A COMPARISON OF FIVE FEDERAL RESERVE CHAIRMEN: WAS GREENSPAN THE BEST?

By

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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 chooses for each chairman which of the various loss functions tried comes closest to matching the actual values of the control variable to the optimal values. 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 chooses for each chairman which of the various loss functions tried comes closest to matching the actual values of the control variable to the optimal values.

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). The loss functions are specified in terms of inflation and unemployment, with differing weights on the two. An overview of the MC model is presented in Section 3, and some of its properties are discussed in Section 4. The loss functions and optimal control procedure are discussed in

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[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.

Section 5, and the results are presented in Section 6.

The MC model is quite different from the macro model that is primarily used in the current literature, namely the "New Keynesian" (NK) model. Arguments for preferring the MC model over the NK model for monetary policy evaluation are presented in Section 2 in Fair (2007), and this discussion will not be repeated here. One of the main arguments for preferring the MC model is that it fits the data much better. In Section 3 a few of the differences between the MC and NK models are discussed, and in Section 6 some of the results in this paper using the MC model are compared to results using the NK model and other smaller models. Given the uncertainty that exists concerning the appropriate formulation of macroeconomic models, it is useful to examine macroeconomic questions with more than one type of model, which is another argument for using the MC model.

The way in which the Fed chairmen are compared in this paper does not appear to have been done before. Romer and Romer (2004) 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 and on the chairman's embrace or non-embrace of modern economic ideas. 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

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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.

There is also a related literature on estimating the parameters of the Fed's objective function along with the parameters of a model. Recent papers include Salemi (1995, 2006), Favero and Rovelli (2003), Ozlale (2003), and Dennis (2006). These papers deal with small linear models and a quadratic objective function, where closed form expressions can be obtained. Salemi (1995) uses a five-variable VAR model; Favero and Rovelli (2003), Ozlale (2003), and Dennis (2006) use versions of the two-equation Rudebusch-Svensson (1999) model; and Salemi (2006) uses a version of the NK model. These papers do not compare Fed chairmen in the way that is done in this paper, but some of their results are comparable to the results here. This is discussed at the end of Section 6.

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

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[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   An Overview of the MC Model[4]

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 what Goodfriend and King (1997) call the "New Neoclassical Synthesis" (NNS), upon which the NK model is based, namely intertemporal optimization and imperfect competition. (The other two features of the NNS are rational expectations and costly price adjustment.) Households maximize expected future

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[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]Some of the material in this section is in Section 2 in Fair (2007).

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. Expectations are not assumed to be rational, contrary to the NNS. 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]

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[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 NNS, where there are adjustment costs to changing prices. The assumption of costly price adjustment is, of course,

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 in the theoretical model, 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 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.

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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.

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. There can thus be unintended inventory

investment and unemployment.

Regarding 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 (1976) critique if expectations are not rational.[6] More specifically, agents are assumed to form future expectations on the basis of past values, where the parameters multiplying these values are constant. Expectations are backward looking in this sense. The parameters in the expectation equations are assumed not to depend on the parameters in the model: expectations not model consistent (rational). In the specification of a decision equation to estimate, if expected future values influence the current decision (which is usually the case), these values are substituted out by replacing them with the lagged values upon which they are assumed to depend. The decision equation is then estimated with these values included. If the parameters in the expectation equations are constant,

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

then this substitution does not introduce non constant parameters in the decision equation. It is usually not the case that one can back out from the estimated decision equation the parameters of the expectations equations, but there is usually no need to do so. Under the above assumptions, expectations have been properly accounted for in the decision equation.

This treatment of expectations does not mean that policy changes have no effect on behavior. Say that the Fed announces a new policy regime, one in which it is going to weight inflation more than it has done in the past. If expectations are rational, this announcement will immediately affect them and thus immediately affect current decisions. Current decisions can be affected even before the Fed has actually changed the interest rate. In the treatment here expectations and thus decisions will be affected only after the interest rate has been changed. Decisions respond to policy changes, but only in response to actual changes in the policy variables. Announcements of new policy rules and the like have no effect on decisions because agents don't know the model and thus don't use it to form their expectations. If expectations were rational, the parameters would change as regimes change, with the Lucas critique then being relevant. In the current treatment the parameters of the estimated decision equations are constant across policy regimes, although the decisions obviously change as the policy variables change.

The equations of the MC model are estimated by two-stage least squares,[7]

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[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.

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]

4 Some Properties of the MC Model[9]

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

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[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.

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

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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.[10] 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.[11]

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 2. 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.

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[10]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.)

[11]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.

Table 2
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.

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 2 and the equation were specified as an inflation equation rather than a price-level equation, 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.

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 unemployment rate was also tried as an explanatory variable in the wage equation, but it was not close to being significant. The price and wage equations are identified because $\log PIM$ is 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 2 (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.

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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[12] 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:

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

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 control variable is the three-month Treasury bill rate, RS.[13] 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:

$$L_1 = E_1 \sum_{t=1}^{k} H_t \tag{2}$$

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[12]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 2. 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.

[13]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.

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where 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, closed-form optimal feedback equations cannot be derived. Only approximate solutions are available.

No discounting is done in equation (2). Whatever one thinks about whether or not the Fed should discount the future, as a practical matter it is very hard to get sensible estimates of discount factors. For example, none of the five papers mentioned in the Introduction that use the linear-quadratic setup estimate the discount factor. A value is simply imposed, ranging across studies from 0.975 to 1.0. Dennis (2006) examines the sensitivity of his results to values between 0.95 and 1.0 and finds that the results are not sensitive to this range. In this paper a value is also simply imposed, namely 1.0.

When solving this problem the Fed is assumed to know the US(EX,PIM) model, the current and future values of the exogenous variables,[14] 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 assump-

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[14]Results were also obtained relaxing this assumption that the current and future values of the exogenous variables are known. This is discussed in Section 6.

tion 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 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 $RS_1^*, RS_2^*, \ldots, RS_T^*$.[15] The 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 $\dot{P}D_t$ 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

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[15]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 $k + 1$.

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, $\dot{P}D$, 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 $\dot{P}D$, 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.[16]

It should be noted that if one's economic model had the concept of a natural rate of unemployment in it, then the model's estimate of the natural rate would be an obvious value to use for the target unemployment rate. If the natural rate changed over time, then the target would change. As noted at the end of Section 4.2, the present model has no concept of a natural rate. There is undoubtedly some low value of the unemployment rate at which the relationship between the

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[16]Results were also obtained using an inflation target of 2.5 percent. This is discussed in Section 6.

price level and the unemployment rate becomes severely nonlinear, but this value cannot be estimated. If it could, this value (or perhaps a value slightly greater than it) would be a candidate for the target value. Again, if this value changed over time, the target would change. Since there is no evidence on this, the target value of the unemployment rate was simply taken to be roughly the smallest value in the sample period, namely 3.5 percent.

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 $\lambda_2 = 4/3$.[17]

There are 208 quarters in the overall sample period, and so with four loss 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.[18]

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

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[17]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.

[18]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.

standard deviation of the optimal values of RS be about the same as the standard deviation of the actual values of RS. The use of the $(RS_t - RS_{1-1})^2$ term leads to interest rate smoothing. Without a term like this, the computed optimal values can be quite erratic, much more erratic than what is ever found in practice. All five of the papers mentioned in the Introduction that use the linear-quadratic setup find significant interest rate smoothing.

The results that are presented in Table 3 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 3 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

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	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

- 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 3 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 4 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 3 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 4
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 Burns' 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 $\dot{P}D$ 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 3 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

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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

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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.

Comparison to Other Results

The primary concern of the five papers mentioned in the Introduction, Salemi (1995, 2006), Favero and Rovelli (2003), Ozlale (2003), and Dennis (2006), is to estimate the parameters of the objective function of the Fed along with the parameters of the model. This concern is related to the second way of evaluating Fed chairmen in this paper, namely choosing for each chairman which of the various loss functions tried comes closest to matching the actual values of the interest rate to the optimal values. In the present case, however, the problem cannot be set up as a linear-quadratic problem because the model is nonlinear, and so the estimation approach of these papers cannot be followed. The model is instead estimated separately (by 2SLS), and the λ weights are simply chosen to minimize the root

mean squared error of the actual interest rate values versus the optimal values.[19] In spite of these differences, there is a common result. All five papers find that the Fed weighted inflation more relative to output in the Volcker-Greenspan period than before.[20] This is consistent with the result in this paper that objective function Owl is closest for Volcker and Greenspan and that objective function Dove$^+$ is closest for Miller and Burns. However, for the period prior to 1970:1, the objective function is back to Owl (for Martin).

With one exception these studies do not address the first way of evaluating Fed chairmen in this paper, which is to compare actual to optimal behavior. They simply assume that the Fed optimized. The exception is Salemi (2006), who estimates the parameters of a policy rule rather than the parameters of the objective function. This allows him to compare the parameter estimates with and without the assumption that the Fed optimizes. He finds that the Fed could have lowered loss by 3.1 percent in the period 1965:1–1980:4 and by 0.5 percent in the period 1980:1–2001:4. This difference is roughly consistent with the results for, say, loss function Owl in Table 3, where $Z^{Act} - Z^{Opt}$ is smaller for Greenspan and Volcker than for Miller and Burns. This is not true, however, for a loss function like Dove$^+$.

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[19]The models are also, of course, quite different from the US(EX,PIM) model. Salemi (1995) uses a five-variable VAR model. The Rudebusch-Svensson (1999) model, used by Favero and Rovelli (2003), Ozlale (2003), and Dennis (2006), is a (backward-looking) two-equation model where the output gap depends on lagged output gaps and the lagged real interest rate and the inflation rate depends on lagged inflation rates and the lagged output gap. Salemi (2006) uses a (forward-looking) two-equation NK model where the output gap depends on lagged output gaps, the expected future output gap, and the real interest rate and the inflation rate depends on the lagged inflation rate, the expected future inflation rate, and the output gap.

[20]Actually, Dennis (2006) never found the output gap to be significant in the Fed's objective function, but he did find the inflation target to be smaller in the Volcker-Greenspan period than before, namely 1.4 percent versus 7.0 percent before.

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. Under the assumption 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.

Since the assumption that the Fed chairmen optimized is a strong one and since the first way of evaluating Fed chairmen in this paper does not require this assumption, most of the weight should probably be placed on this set of comparisons, namely the $Z^{Act} - Z^{Opt}$ values in Table 3. These comparisons are based on the assumption that each Fed chairman could have had the US(EX,PIM) model available for use and could have minimized a loss function in the manner discussed in Section 5. The main requirement for minimizing the loss function is that the error terms for the current quarter are known. As discussed above, the results are not sensitive to the assumption that the current and future exogenous variable values are known. It is an open question on how robust the present conclusions are to the use of different models and informational assumptions.

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