and the output gap.

Data on output (usually real GDP), inflation (usually the percentage change in the GDP deflator), and the federal funds rate or the three-month Treasury bill rate are typically used for the model. Sometimes all the parameters in the model are calibrated and sometimes some parameters are calibrated and some are estimated. This work is all done under the assumption of rational expectations. he parameters that are calibrated or estimated are usually the structural parameters of the theoretical model, and so this analysis is not subject to the Lucas (1976) critique.

3.2 MC Model

The theoretical model upon which the MC model is based was first presented in Fair (1974a). An easier-to-read presentation is in Fair (1984). It has two of the four features of the New Neoclassical Synthesis, namely intertemporal optimization and imperfect competition. Households maximize expected future utility and firms maximize expected future after-tax cash flow. The horizons for the maximization problems are finite. The choice variables for a household are consumption, leisure, and money holdings. The main choice variables for a firm are its price, wage rate, production, and investment. Expectations of future values by households and firms are based on current and past values; they are not assumed to be rational. Disequilibrium is allowed for, and it takes the form of firms telling households the maximum amount of labor they will hire in the period and of actual sales differing from expected sales.

A household takes as given its initial values of money and bonds and the current values of the price, wage rate, interest rate, personal income tax rate, transfer payments, and the labor constraint from firms. It forms expectations of the future values of these variables and solves it optimization problem given a terminal condition on the value of its money plus bonds.

A firm faces a putty-clay technology. Adjustment costs are postulated for changes in labor and the capital stock. Firms set prices and wages in a monopolistic competitive setting. The demand for a firm's product depends on its price relative to the prices of the other firms. A firm expects that other firms' prices are affected by the price that it sets. In other words, a firm expects that other firms will raise (lower) their prices if the firm raises (lowers) its own price. Similarly, the supply of labor to a firm depends on its wage rate relative to the wage rates of the other firms, and a firm expects that other firms' wage rates are affected by the wage rate that it sets.[5]

A firm takes as given all the initial values, including the initial values of other firms' prices and wage rates and the current values of the interest rate and the profit tax rate. It forms expectations of the relevant future values, where again its expectations of other firms' prices and wage rates depend on its own behavior, and solves its optimization problem. It chooses its price, wage rate, amount of each type of machine to purchase, and production. Given its price and wage rate decisions, a firm has an expectation of its sales and of the amount of labor that will be supplied to it. If actual sales turn out to be different from expected, this results in an unexpected change in inventories. If actual labor supply exceeds expected labor supply, the firm is assumed to hire only the expected amount. In fact, the model is set up so that firms communicate to households the amount of labor they are willing to hire (namely, the firms' expected amounts), and households optimize under this constraint, as noted above.

Regarding the expectations of households and firms, for a number of variables equations are postulated specifying how the expectations are formed. For the overall model in Fair (1974a) it is also specified that households and firms estimate the parameters of these equations based on past data. In this sense the expectations

[5]No adjustment costs are postulated for price changes and wage rate changes, and all firms can change their prices and wage rates each period. This is contrary to the fourth feature of the New Neoclassical Synthesis mentioned above, namely costly price adjustment. This assumption of costly price adjustment is, of course, controversial, and it is not necessarily a desirable feature of the synthesis. Bils and Klenow (2004) is a recent study casting doubt on the sticky price assumption.

are sophisticated. The key point about expectations, however, is that they are not specified to be rational or converge to being rational. Because expectations are not rational, disequilibrium can occur, which drives many of the properties of the model. Households and firms never learn the true model; they grope around in a complex world, never quite understanding everything.

Government fiscal policy decisions are exogenous. The government chooses the two tax rates, transfer payments, the amount of goods to purchase, and the amount of labor to hire. On the monetary policy side, an interest rate rule is postulated in which the interest rate depends on inflation and unemployment. Unemployment in the model is the difference between the labor that households would supply if the labor constraint were not binding and the amount they actually supply taking into account the labor constraint in their optimizing problem.

All flows of funds and balance sheet constraints are accounted for in the model. One sector's saving is some other sector's dissaving. One sector's financial liability is some other sector's financial asset.

The model in Fair (1974a) was a closed-economy model, but a two-country model was introduced in Fair (1984). Again, all flows of funds and balance sheet constraints among the sectors of the countries are accounted for. The choice of a household now includes how much to purchase of the foreign good, which is affected by the price of the foreign good relative to the price of the home good. The exchange rate is determined by a reaction function of one of the country's monetary authorities.

The model is solved by numerical techniques, given chosen parameter values and initial conditions. In a model in which disequilibrium is possible, the order of transactions matters, and the order chosen is 1) the government, 2) firms, and then 3) households. Transactions take place after households have optimized. Because firms don't have complete knowledge of the model, their price and wage setting behavior may result in sales differing from expected sales and labor demand differing from the unconstrained labor supply.

The main differences so far between the theoretical work behind the MC model and that behind the NK model are that the MC work considers more decisions, does not assume price stickiness, and does not assume rational expectations. The lack of rational expectations leads to possible disequilibrium since firms may not set market clearing prices and wage rates. There can be unintended inventory investment and unemployment (as defined above).

Another major difference concerns estimation. The theoretical work behind the MC model is used to guide the specification of a model to be estimated (the MC model). Essentially, the theoretical work is used to guide the choice of left hand side and right hand side variables. The empirical equations that are specified are meant to be approximations to the decision equations of the households and firms. The left hand side variables are the decision variables and the right hand side variables are those that the agents take as given in the optimization process. Moving from theoretical work to empirical specifications is a messy business, and extra theorizing is usually involved in this process, especially regarding lags and assumptions about unobserved variables. Although the estimated decision equations are only approximations, they do not suffer from the Lucas critique if expectations are not rational.[6] The equations of the MC model are estimated

[6]Evans and Ramey (2006) have shown that in some cases the Lucas critique is a problem even

by two-stage least squares,[7] and the model has been heavily tested. The latest test results are presented in Fair (2004), and these results will not be discussed here. In general the model does well in the tests. The current version of the MC model consists of 328 estimated equations, with 1,502 coefficients estimated, plus 1,220 estimated trade share equations. None of the coefficients are chosen by calibration. There are 59 countries in the model, where for 21 countries only trade share equations are estimated. In the United States part of the model there are 31 estimated equations and about 100 identities. Many of the identities are needed to account for all the flows of funds and balance sheet constraints.[8]

To summarize, then, the parameters of the theoretical model that is behind the MC model are never estimated, unlike the parameters of the NK model. In the DSGE approach, the theoretical model is the one brought directly to the data, not some approximation of it. If the NK model is well specified, the DSGE approach has the advantage that deep parameters are being estimated. If, on the other hand, the model is not well specified, the estimated model may be a poor approximation.

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if expectations are not rational. These cases are specific to the Evans and Ramey framework, and it is unclear how much they can be generalized.

[7]The estimation periods begin in 1954 for the United States and as soon after 1960 as data permit for the other countries. They generally end between 2004 and 2006. The estimation accounts for possible serial correlation of the error terms. The variables used for first stage regressors for a country are the main predetermined variables in the model for the country.

[8]The latest description of the MC model is in Fair (2004). The model can be analyzed on line or downloaded from the website listed in the introductory footnote. The list of first stage regressors for each equation is also available from the website.

3.3 Critique of the Basic NK Model

The following critique pertains to the basic NK model in the literature. There has been much work modifying and expanding the basic model, and some of the following criticisms do not pertain to some versions of the model. It may be that the following criticisms become moot as the basic NK model continues to be improved. The main argument here is that at the present time NK models are not likely to be good enough approximations of the economy to be trustworthy for evaluating Fed chairmen using the methodology of this paper and that the MC model is a better choice.

There are a number of reasons to think that the basic NK model is not a good approximation of the economy. First, the government and foreign sectors are ignored, both of which are important parts of the economy. Second, the aggregate demand equation seems much too simple. It does not take into account the different determinants of consumption and investment demand (as well as of import and export demand). In the MC model, for example, consumption is disaggregated into services, nondurables, and durables, and investment is disaggregated into residential, nonresidential fixed, and inventory. The estimated equations for these six categories are quite different. For example, stock effects are different. The initial stock of durable goods affects durable spending; the initial stock of housing affects housing investment; the initial stock of capital affects nonresidential fixed investment; and the initial stock of inventories affects inventory investment. Also, there are important initial wealth effects (driven mostly by stock market fluctuations) on consumption. Other key explanatory variables in the consumption and housing investment equations are after-tax real income and interest rates. There are thus many important variables missing from the right hand side of the NK aggregate demand equation. Third, the price equation of the basic NK model ignores wages.[9] In the MC model prices affect wages and vice versa,[10] and this specification has been found to fit the data better than the specification of a single price equation with no right hand side wage variable.[11]

Regarding the use of the basic NK model to analyze monetary policy, one of its key properties seems wrong.[12] In the NK model a positive price shock with the nominal interest rate held constant is explosive (or in some cases indeterminate): inflation increases from the price equation, demand increases from the aggregate demand equation because the real interest rate falls, inflation increases more from the price equation, and so on. In order for the model to be stable, the nominal interest rate must be increased more than the rate of inflation, and so the coefficient on the inflation rate in the nominal interest rate rule must be greater than one. In the MC model, on the other hand, not only is a positive price shock with the nominal interest rate held constant not explosive, it is in fact contractionary. First, real wealth falls, which negatively affects consumption demand. Second, wages lag prices (a property of the estimated price and wage equations) and so real income falls, which also negatively affects consumption demand. Finally, the empirical

[9] A recent exception to leaving wages out of the model is Christiano, Eichenbaum, and Evans (2005), where both staggered wage and price contracts are postulated.

[10] This result is compatible with the theoretical model outlined above in that initial values of other firms' prices and wages affects the firm's price *and* wage decisions.

[11] Also, the results in Fair (2000) suggest that the long run dynamics of equations like the New Keynesian Phillips curve are not right given their focus on inflation rates rather than price levels. For present purposes, however, the more important criticism of the New Keynesian Phillips curve is that it ignores price and wage interactions. Dynamics are discussed in Section 3.

[12] A more extensive discussion of the following points is in Fair (2002).

results suggest that except for nonresidential fixed investment, nominal interest rates matter rather than real interest rates, and so there is no positive effect on demand from a lower real interest rate except for nonresidential fixed investment. The net effect from a positive price shock with the nominal interest rate constant is contractionary in the MC model. So not only does the Fed not have to raise the nominal interest rate more than the inflation rate to prevent an explosive reaction, it does not have to increase the nominal interest rate at all! If this property of the MC model is right, it suggests that the NK model is likely to lead a monetary authority to overreact to an positive inflation shock since the contractionary effects of the shock are not taken into account.

Another way of evaluating the NK model is to see how well it explains the actual data, in this case the data on output and inflation. A useful procedure for comparing models is to compute and compare outside-sample (i.e., outside the estimation period) root mean squared errors (RMSEs). Ireland (2004) computes outside sample RMSEs for a RBC model; Del Negro, Schorfheide, Smets, and Wouters (2006) do the same for a NK model; and outside sample RMSEs are computed in Fair (2004) for the United States part of the MC model. The prediction periods used in these three cases are close enough to allow at least a rough comparison across models to be made. The RMSEs are presented in Table 2.

The "US" model uses actual values of the exogenous variables, and the "US+" model uses forecasted values of the exogenous variables. Ireland considers two versions of the RBC model, a "hybrid" version and a "diagonal" version. He does not compute eight-quarter-ahead predictions, and the model does not include a price variable. The prediction periods and table references are presented at the

Table 2
Outside Sample RMSEs
(percentage points)

	Model	Real GDP Qtrs ahead 4	Real GDP Qtrs ahead 8	GDP Deflator Qtrs ahead 4	GDP Deflator Qtrs ahead 8	No. Obs. Qtrs ahead 4	No. Obs. Qtrs ahead 8
1.	US	1.02	1.46	0.78	1.39	76	72
2.	US+	1.33	1.84	0.87	1.52	76	72
3.	Hybrid RBC	3.45				70	
4.	Diagonal RBC	2.16				70	
5.	NK	2.62	6.05	0.88	1.70	55	51

• Rows 1 and 2 rows from Fair (2004), Table 14.1, p. 166.
• Rows 3 and 4 from Ireland (2004), Table 5, p. 1218.
• Row 5 computed from Del Negro et al. (2006), Table 2, p. 36.
• Basic prediction periods: 1983.1–2002.3 for rows 1 and 2; 1985.1–2002.2 for rows 3 and 4; 1985.4–2000.1 for row 5.

bottom of Table 1. There are 76 four-quarter-ahead observations for the US and US+ models, 70 for the RBC models, and 55 for the NK model.

Table 2 shows that the NK model does poorly regarding real GDP. The four-quarter-ahead RMSE is about twice a large as those for the US and US+ models, and the eight-quarter-ahead RMSE is over three times as large. For the four-quarter-ahead results, the NK model is better than the hybrid RBC model, but worse than the diagonal RBC model. The NK model is much closer to the US and US+ models for the GDP deflator. These results thus suggest that the NK aggregate demand equation is not well specified, a point argued above.

Another way of testing the NK model is to test the assumption of rational expectations, which play a large role in the model. Although it is hard to test this assumption, results have generally not been supportive—see, for example, Fair (2004), Fuhrer and Rudebusch (2004), and Rudd and Whelan (2006). The results in Rudd and Whelan (2006) are particularly strong against the assumption of rational expectations in the new-Keynesian Phillips curve. Given the results to date, a useful working hypothesis would appear to be that expectations are not rational rather than rational.

To conclude, the methodology behind the MC model is to estimate approximations to decision rules. Given the heterogeneity of agents, the complexity of the actual decision making processes, the complexity of the interactions among agents, and the quality of the macro data, it may be too much to expect that a good approximation of the economy can be obtained by directly estimating the parameters of a representative-agent theoretical model like that of the NK model. It may be better to settle for estimated approximations to decision rules. And if expectations are not rational, the Lucas critique is not likely to be a problem. The basic NK model does not appear trustworthy for analyzing monetary policy issues. Models more tied to the data are needed, and the MC model is one alternative. Table 3 summarizes the comparison of the basic NK model and the MC model discussed in this section.

Table 3
The Basic NK Model versus the MC Model

Property	NK Model	MC Model
Intertemporal optimization?	Yes.	Yes.
Rational expectations?	Yes.	No.
Imperfect competition?	Yes.	Yes.
Costly price adjustment?	Yes.	No.
Estimation.	Parameters of the theoretical model are calibrated or estimated.	The theoretical model is used to guide the specification of the econometric model, which is then estimated. No calibration for ecoometric model.
Demand disaggregation.	One aggregate demand equation.	Three consumption equations: services, nondurables, durables; three investment equations: nonresidential fixed, residenial, inventory; import demand equation.
Government sector?	Usually not.	Yes.
Foreign sector?	Usually not.	Yes.
Stock effects?	No.	Yes, on durable consumption, residential investment, nonresidential fixed investment, inventory investment.
Wealth effects?	No.	Yes, on the three categories of consumption.
Wage equation?	Usually not.	Yes, separately estimated wage and price equations.
Real versus nominal interest rate effects.	Real effects imposed.	Tested, where nominal interest rates generally dominate.
Effects of a positive price shock with the nominal interest rate held constant.	Explosive or indeterminant.	Contractionary.
Lucas critique a problem?	No.	Not under the assumptions about expectations.
Long run tradeoff between inflation and output?	No.	Lack of tradeoff not tested because of limited data; see last paragraph in Section 4.2. Relationship likely to be nonlinear.
Accuracy.	See Table 2.	See Table 2.

4 Some Properties of the MC Model[13]

4.1 Interest Rate Channels

It will be useful to outline the various channels through which interest rates affect output in the U.S. part of the MC model. Consider a decrease in the U.S. short term interest rate, say a policy change by the Fed. This decreases long term interest rates through estimated term structure equations. Interest rates appear as explanatory variables in the consumption, residential investment, and nonresidential fixed investment equations, all with negative coefficient estimates. In addition, decreases in interest rates have a positive effect on the change in stock prices through an estimated capital gains and losses equation, which has a positive effect on household wealth. This in turn has a positive effect on consumption because wealth appears as an explanatory variable in the consumption equations. Also, a decrease in U.S. interest rates (relative to other countries' interest rates) leads to a depreciation of the U.S. dollar through estimated exchange rate equations.[14] Other things being equal, this depreciation is expansionary because U.S. exports rise and U.S. imports fall. A decrease in interest rates thus has a positive effect on aggregate demand through these channels.[15]

[13]Some of the material in this section is in Sections 3.1, 3.2, and 3.3 in Fair (2007).

[14]A relative interest rate variable appears in the exchange rate equations for Canada, Japan, the United Kingdom, and Germany (Euroland after 1999). (All exchange rate equations are relative to the U.S. dollar.)

[15]There is one effect that works in the opposite direction. An decrease in interest rates decreases household interest income, which has a negative effect on household expenditures through a disposable income variable in the household expenditure equations. This effect is, however, smaller than the positive effects, and so the net effect of an interest rate decrease is positive.

4.2 The U.S. Price Equation

It will also be useful to outline the main price equation in the U.S. part of the MC model. In this equation the log of the price level (the private nonfarm price deflator) is regressed on a constant, the lagged logged price level, the log of the wage rate, the log of the import price deflator, the unemployment rate, and the time trend. The coefficient estimates are presented in Table 4. The cost variables are the wage rate and the import price deflator, and the demand variable is the unemployment rate. The time trend is added to pick up trend effects on the price level not captured by the other variables. Adding the time trend to this equation is like adding a constant term to an equation specified using the inflation rate rather than the price level.

This equation does well in various chi-squared tests—reported in Table A10, p. 206, in Fair (2004), with updated results on the website. No significant improvement in fit occurs when 1) the logged price level lagged twice, the log of the wage rate lagged once, the log of the import price deflator lagged once, and the unemployment rate lagged once are added as explanatory variables, 2) the equation is estimated under the assumption of fourth order serial correlation of the error term, 3) the log of the wage rate led once is added, 4) the log of the wage rate led four times is added, 5) the log of the wage rate led eight times is added, and 6) an output gap variable is added. When the output gap variable is added, the unemployment rate retains its significance, and so it dominates the output gap as an explanatory variable.

If the wage rate variable were dropped from the equation in Table 4 and the equation were specified as an inflation equation rather than a price-level equation,

Table 4
U.S. Price Equation
LHS Variable is $\log PF$

RHS Variable	Coef.	t-stat.
cnst	-0.036	-3.21
$\log PF_{-1}$	0.881	92.56
$\log W$	0.040	3.36
$\log PIM$	0.050	21.23
$UR/100$	-0.177	-7.40
time trend	0.00032	9.88
SE	0.00343	

- PF = private nonfarm price deflator.
- W = nominal wage rate adjusted for labor productivity.
- PIM = import price deflator.
- UR = unemployment rate.
- Estimation period: 1954:1–2006:1.
- Estimation method: 2SLS.

the coefficient on $\log PF_{-1}$ would be one. In addition, if lagged inflation were added as an explanatory variable to the inflation equation, this would introduce $\log PF_{-2}$ with restrictions on the coefficients of both $\log PF_{-1}$ and $\log PF_{-2}$. These restrictions were tested in Fair (2000) and updated to other countries in Chapter 4 in Fair (2004). They were rejected for the United States and generally rejected for the other countries. They suggest that the price equation should be specified in terms of price levels rather than inflation rates or changes in inflation rates. Using *changes* in inflation rates is off by two derivatives!

The wage equation in the U.S. part of the MC model has $\log W$ on the left hand side and on the right hand side: the constant, $\log W_{-1}$, $\log PF$, $\log PF_{-1}$, and the time trend. The price and wage equations are identified because $\log PIM$ and

UR are excluded from the wage equation, and $\log W_{-1}$ is excluded from the price equation. In the estimation of the wage equation a long run restriction was imposed regarding the real wage, which is that the derived real wage equation does not have on the right hand side the price level separately or the wage rate separately. This restriction is not rejected by the data. The price and wage equations were tested in Fair (2000) and (2004, Chapter 4) against standard NAIRU equations, and they lead to considerably more accurate price level and inflation predictions. This is consistent with the rejection of the NAIRU dynamics mentioned above.

A long run property of the price and wage equations is the following. If, say, the unemployment rate is permanently decreased by one percentage point, the price level is permanently higher, but the inflation rate converges back to its initial value. There is no permanent effect on the inflation rate. The evidence in favor of this property is the lack of rejection of the restrictions discussed above.

Regarding this long run property, it is obviously not sensible to think that the unemployment rate can be driven to zero with no permanent effect on the inflation rate. The problem in my view with the specification in Table 4 (or with specifications in terms of inflation rates or changes in inflation rates) is the linearity assumption regarding the effect of the unemployment rate or measures of the output gap on the price level (or the inflation rate or the change in the inflation rate). At low levels of the unemployment rate, this effect is likely to be nonlinear. I have tried for both the United States and other countries to pick up nonlinear effects, but there appear to be too few times in which the unemployment rate is very low (or the output gap very small) to allow sensible estimates to be obtained. This does not mean, however, that the true functional form is linear, only that the data are insufficient for estimating the true functional form. What this means regarding the MC model is that one should not run experiments in which unemployment rates or output gaps are driven to historically low levels. Price-level or inflation-rate equations are unlikely to be reliable in these cases.

4.3 The US(EX,PIM) Model

The optimal control procedure described in the next section is too costly in terms of computer time to be able to be used for the entire MC model, and a subset of the model, denoted the "US(EX,PIM)" model, has been used. This model is exactly the same as the model for the United States in the overall MC model except for the treatment of U.S. exports (EX) and the U.S. price of imports (PIM). These two variables change when the short term interest rate (RS) changes—primarily because the value of the dollar changes—and the effects of RS on EX and PIM were approximated in the following way.

First, for given values of α_1 and α_2, $\log EX_t - \alpha_1 RS_t$ was regressed on a constant, t, $\log EX_{t-1}$, $\log EX_{t-2}$, $\log EX_{t-3}$, and $\log EX_{t-4}$, and $\log PIM_t - \alpha_2 RS_t$ was regressed on a constant, t, $\log PIM_{t-1}$, $\log PIM_{t-2}$, $\log PIM_{t-3}$, and $\log PIM_{t-4}$. The estimation period was 1976:1–2006:1. Second, these two equations were added to the US(EX,PIM) model, and an experiment was run in which RS was exogenously decreased by one percentage point. This was done many times for different values of α_1 and α_2. The final values of α_1 and α_2 chosen were ones whose experimental results most closely matched the results for the same experiment using the complete MC model. The final values chosen were

-.0004 and -.0007, respectively.

The EX and PIM equations were not used for Martin because his period was one of fixed exchange rates. For Martin EX and PIM were simply taken to be exogenous.

5 The Loss Functions and Optimal Control Procedure

The loss in quarter t is assumed to depend on the deviation of the inflation rate ($\dot{PD}_t$) from a target value of 1.5 percent[16] and the deviation of the unemployment rate (UR_t) from a target value of 3.5 percent. More specifically, the total loss for quarter t is assumed to be:

$$\begin{aligned} H_t = \lambda_1(\dot{PD}_t - 1.5)^2 + \lambda_2(UR_t - 3.5)^2 + 1.0(RS_t - RS_{t-1})^2 \\ +1.0/(RS_t - 0.499) + 1.0/(16.001 - RS_t) \end{aligned} \tag{1}$$

where λ_1 is the weight on inflation deviations and λ_2 is the weight on unemployment deviations. The last two terms in (1) insure that the optimal values of RS will be between 0.5 and 16.0. The middle term penalizes changes in RS. The choice of target values and weights is discussed in Section 6.

The optimal control procedure is as follows. Take the control period of interest to be 1 through T. For example, for Martin 1 is 1954:1 and T is 1969:4. The

[16] PD in the model is the price deflator for domestic sales, and this is the price variable that the Fed is assumed to care about. It differs from PF, the private nonfarm price deflator, which is the price variable explained in Table 4. PD, contrary to PF, includes import prices and excludes export prices. It is close in concept to the consumer price index. The exact definitions of PD and PF are in Fair (2004) and on the website.

control variable is the three-month Treasury bill rate, RS.[17] Consider computing the optimal value of RS for quarter 1, RS_1^*. The loss function that is minimized is assumed to be the expected value of the sum of the quarterly losses:

$$L_1 = \mathcal{E}_1 \sum_{t=1}^{k} H_t \tag{2}$$

where $\mathcal{E}_1$ denotes the expected value using information available at the time the decision is made and where k is a large number discussed below. This is not a linear–quadratic control problem because the US(EX,PIM) model is nonlinear and the loss function is not completely quadratic. Consequently, optimal feedback equations cannot be derived. Only approximate solutions are available.

When solving this problem the Fed is assumed to know the US(EX,PIM) model, the current and future values of the exogenous variables,[18] and the error terms (shocks) for quarter 1. The error terms for quarters 2 and beyond are set to zero, their expected values. The assumption that the Fed knows the US(EX,PIM) model may bias the results against the early Fed chairmen if the model that they actually had at their disposal was less accurate than the model that later chairmen had. For the results in this paper all the Fed chairmen are assumed to have the same knowledge about the economy, namely the US(EX,PIM) model. The main exogenous variables in the US(EX,PIM) model are fiscal-policy variables, and so the assumption here is that the Fed knows future fiscal-policy plans. Since the Fed meets more than once a quarter and since RS is the average value for the quarter, the assumption that the Fed knows the shocks for quarter 1 is not unreasonable. The

[17] The actual control variable of the Fed is the federal funds rate, but this rate and RS are so highly correlated that it makes little difference which is used.

[18] The relaxation of this assumption that the current and future values of the exogenous variables are known is discussed in Section 6.

Fed is essentially assumed to have a good idea of what is going on in the quarter in which it is making its decisions.

Given these assumptions, the problem of minimizing L_1 is converted into a deterministic control problem, where the first quarter errors are the actual historical errors and the future errors are all zero. The problem is to choose values of RS_t, $t = 1, \ldots, k$, to minimize L_1 subject to the US(EX,PIM) model. This problem can be solved by the method in Fair (1974b), which sets up the problem as an unconstrained nonlinear optimization problem and uses an optimization algorithm like DFP to find the optimum.

Although optimal values of RS are computed for quarters 1 through k, only the value for quarter 1 is actually implemented. Consequently, k only needs to be large enough to make RS_1^*, the optimal value for quarter 1, insensitive to larger values of k. For the work in this paper k was taken to be 32 quarters. Making k larger than this had a trivial effect on the computed optimal value of RS for the first quarter.

Once RS_1^* is computed, the problem switches to quarter 2. The model is solved for quarter 1 using RS_1^* and the actual error terms for quarter 1 (which the Fed is assumed to have known), and the problem that begins with quarter 2 runs off of this base. Everything is the same except that t now runs from 2 through $k+1$. In particular, the Fed is now assumed to know the actual error terms for quarter 2. Once RS_2^* is computed, the problem switches to quarter 3, and so on. Altogether T deterministic control problems are solved, resulting in $RS_1^*, RS_2^*, \ldots, RS_T^*$.[19] The

[19]Remember that there are actually $T \cdot k$ optimal values computed, but only the first value from each deterministic control problem is used. For example, RS_2^* is the first optimal value from the solution of the control problem than begins in quarter 2 and ends in quarter $k+1$.

economy that would have existed if these values had been chosen is obtained by solving the model for quarters 1 through T using these values of RS and the actual error terms. The endogenous variable values in this economy can then be compared to the actual endogenous variable values. The endogenous variable values that are obtained from the solution of the model using $RS_1^*, RS_2^*, \ldots, RS_T^*$ and the actual error terms will be called the "optimal" values. As just noted, behind these values are the solutions of T deterministic control problems.

It will be useful to let Z denote the mean loss:

$$Z = \frac{1}{T_2 - T_1 + 1} \sum_{t=T_1}^{T_2} H_t \tag{3}$$

where T_1 through T_2 is the period of the particular Fed chairman of interest. Z is computed in the next section for each Fed chairman's period for the actual values of $\dot{PD}_t$ and UR_t and the "optimal" values obtained from the solutions of the optimal control problems.

6 Results

The Four Loss Functions

The results of any optimal control exercise obviously depend on the choice of target values and weights in the loss function. The target value of 3.5 percent for UR, the unemployment rate, is smaller than all values except three under Martin, 1968:4–1969:2, where the value was 3.4 percent. The largest value of UR in the 1954:1–2005:4 period is 10.68 percent in 1982:4 under Volcker. The rate of inflation, $\dot{PD}$, can be erratic on a quarterly basis. Looking at its four-quarter moving average, this average is smaller than 1.5 percent, the target value for $\dot{PD}$, for 31 quarters under Martin, 1954:1–1955:2 and 1958:1–1964:1, and 13 quarters under Greenspan, 1994:2, 1997:2–1999:1, and 2001:4–2002:3. The largest value of the four-quarter moving average is 12.03 percent in 1974:4 under Burns. Because of the larger range of the inflation values, the choice of a target value for inflation is more problematic than the choice for the unemployment rate. Given the inflation target of 1.5 percent and the quadratic specification, if, say, inflation is lowered from 8 percent to 7 percent, this has a much larger effect on Z than if inflation is lowered from 3 percent to 2 percent. Most people would probably agree that lowering from 8 to 7 should be given more points that lowering from 3 to 2, but it could be that the quadratic over does it and that different target values should be used for different chairmen. The choice here, however, was to use the same target value and examine the sensitivity of the results to different λ weights.

Four sets of values of λ_1 and λ_2 were tried, denoted "Hawk," "Owl," "Dove," and "Dove$^+$." Hawk weights inflation loss three times as much as unemployment loss: $\lambda_1 = 3/2$ and $\lambda_2 = 1/2$; Owl weights inflation loss twice as much as the unemployment loss: $\lambda_1 = 4/3$ and $\lambda_2 = 2/3$, Dove weights the two equally: $\lambda_1 = 1$ and $\lambda_2 = 1$, and Dove$^+$ weights inflation loss half as much as unemployment loss: $\lambda_1 = 2/3$ and $\lambda_2 = 4/3$.[20]

There are 208 quarters in the overall sample period, and so with four loss

[20] It was not easy choosing a bird between a hawk and a dove. Switzerland is a neutral country and I thought of using its national bird, but it has no national bird. Canada is another possibility, but its national bird is the loon, which has other meanings that one would not want to attribute to monetary policy makers. However, three of Canada's provinces, Alberta, Manitoba, and Quebec, have the owl as their bird, and the owl is associated with wisdom, a characteristic that monetary policy makers should have. So I chose the owl. My wife, Sharon Oster, who never seems to take macroeconomics very seriously, suggested tit willow.

functions tried, a total of 832 deterministic control problems were solved. With a few exceptions, the length of the horizon for each problem was 32 quarters.[21]

The choice of a weight of 1.0 on the $(RS_t - RS_{1-1})^2$ term in (1) with λ_1 and λ_2 summing to 2.0 was made after some experimentation. The aim was to have the standard deviation of the optimal values of RS be about the same as the standard deviation of the actual values of RS.

The results that are presented in Table 5 can be used to examine both the question of how well a non-optimizing chairman could have done had he minimized various loss functions and the question of what loss function an optimizing chairman approximately used. The variables listed in Table 5 per chairman and per loss function are 1) the actual and optimal values of Z, 2) the average unemployment rate, $\bar{UR}$, 3) the average rate of inflation, $\bar{PD}$, 4) the average interest rate, $\bar{RS}$, 5) the standard deviation of the interest rate, SD_{RS}, 6) and the root mean squared error of the actual interest rate versus the optimal interest rate. The difference between Z actual and Z optimal is a measure of how much better a chairman could have done had he optimized. The root mean squared error is a measure of how close his actual values of RS are to the optimal values.

Regarding Z, it is important to note that it is not what is minimized in the optimal control calculations. Z is based on the solutions of $T_2 - T_1 + 1$ control problems, not just on one problem that minimizes it. In fact, there is no guarantee that the value of Z based on the actual values of inflation and the unemployment

[21] A forecast from the model between 2006:2 and 2009:4 was used to extend the sample period for the experiments, and so for Greenspan the end of the horizon was never greater than 2009:4. For Martin the end of the horizon was never greater than 1971:4. Having the horizon end after 1971 for Martin, which is the beginning of high inflation rates, led to erratic end-of-horizon effects, which is the reason for this constraint.

Table 5
Actual and Optimal Values

	Actual Values	Optimal Values for Loss Function: Hawk	Owl	Dove	Dove^{+}
	Greenspan (1987:4–2005:4)				
Z^{Act}	–	6.60	7.06	7.96	8.86
Z^{Opt}	–	6.02	6.79	8.05	9.09
$Z^{Act} - Z^{Opt}$	–	0.58	0.27	−0.09	−0.23
$\bar{UR}$	5.53	5.61	5.56	5.51	5.47
$\bar{PD}$	2.34	2.14	2.26	2.34	2.37
$\bar{RS}$	4.46	5.98	4.71	4.00	4.16
SD_{RS}	2.00	2.15	2.28	2.23	2.43
$RMSE_{RS}$	–	4.30	1.62	1.69	2.18
	Volcker (1979:4–1987:3)				
Z^{Act}	–	40.10	40.29	40.68	41.06
Z^{Opt}	–	35.76	36.71	37.60	38.87
$Z^{Act} - Z^{Opt}$	–	4.34	3.58	3.08	2.19
$\bar{UR}$	7.76	7.98	7.57	6.99	6.76
$\bar{PD}$	4.66	4.40	4.77	5.24	5.40
$\bar{RS}$	9.42	10.98	9.33	6.23	4.74
SD_{RS}	2.93	2.64	3.30	3.54	3.52
$RMSE_{RS}$	–	5.69	3.47	13.66	27.48
	Miller (1978:1–1979:3)				
Z^{Act}	–	107.05	96.58	75.65	54.72
Z^{Opt}	–	79.76	75.09	68.21	57.08
$Z^{Act} - Z^{Opt}$	–	27.29	21.49	7.44	−2.36
$\bar{UR}$	5.96	6.88	6.80	6.36	5.81
$\bar{PD}$	9.59	8.18	8.29	8.97	9.85
$\bar{RS}$	8.18	13.29	12.90	10.37	7.16
SD_{RS}	1.41	1.84	1.83	1.47	1.10
$RMSE_{RS}$	–	27.02	23.12	5.27	1.53
	Burns (1970:1–1977:4)				
Z^{Act}	–	55.10	51.13	43.18	35.23
Z^{Opt}	–	45.28	44.28	41.21	35.39
$Z^{Act} - Z^{Opt}$	–	9.82	6.85	1.97	−0.16
$\bar{UR}$	6.26	7.35	7.41	7.03	5.86
$\bar{PD}$	6.54	5.65	5.62	5.90	6.93
$\bar{RS}$	5.73	9.32	9.77	8.12	4.81
SD_{RS}	1.39	3.26	2.99	2.72	2.19
$RMSE_{RS}$	–	20.16	22.44	10.88	3.49
	Martin (1954:1–1969:4)				
Z^{Act}	–	7.29	7.25	7.16	7.08
Z^{Opt}	–	6.58	6.57	6.44	6.17
$Z^{Act} - Z^{Opt}$	–	0.71	0.68	0.72	0.91
$\bar{UR}$	4.89	4.73	4.74	4.74	4.72
$\bar{PD}$	1.97	1.99	1.98	1.99	1.99
$\bar{RS}$	3.37	3.04	2.89	2.63	2.42
SD_{RS}	1.45	1.99	1.75	1.38	1.21
$RMSE_{RS}$	–	2.51	2.22	2.38	3.02

Notes to Table 5

- See notes to Table 1.
- Z^{Act} = Actual value of Z.
- Z^{Opt} = Optimal value of Z.
- $\bar{UR}$ = mean of UR.
- $\bar{\dot{PD}}$ = mean of $\dot{PD}$.
- $\bar{RS}$ = mean of RS.
- SD_{RS} = standard deviation of RS.
- $RMSE_{RS}$ = root mean squared error, actual RS versus optimal RS.
- Hawk: $\lambda_1 = 3/2$ and $\lambda_2 = 1/2$ in equation (1).
- Owl: $\lambda_1 = 4/3$ and $\lambda_2 = 2/3$ in equation (1).
- Dove: $\lambda_1 = 1$ and $\lambda_2 = 1$ in equation (1).
- Dove$^+$: $\lambda_1 = 2/3$ and $\lambda_2 = 4/3$ in equation (1).

rate will be greater than the value of Z based on the predicted values of inflation and the unemployment rate using the computed optimal values of RS. Z is just meant to be a summary measure.

Greenspan

Table 5 shows that had Greenspan minimized loss function Hawk (using the procedure in this paper), he would have lowered the average loss that he actually obtained by 0.58 points (from 6.60 to 6.02). The average unemployment rate would have been 5.61 percent rather than 5.53 percent, the average inflation rate would have been 2.14 percent rather than 2.34 percent, and the average interest rate (the control variable) would have been 5.98 percent rather than 4.46 percent. For loss function Owl the potential gain is 0.27 points, and for loss functions Dove and Dove$^+$ the potential gain is negative (-0.09 and -0.23 points respectively). A negative potential gain means that Greenspan's actual behavior was better in terms of leading to a lower value of loss than what would have been achieved had the particular loss function been minimized using the procedure in this paper. Greenspan thus looks very good for Dove and Dove+ and fairly good for Owl. Hawk is a little worse. The root mean squared error is smallest for Owl and almost as small for Dove, and so under the assumption that Greenspan minimized a loss function, the loss function is approximately Owl or Dove. Greenspan is least close to minimizing loss function Hawk, since it has the highest root mean squared error.

Volcker

The gain that Volcker could have achieved by optimizing is also highest for Hawk and lowest for Dove$^+$, but even for Dove$^+$ the gain is positive (2.19 points). Regardless of the loss function, the results say that Volcker could have done better. Table 6 present the values by quarter for Volcker for loss function Owl. The table shows that Volcker allowed fairly large changes in the interest rate in the first three years of his term (primarily because he was trying to target the money supply in this period). The optimal control results in Table 5 are essentially saying that regardless of the loss function, Volcker should have smoothed more in his first three years. The root mean squared error is smallest for Owl, and so if Volcker minimized a loss function, the loss function is closest to Owl.

Burns

The results for Miller are based on only 7 observations, and so Miller will be skipped for now. The Burns results are quite clear. The potential gain is large for Hawk and Owl, moderate for Dove, and negative but close to zero for Dove$^+$. The root mean squared error is by far the smallest for Dove$^+$. So if Burns minimized a loss function, the loss function was closest to Dove$^+$. If he did not, his actual

Table 6
Volcker Results for Loss Function Owl

Quarter	RS^*	RS^a	UR^*	UR^a	$\dot{PD}^*$	$\dot{PD}^a$
1979.4	13.41	11.80	5.96	5.94	9.69	9.81
1980.1	15.20	13.46	6.38	6.30	11.48	11.79
1980.2	14.70	10.05	7.54	7.32	5.95	6.62
1980.3	14.88	9.24	8.14	7.68	8.30	9.35
1980.4	14.95	13.71	8.13	7.40	9.10	10.30
1981.1	14.73	14.37	8.37	7.43	8.29	9.47
1981.2	14.14	14.83	8.44	7.40	6.30	7.15
1981.3	12.76	15.09	8.40	7.42	7.88	8.29
1981.4	11.06	12.02	9.05	8.24	6.20	6.51
1982.1	9.41	12.89	9.40	8.84	5.82	5.63
1982.2	8.31	12.36	9.65	9.43	3.90	3.26
1982.3	6.96	9.71	9.77	9.94	5.35	4.37
1982.4	6.72	7.93	10.12	10.68	4.20	3.13
1983.1	6.97	8.08	9.53	10.40	2.34	1.14
1983.2	7.89	8.42	9.01	10.10	3.56	2.24
1983.3	8.59	9.19	8.14	9.36	6.30	4.98
1983.4	9.35	8.79	7.29	8.54	4.23	3.14
1984.1	10.03	9.13	6.68	7.87	4.73	3.85
1984.2	10.09	9.84	6.40	7.48	5.07	4.38
1984.3	9.50	10.34	6.54	7.45	3.28	2.76
1984.4	9.00	8.97	6.50	7.28	2.74	2.37
1985.1	8.01	8.18	6.61	7.28	4.07	3.86
1985.2	7.14	7.52	6.74	7.29	2.69	2.49
1985.3	6.26	7.10	6.75	7.21	2.45	2.33
1985.4	6.63	7.15	6.64	7.05	2.87	2.77
1986.1	6.95	6.89	6.64	7.02	2.06	2.03
1986.2	6.10	6.13	6.88	7.18	0.32	0.40
1986.3	5.46	5.53	6.77	6.99	3.30	3.43
1986.4	5.03	5.34	6.70	6.84	2.20	2.36
1987.1	5.42	5.53	6.56	6.62	1.80	2.02
1987.2	6.20	5.73	6.29	6.28	2.81	3.12
1987.3	6.74	6.03	6.11	6.01	3.49	3.89

- See notes to Table 1.
- ^{a} = actual value, * = optimal value.

behavior is poor for loss functions Hawk and Owl, medium for Dove, and good for Dove$^+$. The negative potential gain for loss function Dove$^+$ says that Burn's actual behavior was slightly better in terms of leading to a lower value of loss function Dove$^+$ than what would have been achieved had loss function Dove$^+$ been minimized using the procedure in this paper.

Martin

The potential gains for Martin do not vary much across the four loss functions, and, like for Volcker, the results say that Martin could have done better for all the loss functions. The root mean squared error is smallest for Owl, but the values for Hawk and Dove are close to that for Owl. Martin did not have an inflation problem between 1958 and 1963 in the sense that $\dot{PD}$ was below its target value of 1.5 percent during almost all of this period, and the optimal control results say that he should have lowered the unemployment rate more in this period. The average value of the actual interest rate in Table 5 for Martin is larger than that average value of the optimal interest rate even for loss function Hawk.

Miller

For what it is worth, given the small number of observations, the story for Miller is very similar to the story for Burns.

Comparisons Across Chairmen

So, was Greenspan the best of the five chairmen? The above discussion of the individual chairmen shows that this is a complicated question. The evaluation of Burns and Miller clearly depends on the loss function. For loss function Dove$^+$ both do fine, but otherwise not. The reason than Burns and Miller are generally judged unfavorably is probably because most people have loss functions that are much more hawkish than Dove^{+}. In other words, loss function Dove^{+} probably weights inflation loss relative to unemployment loss much too little for most people. And for loss function Owl, for example, Burns and Miller could have done much better.

The story is different for Volcker and Martin. The results say that both could have done better for any of the loss functions. Volcker could have smoothed more early in his term, and Martin could have lowered the unemployment rate during some of his term when inflation was not a problem.

Greenspan looks good across the four loss functions. The largest potential gain is for loss function Hawk, but even here the potential gain is small relative to the potential gains for the other chairmen. One could thus conclude that Greenspan is the best for loss functions Hawk, Owl, and Dove. For loss function Dove^{+} Greenspan, Miller, and Burns are essentially tied.

Robustness of the Results

The results are not sensitive to the assumption that the exogenous variable values are known. A second set of results was obtained using a version of the model in which a fifth-order autoregressive equation with a constant term and time trend was estimated for each exogenous variable except dummy variables, and these equations were added to the model. A total of 88 equations were added. This is a version of the model in which there are no exogenous variables except for a few dummy variables. The same optimal control procedure was applied to this version as was applied to the basic version. None of the above comparisons were changed using this version. The story for each chairman is the same.

Another set of results was obtained using 2.5 percent as the target value for inflation rather than 1.5 percent. This choice is somewhat problematic because the actual inflation rate is lower than 2.5 percent for many quarters, which implies, other things being equal, that the Fed in many cases should stimulate the economy to get the inflation rate back up. This choice also means that each loss function is less hawkish than it was before. The stories are also similar for this set of results, although Greenspan, Miller, and Burns look slightly better because of the less Hawkish loss functions. It is still the case that Volcker and Martin could have done better for all loss functions.

7 Conclusion

The results are summarized at the end of the previous section, and this will not be repeated here. The conventional wisdom that Miller and Burns did not do well is supported by the results unless one is very dovish. Volcker and Martin could have done better across all loss functions, and Greenspan did well across all loss functions. Assuming that each chairman minimized a loss function, the loss function that comes closest to matching this behavior is Owl for Greenspan, Volcker, and Martin, and Dove$^+$ for Miller and Burns.

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