It's What They Do, Not What They Say: How to Infer the Stabilization Objectives of a Central Bank

Michael K. Salemi*
Department of Economics
CB 3305, Gardner Hall, UNC-CH
Chapel Hill, NC 27599-3305 USA
Michael_Salemi@unc.edu

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I first visited the Graduate Institute of International Studies in 1982. Alexander Swoboda and Hans Genberg had been awarded a Swiss National Science Foundation grant to study the effect on Switzerland of foreign economic shocks. Alexander and Hans planned to undertake a statistical analysis using Vector Autoregressions and needed a project overseer. They had originally recruited Richard Meese but, late in the Spring, Meese discovered that he could not come.

It thus happened that I received a "cold call" one April evening asking me to join the research team. My immediate reaction was that it was too late to ask for a leave. Teaching assignments had been set and the market for visitors concluded. But, as I told Hans, the opportunity was too good for me to assume that a leave could not be arranged. And so, expecting the worst, I made an appointment to see my department chair.

Sometimes the gods smile. My department chair agreed that the opportunity was too good to pass up. And so, family in tow, I arrived in Geneva the following August to begin a personal and academic adventure that has provided rich opportunities and a lots fun from then until today.

The project went well. Alexander, Hans and I were able to publish its findings (Genberg, Salemi and Swoboda, 1983 and 1985). Good things led to others and within a couple of years we began to study Swiss monetary policy. In particular, we were interested in whether a formal analysis would confirm conventional wisdom that the Swiss National Bank (SNB) was an "inflation hawk." The claim was not obviously true since estimates of the SNB reaction

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function showed that it responded to many different variables including the exchange rate. The SNB project was my first attempt to use inverse control and began a research program that I have been working on ever since. It is that program, which owes its beginning to Alexander, Hans, and HEI, that is the subject of this paper. Ironically, as I will explain later, the program has cycled back to once again consider Swiss monetary policy.

I first offer a non-technical explanation of inverse control built. I describe decisions that a researcher must make to undertake an inverse control analysis. I explain how several coauthors and I have used inverse control to study central bank policy in a variety of settings. Finally, I connect inverse control to some of Alexander's published ideas.

1 What Is Inverse Control?

In the standard control problem, a researcher begins with hypotheses about the economic environment and an agent's objectives and derives a rule for the agent's behavior–the mapping from the environment to the agent's choice variable that provides the highest value of the agent's objective function. Inverse control is inferring the parameters of the agent's objective function from the agent's actions. Both techniques depend crucially on the assumption that the agent behaves optimally.

In a monetary policy application of inverse control, the decision maker is the central bank and the objective function describes central bank preferences. The central bank may be assumed to minimize a loss function or maximize utility of a representative agent. The rule of the central bank is a reaction function that explains how the bank adjusts its policy instrument to changes in the economic environment. The environment is represented by a model that explains the evolution of the endogenous variables that the bank is trying to stabilize or that affect the utility of the representative agent.

Given an estimated structural model and a characterization of central bank stabilization objectives, the control theory exercise is to find the optimal coefficients of the reaction function. The inverse control theory exercise is to infer the values of the central bank objective function from estimates of the parameters of the economic model and the bank reaction function.

1.1 A Simple Example

The following model, while too simple, provides a useful illustration of inverse control. Let y and p be percentage departures of output and inflation from target values. Let u and v be serially uncorrelated random shocks to aggregate demand and supply and let r be the short-term interest rate used by the bank as its policy instrument. Suppose that y, p and r evolve according to:

$$\begin{aligned} y_t &= a y_{t-1} - b r_t + u_t \\ p_t &= \alpha p_{t-1} + \beta r_t + v_t \\ r_t &= \theta_1 u_t + \theta_2 v_t \end{aligned}$$

The first equation is a stylized IS schedule in which output is inversely related to the short term interest rate and u is a demand shock. The second equation is a stylized Phillips schedule in which inflation is also affected by r, possibly because changes in r proxy for changes in aggregate demand. The Phillips curve is specified simply so that it is easy to derive the optimal values for the reaction function coefficients. The third equation is a reaction function that allows the central bank to react to demand and supply shocks. Let $Var(x)$ be the unconditional variance of x and suppose that the central bank minimizes

$$L = Var(p_t) + \lambda Var(y_t))$$

where λ measures the relative importance to the central bank of stabilizing output. The reduced form equations for y and p are:

$$\begin{aligned} y_t &= a y_{t-1} + (1 - b\theta_1) u_t - b\theta_2 v_t \\ p_t &= \alpha p_{t-1} + \beta\theta_1 u_t + (1 + \beta\theta_2) v_t \end{aligned}$$

Assume for simplicity that $\sigma_{uv} = 0$. Straightforward manipulation of the partial derivatives of L with respect to $\theta_1$and θ_2 shows that the loss minimizing coefficients of the reaction function are:

$$\begin{aligned} \theta_1^* &= \frac{1}{b} \frac{b^2 \lambda (1 - \alpha^2)}{(1 - a^2)\beta^2 + \lambda b^2 (1 - \alpha^2)} \\ \theta_2^* &= \frac{-(1 - a^2)\beta}{(1 - a^2)\beta^2 + \lambda b^2 (1 - \alpha^2)} \end{aligned} \tag{1}$$

Even for this very simple model, the optimal settings of the reaction function coefficients are non-linear functions of all the model parameters. Only in special cases will the mapping simplify in an intuitive way. If for example $\lambda = 0$, the optimal values of θ_1 and θ_2 are zero and $-\frac{1}{\beta}$. When the central bank cares only about stabilizing the inflation rate, it will completely offset the Phillips curve shock and not respond to the demand shock. As $\lambda \to \infty$, optimal θ_2 converges to zero and optimal θ_1 converges to $\frac{1}{b}$ because when the bank cares only about stabilizing output, it will completely offset the demand shock and not respond to the Phillips curve shock. In general, the central bank will respond to both demand and supply shocks in a way that allows the researcher to infer λ, the relative importance to the bank of stabilizing output.

How would inverse control work in the context of this simple model? The six parameters of the three equation system for y, p, and r are exactly identified without the auxiliary restriction that the central bank minimizes L. The optimal policy restriction introduces one new parameter, λ, and imposes two new restrictions across the six parameters implying overidentification. Using inverse control amounts to estimating the five free parameters of the model (a, α, b, β, and λ) while constraining θ_1 and θ_2 to equal θ_1^* and θ_2^*. A test of the joint hypothesis that the model and loss function are correctly specified and that the central bank minimizes loss is based on the likelihood ratio that compares the fit of the restricted model with the fit of the model when a, α, b, β, θ_1 and θ_2 are treated as free parameters. Estimating the model subject to the optimal policy restrictions provides an estimate of λ and a test of the optimality hypothesis.

1.2 Literature

Friedlaender (1973) makes the point that one may not infer the objectives of policy makers by casual inspection of their policy rules because reaction function coefficients are combinations of preference function and model parameters. Chow (1975, 1981) provides an early introduction to control and inverse control. Hansen and Sargent (1980) and Sargent (1987) show how to apply control theory to a variety of economic problems. Taylor (1979) provides an early application of control theory to monetary policy.

Others have used an inverse control approach to study monetary policy. Dennis (2005) argues that the reason for the apparent disconnect between optimal and historical policies is that counterfactual policy analysis is often carried out using a parameterized loss function that is inconsistent with outcomes observed in U.S. data. Favero and Rovelli (2003), Ozlale (2003), and Dennis (2005) estimate backward-looking models of aggregate demand and supply subject to an auxiliary condition that the policy rule minimizes a quadratic loss function. Salemi (2006) and Dennis (2004) demonstrate how to expand the inverse control analysis of policy to forward-looking models embodying rational expectations. Dennis, Leitemo, and Soderstrom (2006) use robust control techniques to study the effects of model uncertainty on U.K. monetary policy.

2 Implementing Inverse Control

Undertaking an inverse control analysis of central bank policy involves several decisions. The first is how to model state transition. One possibility is a VAR although the Lucas critique argues against using the estimated model to predict the implications of alternative policies. Another possibility is a system of expectational difference equations, like that used by Walsh (1998) as a New Keynesian framework for monetary analysis. In this case, the researcher estimates the coefficients of the equation system together with the parameters of the bank objective function. Under the maintained hypothesis that the equation system is invariant to changes in policy, the researcher may use the estimated system to study policy alternatives. A third possibility is to set out a dynamic general equilibrium model in which all the parameters have natural structural interpretations.

The second decision is how to model central bank objectives. One can assume along with Poole (1970) that the central bank minimizes a loss function the elements of which are expected squared departures of economic variables from their target values weighted by parameters that measures the relative importance of each objective. Or one can assume, along with Rotemberg and Woodford (1997), that the central bank maximizes the utility of a representative agent. With the Rotemberg and Woodford approach, the weights on squared departures of p and y in the quadratic approximation are not "free parameters" but fixed and known functions of the parameters of the representative agent model. With the loss function approach, the weights are free parameters up to a normalization.

Both specifications are reasonable and interesting. Given a representative agent model, it is natural to assume that the central bank maximizes social welfare. On the other hand, a researcher might believe, for example, that the central bank places more weight on stabilizing output than is consistent with maximizing representative-agent utility, because the bank believes that the social costs of unemployment fall more heavily on low income households. In any case, the test that the central bank behaves optimally is separate from the test that it maximizes social welfare. The first test requires the researcher to fit the model with the optimal-policy restrictions imposed and the objective function weights free. The second test requires the researcher to refit the model with the optimal-policy restrictions imposed and the loss function weights set to the values consistent with social welfare maximization.

The researcher must next choose a strategy for imposing the optimal-policy restrictions. To fix ideas, I will explain the alternatives given that the class of admissible policies is the class of simple, fixed-parameter policy rules. In particular, I assume that the central bank policy rule takes the form

$$r_t = \theta' X_{t-1} + w_t \tag{2}$$

where r_t is the short term interest rate controlled by the central bank, X_{t-1} is a vector of state variables determined at time $t-1$, θ is a conforming vector of policy-rule coefficients and w_t is a serially uncorrelated error that captures the idiosyncratic part of policy and is sometimes termed a "policy shock." Kydland and Prescott (1977) makes the case for policy rules. Levin, Wieland and Williams (1999) argue that simple policy rules like (2) perform well across a variety of macroeconomic models featuring rational expectations. McCallum (1999) favors simple rules because they show how a variable the central bank can actually control should vary with information that the bank can readily observe at the beginning of period t.

If the model is very simple it may be possible to derive analytic expressions for the coefficients of the policy rule like (1). In that case, the researcher simply uses these expressions in the course of estimating the model. If the model involves rational expectations of future variables, it is generally not possible to derive analytic expressions for the optimal settings of the policy-rule coefficients and the researcher must resort to numerical methods.

One possibility is a "brute force approach." Suppose that the researcher decides to estimate the model by Full Information Maximum Likelihood (FIML). Let ρ be the vector of structural parameters and θ the vector of policy-rule coefficients. FIML estimation requires a program that computes the likelihood of any ρ and θ. The brute force approach uses an optimization sub-program that finds, for a given ρ, the θ that maximizes the policy objective. Brute force estimation involves computing optimal values of θ a great many times as the FIML hillclimber seeks the value of ρ that maximizes the likelihood function.

Givens and Salemi (2008) provide a second possibility by showing how to write the first order necessary conditions for policy optimality as linear combinations of the elements of the covariance matrix of the model's reduced form errors. Using the sample counterparts of the covariance terms allows the researcher to write the first order conditions as moment conditions and estimate the restricted model by generalized method of moments (GMM) as introduced by Hansen (1982).

3 It's What They Do, Not What They Say

In this section, I explain how coauthors and I have used inverse control to answer a number of questions about monetary policy. Camen, Genberg and Salemi (1990) studies Swiss monetary policy under fixed exchange rates (1964-71) and floating (1973-81). The paper takes a two step approach. In the first step, a VAR is estimated using monthly data for the Swiss money base, the Swiss short term interest rate, Swiss and German wholesale price indexes, and the three month US Treasury Bill rate plus the Swiss Franc Dollar exchange rate for the floating rate period. Genberg, Salemi and Swoboda (1987) explains why these variables ought to be used to study Swiss monetary policy and documents that Swiss industrial production is remarkably independent of movements in Swiss and foreign macro variables so that it makes sense to exclude it from the analysis. The VAR equation for base money is treated as a policy rule.

In the second step, the VAR coefficients are held fixed and the parameters of the SNB loss function are estimated. The loss function implies that the SNB has three stabilization objectives: the rate of interest, the inflation rate, and the money base itself. The weight on the money base is normalized to one and the weights on the other two objectives are estimated. The estimation criterion is the sum of squared differences between coefficients of the optimal and estimated reaction functions so that the second step amounts to finding objective function weights that reconcile optimal with observed monetary policy.

The paper reports several interesting findings. The Swiss money base is highly endogenous responding to shocks in all the system variables (including the exchange rate during the floating rate period). The best reconciliation of observed and optimal policy occurs for a loss function with much greater weight placed on inflation stabilization than on either of the other objectives. This finding characterizes both the fixed rate and flexible rate periods and is robust to many features of the specification. The paper concludes that the SNB reacted to changes in the exchange rate not because it sought to stabilize it but because the exchange rate carried information about the future course of inflation. The hypothesis that SNB policy was optimal fails although the two-step approach may mean that the test is biased against the null.

Camen, Genberg, and Salemi (1991) uses inverse control to study convergence of central bank policy during the EMS period. The paper estimates VAR's for both the French and German economies over the entire floating rate period (1974-1987) and over the EMS sub-period (1979-1987). It characterizes Banque de France and Bundesbank policy by finding loss function weights that reconcile the observed reaction functions with loss-minimizing policy rules.

The analysis reveals that the most important objective of Bundesbank policy was inflation stabilization over the entire period and over the EMS sub-period. The preferences of the Banque de France were different. During the floating rate period, the best reconciliation of observed and optimal policy occurs for a loss function where the Banque de France places little weight on stabilizing inflation and more weight on stabilizing output and exchange rates (although the restricted reaction function does not fit the well for the entire period). During the EMS sub-period, the most important stabilization objective of the Banque de France was clearly stabilization of the inflation rate and there is a much better match between the observed reaction function and a loss minimizing one. Overall, the analysis provides evidence that the monetary policies of the Bundesbank and Banque de France became far more harmonious during the EMS period.

While the previous papers take a two step approach to policy analysis, the next three combine the two steps into one. Salemi (1995) asks whether Federal Reserve policy is consistent with loss function minimization and estimates the arguments and weights of the Federal Reserve loss function. It uses monthly data from 1947 through 1992 on industrial production, the producer price index, M1, the S&P composite stock index, the unemployment rate, and several measures of the short-term interest rate and considers three policy regimes: 1947–1969, 1970–1979:9, and 1979:10–1992:10. The state transition equation is a VAR that includes equations for money growth and the interest rate so that both can be considered as candidates for the Fed's policy instrument.

The paper reaches three conclusions. First, for all the regimes, the hypothesis that the Federal Reserve minimized a loss function is not rejected by the data. Second, the optimal-policy restrictions are in better agreement with the data if money growth is the Fed policy instrument until 1982 and if the federal funds rate is the policy instrument after 1982. Third, the Fed pursued different objectives in each policy regime. Between 1947 and 1969, the Fed appeared most interested in stabilizing interest rates and inflation rates. After the Treasury Accord, it placed less weight on stabilizing inflation and more on stabilizing output. In the 1970's, Fed placed greatest weight on stabilizing output, some weight on stabilizing inflation, and little or no weight on stabilizing interest rates. With the onset of the monetarist experiment in 1979, the Fed placed much greater weight on stabilizing inflation. After 1982, the Fed substantially lowered the weight place on stabilization of money growth and output so that stabilization of inflation and the interest rate were the chief objectives of monetary policy.

Salemi (2006) again studies U.S. monetary policy using inverse control but uses a state transition equation derived from the following set of forward looking expectational difference equations:

$$\begin{aligned} y_t &= \lambda E_t y_{t+1} + a_1 y_{t-1} + a_2 y_{t-2} - b(r_r - E_t p_{t+1}) + u_t \\ p_t &= \beta y_t + \alpha_1 E_t p_{t+1} + \alpha_2 p_{t-1} + v_t \\ r_t &= \theta_1 y_{t-1} + \theta_2 p_{t-1} + \theta_3 r_{t-1} + \theta_4 y_{t-2} + w_t \end{aligned} \quad (3)$$

The first equation is an IS schedule which can be obtained by combing the linearized Euler equation that characterizes a household's optimal choice of consumption with a market clearing condition. The presence of expected future output results from the desire to smooth consumption and the lags in output result from habit persistence and delays between decision making and implementation. An increase in the real rate of interest lowers desired consumption and output by making saving more attractive. The second equation is a Phillips curve where the presence of expected future inflation is due a Calvo mechanism and the presence of lagged inflation is due to indexation to the economywide inflation rate by firms that are unable to re-optimize their price. An increase in output raises inflation by raising the marginal cost faced by the representative intermediate goods firm. The third equation is the policy rule of the Federal Reserve which is permitted to respond to each variable in the state vector dated $t-1$ and earlier. The Fed is assumed to choose values for the coefficients of the policy rule that minimize

$$L = E_t \sum_{j=1}^{\infty} \delta^j X'_{t+j} W X_{t+j} \quad (4)$$

where X is the state vector, W is a conformable matrix with Fed stabilization objective weights down the diagonal and δ is the Fed's time rate of discount.

Salemi (2006) reaches several conclusions. First, given quarterly data for 1965 to 2001, there is evidence of a policy regime shift beginning in 1980:I but there is no evidence of a break in the structural equations at that date. Second, estimating the model subject to the optimal policy restrictions sharpens estimates of several structural parameters. In particular, the estimate of α_1 is larger and more significant when the optimal policy restrictions are imposed than when they are not. There is intuition for this result. During the period, short term interest rates are highly persistent with estimates for θ_3 equal to about 0.90 in the first regime and 0.85 in the second. To reconcile interest rate persistence with optimal behavior requires a model in which private agents are forward looking. Third, stabilization of inflation was a more important Fed objective than stabilization of other variables before and after 1980. Finally, there is evidence that the Fed's policy rule was not optimal during the 1965-80 regime because it did not respond strongly enough to inflation shocks.

Salemi (2006) estimates its model and loss function by quasi maximum likelihood which requires computation of optimal policy-rule coefficients each time sample likelihood is computed. Givens and Salemi (2007) develops a new GMM algorithm for estimating structural parameters subject to optimal policy restrictions. The algorithm combines the least squares normal equations with the first-order necessary conditions that characterize the policymaker's optimal choice of policy. The algorithm is computationally more efficient than the brute force approach because it searches freely over values of the structural parameters, the loss function weights, and the policy-rule coefficients for those that satisfy a collection of moment conditions, a subset of which correspond to the first order conditions of the policymaker's control problem. Intuitively, the algorithm "creeps up" on parameter values that both fit the data and satisfy optimality. The algorithm is still an example of inverse control because it estimates monetary policy objectives by observing the actions embodied in the policy rule.

Givens and Salemi report a battery of Monte Carlo simulations that show how the algorithm performs when used to estimate ever more complicated models. When the hypothesis of policy optimality is true, the simulations show that the algorithm returns unbiased estimates of all structural parameters including the relative weights of the central bank's objective function. The benefits from imposing true optimal-policy restrictions emerge in the form of reduced uncertainty about many of the structural parameters. One shortcoming is that for over-identified models application of the standard chi-squared test rejects the optimality restrictions too often, particularly in small samples.

The most interesting finding concerns what happens when false optimality restrictions are imposed in the course of estimation. The simulations indicate that GMM delivers unbiased and precise estimates of the policy rule coefficients but biased estimates of some of the structural parameters. However, the standard chi-squared test rejects false optimality restrictions with very high frequency even in small samples.

Givens and Salemi also take their models and GMM procedure to data describing U.S. monetary policy between 1979 and 2001. When the model is given by (3), their findings are similar to those reported by Salemi (2006). When they use a representative agent model, they find that imposing optimal-policy restrictions has a very large impact on estimates of the structural parameters. When the policy rule coefficients are unrestricted, the estimate of the degree of habit formation is close to the values reported in the literature. In the restricted case, the estimate is much larger. The coefficient of relative risk aversion is 4.43 when the optimality restrictions are not imposed and near zero when they are. Imposing the restrictions also affects estimates of "supply side parameters–lowering the degree of price stickiness and raising the degree of inflation indexation by firms unable to re-optimize their price.

In 2005, Rouben Atoian, then a Ph.D., student at UNC, used inverse control theory to analyze Swiss monetary policy. Atoian (2005) builds an open economy, representative agent model in which imported goods are inputs to the production process, contracts explain wage stickiness, and households derive utility from consuming a composite good and using the services of money. The exchange rate is determined by the interest parity condition implied by the Euler equation describing optimal household holdings of domestic and foreign bonds. Atoian assumes that the central bank minimizes a loss function like (4) with the weight on inflation stabilization normalized to one and the weights on output and interest rate stabilization treated as unknown parameters. The reaction function explains how the SNB adjusts the short term rate of interest in response to changes in output, the real exchange rate, inflation, and the lagged interest rate.

Atoian considers two policy regimes: 1973-1987 and 1988-2003. He finds that the SNB placed relatively little weight on stabilizing output (0.14 in the first regime and 0.06 in the second, neither weight significant). He also finds that the SNB placed small but significant weight on stabilizing interest rates in both regimes.

Atoian's work underscores the theme that it is not possible to infer central bank objectives by a casual inspection of a reaction function. He finds that the reaction function coefficient on lagged inflation is negative in both regimes but that the SNB cared most about stabilizing inflation. The reason for this apparent anomaly is that the other variables in the reaction function also carry information about the future course of inflation. Atoian finds that the most important shocks hitting the Swiss economy were output and risk premium shocks. When he computes the impulse responses implied by the model, he finds that output shocks tend to raise inflation while risk premium shocks tend to lower it. He also finds that the SNB countered the inflation effects of both shocks by raising the interest rate in response to output shocks and lowering it in response to risk premium shocks.

4 Conclusions

What is the connection between the ideas I have presented and those of Alexander? There are several. Swoboda (1973) argues that under fixed exchange rates there is a trade-off between using monetary policy to pursue, in the short run, internal and external balance and thus points explicitly to the linkage between policy objective functions and policy. Swoboda (1991) discusses policy coordination by central banks and again emphasizes that coordination must be based on short term policy objectives. The conclusion to this paper to me reads like a recommendation for the approach to policy harmonization set out in Camen, Genberg and Salemi (1991). Finally, Genberg and Swoboda (2005), in the context of exchange rate regimes, point out that a researcher should pay attention both to what central banks say about their objectives and what they do. What they call a "de facto" classification is very close to what this paper calls inverse control.

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