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Abstract

Carlin and Soskice (2005) advocate a 3-equation model of stabilization policy, the *IS*-*PC*-*MR* model. Their third equation is the monetary reaction rule *MR* derived by assuming that governments have performance objectives, but are constrained by an augmented Phillips curve *PC*. Central banks achieve their preferred outcome by setting interest rates along an *IS* curve. We simplify their model to 2 equations (*PC* and *MR*), developing a state space econometric specification of this solution, and adding a random walk model of unobserved potential growth. Applying this model to a panel of North Atlantic countries, we find it historically consistent with an inflation target of about 4%. Significant interdependence is found in the between-country covariance of inflation and growth shocks, but not of potential output. Beginning with the approximation that expected inflation is the most recent observation, we extend the model to introduce alternative assumptions about expectations with mixed results, evidence for the sticky-price model, but doubts about activist policy.

JEL codes: E61, E63
Keywords: new Keynesian policy, inflation targets, expectations

1. Introduction

Central to the Carlin and Soskice approach to policy is a monetary rule derived by assuming that governments have inflation and output targets, constrained by a Phillips curve.[1] Using the state space methodology to specify a model of policy formation, we estimate the dynamic behavior of inflation and growth for a panel North Atlantic economies. This methodology is appropriate because our model involves unobserved state variables: the output gap and potential growth rate. By formalizing the relation between observables and unobservables, it provides Bayesian forecasts of the unobservables at each point in time conditioned on available information.

Although we do not formally model international trade, we introduce linkages in the form of the between-country covariance of shocks. We find substantial international covariance in inflation and growth shocks, but little covariance in underlying potential growth shocks.

Because expected inflation enters the analysis as a shift in the Phillips curve, an important modeling assumption is the nature of inflation forecasts. We explore several possibilities econometrically: the simple inertial model, strongly rational expectations, the Kalman filter forecast and the new Keynesian sticky-price model. The Kalman inflation forecast based on available information is a good candidate to replace the inertial expectations approximation of our initial estimation. A two-step estimation method improves the empirical fit, but raises fundamental questions about stabilization doctrine.

2. Macroeconomic structure and objectives

The monetary policy literature invariably invokes an augmented Phillips curve as a structural constraint on policy makers. Conventionally this is an inverse relation between the unexpected inflation and the gap between actual and natural unemployment. Since the potential output Y_t^* is conceptually related to the equilibrium or natural rate of unemployment, the output gap can be substituted for the unemployment gap as the measure of macroeconomic disequilibrium,

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[1] This model also known as the political business cycle. The original insight for this literature dates to Kalecki (1943); also see Nordhaus (1975). Modern versions begin with Kydland and Prescott (1977) who introduced the logic of rational expectations; Barro and Gordon (1983) further develop this logic.

$$\pi_t = E^a_{t-1}\pi_t + \psi x_t + \varepsilon_t, \tag{1}$$

where π_t is the inflation rate, $x_t \equiv \ln(Y_t) - \ln(Y_t^*)$ is the output gap, Y_t is real output and ε_t an inflation shock. Expected inflation $E^a_{t-1}\pi_t$ is interpreted as the forecast of a typical agent based on information available in the previous year; the operator subscript dates the forecast. Assuming expectations are fulfilled in the long run, (1) rules out any long-run deviation from $x = 0$. However, as long as economic agents do not fully anticipate fiscal, monetary and other policies, governments are able to temporarily increase output at the cost of higher inflation.

Another essential element is an assumption about political objectives. A popular possibility supposes that the government's goals are given by a quadratic function of the output gap and inflation,[2]

$$U_t = -\left({\pi_t}^2 + \left(\pi_t - \hat{\pi}\right)^2\right), \tag{2}$$

where $\hat{\pi}$ is the inflation target. Textbooks often define social welfare as an aggregation of individual preferences. Governmental targets may reflect a weighted average of citizen preferences.[3] Woodford (2003) establishes microfoundations for several close relatives of this function form as an approximation to the utility of a representative consumer-worker.

Quadratic forms are tractable because they result in linear solutions.[4] Within the quadratic family, a variety of alternatives are plausible. Equation (2) has circular indifference curves, but these can be made elliptical by adding a parameter to reflect the relative weight of inflation versus output goals. Often the output target exceeds its potential level.[5] Some models invoke parabolic indifference curves.[6] Kiefer (2008) estimates eight different quadratic forms. He confirms the conventional wisdom that it is not possible to

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[2] For example, see Clarida et al. (1999).

[3] Objectives might also include the discounted value of expected future outcomes. The government might plan for its current term of office only, or it might plan to be in office for several terms, discounting the future according to the probability of holding office. Alternatively, it might weigh pre-election years more heavily. Here we assume that only current conditions matter. See Kiefer (2000) for empirical evidence that only current conditions matter in political macroeconometrics.

[4] Ruge-Murcia (2003) presents evidence that questions the conventional linearity assumption. He develops an alternative where the government's inflation preferences are asymmetrical around its target.

[5] Barro and Gordon (1983) assume a zero inflation target and an unemployment target below that natural rate.

[6] See, for example, Romer (1993) or Alesina et al. (1997).

statistically separate the goal weight, the inflation target and the output target.[7] Thus, our target parameter $\hat{\pi}$ may be interpreted as a composite of weights and targets.

3. Optimal policy with an inflation target

The government has limited options in the new Keynesian model; it may be able to lean against the macroeconomic wind.[8] Following Carlin and Soskice, we assume that policy making is only effective after a one-year delay. Accordingly, we add an expectations operator and redate the objective as the government's expectation of next year's outcome,

$$E_t^g U_{t+1} = -E_t^g\left(\pi_{t+1}{}^2 + \left(\pi_{t+1} - \hat{\pi}\right)^2\right).$$

They explain this delay as a lag in the *IS* relation between interest rate and output gap.[9] Recognizing that the government has more tools than just interest rates, we likewise assume this one-year lag applies to the other policy instruments. Subject to the Phillips curve constraint, the government's preferred inflation for next year is $\dfrac{E_t^a \pi_{t+1} + E_t^g \varepsilon_{t+1} + \psi^2 \hat{\pi}}{1+\psi^2}$. To the extent that agents are rational and well informed they would expect this inflation rate, however if they behave otherwise, the policy maker can lean against the wind.

Adding a inflation shock and lagging by one period, gives inflation as

$$\pi_t = \frac{E_{t-1}^a \pi_t + E_{t-1}^g \varepsilon_t + \psi^2 \hat{\pi}}{1+\psi^2} + \varepsilon_t .$$

Using the Phillips curve and adding an inflation shock the output gap is

$$x_t = -\psi \frac{E_{t-1}^a \pi_t - \hat{\pi}}{1+\psi^2} + \frac{E_{t-1}^g \varepsilon_t}{\psi\left(1+\psi^2\right)} + \xi_t .$$

The inflation ε_t and the output ξ_t shocks are taken to be exogenous.

Output gap and the growth rate are equivalent measures of stabilization policy because the real output growth rate can be defined in terms of the output gap as $g_t \equiv g_t^* - x_{t-1} + x_t$, where

[7] Also see Ireland (1999).
[8] Fischer (1977) is an early example in this literature.
[9] Although plausible, such policy lags conflict with conventional consumer choice derivations of the *IS* curve which do not show any lag; for example see Gali (2008).

$g_t \equiv \ln(Y_t) - \ln(Y_{t-1})$ and $g_t^* \equiv \ln(Y_t^*) - \ln(Y_{t-1}^*)$. Thus, we rewrite output in terms of the growth rate. In summary, our 2-equation model of the macroeconomy is

$$\begin{aligned} \pi_t &= \frac{E_{t-1}^a \pi_t + E_{t-1}^g \varepsilon_t + \psi^2 \hat{\pi}}{1+\psi^2} + \varepsilon_t \\ g_t &= g_t^* - x_{t-1} - \psi \frac{E_{t-1}^a \pi_t - \hat{\pi}}{1+\psi^2} + \frac{E_{t-1}^g \varepsilon_t}{\psi(1+\psi^2)} + \xi_t \end{aligned} . \tag{3}$$

Among other things, (3) implies that observed inflation and growth depend on shocks, conditions inherited from the past, expectations and policy targets. We suppose that the various government agencies (central banks and treasuries) act as one to implement this policy.

The output gap is an unobserved variable.[10] Conventional measures of the output gap suffer from the shortcoming that they are often defined by exogenously detrending observed real GDP. We endogenize the output gap by assuming that real potential growth follows a random walk, defining the level of potential GDP recursively,

$$\begin{aligned} g_t^* &= g_{t-1}^* + \upsilon_t \\ \ln(Y_t^*) &= \ln(Y_{t-1}^*) + g_t^* \end{aligned} \tag{4}$$

We assume that the potential growth shocks follow the normal distribution $\upsilon_t \sim N(0, \sigma_\upsilon^2)$, and that these are independent of inflation or output shocks. This model recognizes that the underlying growth rate changes over time, but that its next turning point is unpredictable. It is simple and agnostic; other models are plausible.[11]

In the long run agents come to understand that a policy of $\hat{\pi} > 0$ implies inflation; this expectation is a self-fulfilling prophecy. In the absence of shocks or uncertainty, the time-consistent equilibrium inflation rate should occur where inflation is just high enough so that the government is not tempted to

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[10] Some authors allow the perceptions of the policy makers about the structure of the economy to differ from reality; our model allows only for prediction errors with respect to the output gap and the potential growth rate, not the slope of the Phillips curve. See Sargent et al. (2006).

[11] Natural growth and natural unemployment are analogous processes. Barro and Gordon (1983) assume that natural unemployment follows an AR(1) process, Gordon (1997) assumes a random walk, Ireland (1999) assumes an ARIMA(1,1,0) and Ruge-Murcia (2003) a higher order ARIMA. Clark (1989) assumes that $\ln(Y_t^*)$ follows an I(2) process, or a random walk in natural growth.

spring a policy surprise. This equilibrium occurs at the potential output, potential growth and the inflation target, $x = 0, g = g^*, \pi = \hat{\pi}$.

This formulation takes the form of a state space model including unobserved state and observed variables. Our state equations are (4); substituting the output gap definition into (3) gives our observation equations.[12] The observation equations are reduced forms determined by $E^a_{t-1}\pi_t, E^g_{t-1}\varepsilon_t, x_{t-1}$ and g^*_t; these equations are linear in the variables, but nonlinear in coefficients. Conditional only on predetermined information (observations up through the t-1st year) the Kalman filter defines a recursive forecast of the unobserved variables, $E_{t-1}g^*_t, E_{t-1}\ln\left(Y^*_t\right)$ and $E_{t-1}x_t$. These are Bayesian updates, weighted averages of the previous forecasts and current observations. Although we offer no evidence that governments learn according to Bayes rule, we interpret these predictions as rational, an estimate of what a forecaster could have thought about the underlying potential of the economy and current performance at the time that policy decisions were being implemented. The state space framework is thus appropriate to the study of behavior involving expectations. These forecasts are conditional on unknown model parameters, the Phillips curve slope and inflation target. We estimate these parameters, along with the evolving state variables, by maximizing the model's likelihood function.[13] These estimates are consistent because the right-hand-side variables are predetermined. We assume that the shocks, ε_t, ξ_t and υ_t, are distributed normally without autocorrelation or covariance. This is questionable since autocorrelation is widely observed in macroeconomic time series, but it is convenient because it implies that $E^g_{t-1}\varepsilon_t = 0$. We investigate its appropriateness further below.

In comparison to the literature on monetary policy econometrics this is a small and stylized specification. Recent research reports much more complicated models; see the dynamic stochastic general equilibrium approach of Christiano et al. (2005) or Smets and Wouters (2003). The latter, for example, specifies 4 structural parameters without estimation and estimate 32 additional parameters in a 9-equation

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[12] See Hamilton (1994) for a textbook presentation of the Kalman filter methodology.

[13] This state space estimate is initiated with prior opinions about the state variables, $\ln\left(\hat{Y}^*_{0|-1}\right)$ and $\hat{g}^*_{1|0}$, and their variances.

model by Bayesian methods. Their approach includes habit formation in consumption, technology and preference shocks, capital adjustment costs and less than full capacity utilization; it also accounts for sticky prices and wages, along with markups deriving from market power. This model enables a sophisticated method of estimating potential output, the prediction of the estimated model after forcing flexible prices and wages and restricting all markups to zero. Our 2-equation model estimates only 2 parameters by a conventional maximum likelihood method; it supposes that our simple potential growth model can approximate the more complicated evolution resulting from technology and preference shocks. Although these recent studies include a detailed description of consumer and firm objectives and behavior, they often model government behavior without an objective function as an agnostic stochastic process.

4. Two other timing assumptions

We call the above development the *single-lag* model. Some authors assume that the government implements effective policy remedies for inflation and output shocks without any lag. For example, Clarida et al. (1999) specify an *IS* curve in which current interest rates determine current outputs. If this is possible, the relevant objective function has the current date,

$$E_t^g U = -E_t^g\left(x_t^{\ 2} + \left(\pi_t - \hat{\pi}\right)^2\right)$$

Solving by the same method and recognizing that $E_t^g \varepsilon_t = \varepsilon_t$, gives a *no-lag* specification,

$$\begin{aligned}\pi_t &= \frac{E_{t-1}^a \pi_t + \psi^2 \hat{\pi}}{1+\psi^2} + \frac{\varepsilon_t}{1+\psi^2} \\ g_t &= g_t^* - x_{t-1} - \psi\left(\frac{E_{t-1}^a \pi_t - \hat{\pi}}{1+\psi^2}\right) - \frac{\psi \varepsilon_t}{1+\psi^2}\end{aligned} \tag{5}$$

Output shocks do not appear in (5); this is consistent with the theoretical result that optimal policy perfectly accommodates any output shifts, either temporary or potential.[14] Except for the error structure, (5) is identical to (3), where we assumed that the government policy is effective with a one-year delay.

A third possibility stipulates a *double-lag*: the output impact is delayed by one year, and the inflation impact is delayed by two years. Svensson (1997) hypothesizes that output is affected by the

[14] This is Clarida's baseline result; they also extend their analysis to policy lags and imperfect information.

interest rate after one year as before, and that inflation effects are delayed for additional year due to the lagging of the output gap in the Phillips curve,[15]

$$\pi_t = E_{t-1}^{a}\pi_t + \psi x_{t-1} + \varepsilon_t . \tag{6}$$

We develop an empirical test of this alternative. Now the relevant objective dates only the arguments as they are initially affected by current policy,[16]

$$E_t^g U = -E_t^g\left({x_{t+1}}^2 + \left(\pi_{t+2} - \hat{\pi}\right)^2 \right)$$

Solving as before, lagging appropriately, and adding random shocks to both the inflation and output solution gives

$$\begin{aligned} \pi_t &= \frac{E_{t-2}^g\left(E_{t-1}^a \pi_t\right) + E_{t-2}^g \varepsilon_t + \psi^2 \hat{\pi}}{1+\psi^2} + \varepsilon_t \\ g_t &= g_t^* - x_{t-1} - \psi \frac{E_{t-1}^g\left(E_t^a \pi_{t+1}\right) - \hat{\pi}}{1+\psi^2} + \frac{E_{t-1}^g \varepsilon_{t+1}}{\psi\left(1+\psi^2\right)} + \xi_t \end{aligned} \tag{7}$$

where $E_{t-2}^g\left(E_{t-1}^a \pi_t\right)$ denotes the government's expectation in t-2[nd] year of the private sector's forecast to be formed in the t-1[st] year, and $E_{t-2}^g \varepsilon_t$ is a two-year forecast of the inflation shock. This double-lag model implies that inflation is affected by the government's two-year forecast of inflation. A two-year government forecast affects growth too, but here it is only one year old as government looks ahead to influence inflation in the t+1[st] year.

Carlin and Soskice favor the double-lag as being more realistic, and for facilitating the derivation a Taylor rule. Our three solutions, (3), (5) and (7), are consistent with the proposition that policy under imperfect information can be characterized as the certainty equivalent of the perfect information policy, nevertheless the equation differences suggest an empirical comparison.

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[15] He offers no theoretic foundation for this additional lag.

[16] For simplicity we do not discount the inflation term even though that it would be appropriate for this dating.

5. An empirical comparison of assumptions

We study the above models with a panel of interrelated countries. We do not make any explicit adjustments for openness or international trade. Our justification for this rests on a theoretical result in Clarida et al (2001), that stabilization policy in an open economy is qualitatively the same as that of a closed economy.

Our data are derived from the Penn World Table (PWT7.0), which includes internationally comparable time series on the national accounts for almost all the countries in the world for 1950-2009. We add a subscript to all variables to indicate the i^{th} country. Percentage growth is measured as the log difference in real GDP per capita. Although it is customary to study stabilization with aggregate statistics, such analysis is also equally appropriate with per capita data.[17] Our inflation rate is defined using purchasing power parity and GDP estimates from the PWT. In Table 1 the numerator of the implicit deflator is GDP per capita measured in current local currency, and the denominator is the same quantity measured in real terms (2005 local currency units). Table 2 reports descriptive statistics. These countries are chosen for data availability and because they are part of the North Atlantic block of economies.

Table 1. Variable definitions

	symbol	definitions using PWT 7.0 variable names
real GDP per capita	Y_{it}	$RGDPCH_{it}$
growth rate	g_{it}	$100\left[\ln\left(RGDPCH_{it}\right)-\ln\left(RGDPCH_{it-1}\right)\right]$
implicit deflator	p_{it}	$\dfrac{PPP_{it}\left(CGDP_{it}\right)}{PPP_{i2005}\left(RGDPCH_{it}\right)}$
inflation rate	π_{it}	$100\left[\ln\left(p_{it}\right)-\ln\left(p_{it-1}\right)\right]$

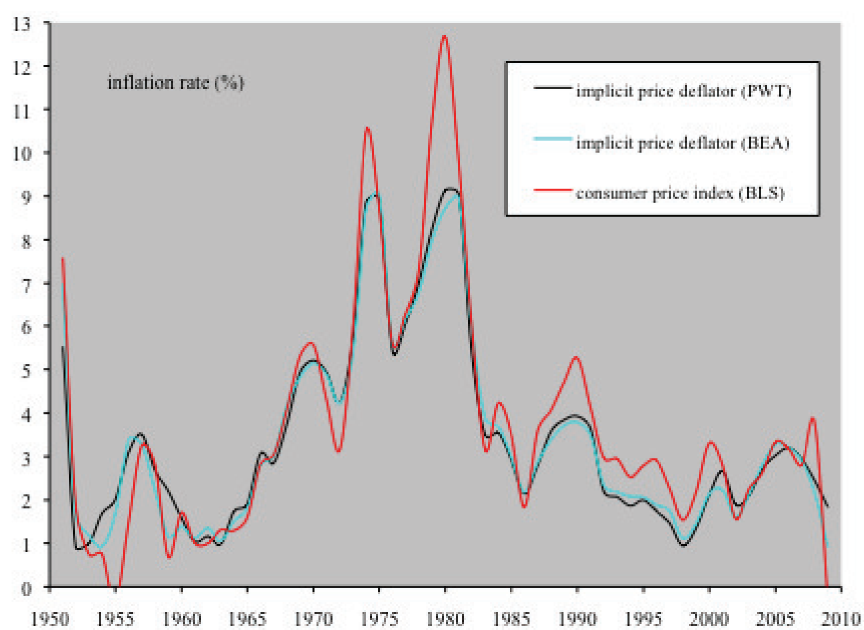
[17] The difference is that aggregate growth rates include population growth. Since population growth changes slowly, this has little effect on short-run outcomes.

Table 2. Macroeconomic performance, 1953-2009 averages

	GDP deflator inflation (%)	real GDP growth (% per capital)
Austria	3.32	3.03
Belgium	3.37	2.50
Canada	3.80	1.88
Denmark	4.60	2.30
Finland	5.27	2.68
France	4.65	2.40
Ireland	5.89	3.02
Italy	6.38	2.69
Netherlands	3.71	2.38
Norway	4.65	2.83
Sweden	4.81	2.10
Switzerland	2.82	1.79
United Kingdom	5.53	1.98
United States	3.44	1.82
average	4.45	2.39

Figure 1 compares our PWT measure of domestic inflation to official US statistics. It is clear that they are quite close and that ours can be interpreted as the implicit deflator rate, an appropriate indicator of macrostabilization.

Figure 1. Comparing US inflation rates



The goodness-of-fit statistics in Table 3 are the basis for our inferences about stochastic structure. Our sample period is 1953-2009, 798 observations altogether. The table reports log likelihoods for our basic state space model (3) and (4) under different covariance assumptions: the variance of potential growth shocks, between-country error covariance and within-country serial correlation. Of course, other assumptions about the error structure are possible.

Table 3. Comparative log likelihood statistics: backward-looking expectations, single-lag timing, 14 North Atlantic countries, 798 observations, 1953-2009

potential growth volatility	$\sigma_\upsilon^2 = 0.01$	$\sigma_\upsilon^2 = 0.16$	$\sigma_\upsilon^2 = 0.64$
independence between countries			
spherical errors	-4194	-3947	-3882
AR(1) errors	-3688	-3678	-3679
between-country covariance			
spherical errors	-3963	-3720	-3660
AR(1) errors	-3482	-3470	-3470

We assume inertial expectations, replacing $E_{t-1}^a \pi_{it}$ by π_{it-1}. Although many economists view such backward-looking models with suspicion because they lack microfoundations and because their forecasts can be irrational, they are well known to provide a good empirical fit. This simple forecasting rule has the desirable property that it can converge to the time-consistent equilibrium. In the next section we explore several alternative expectation specifications.

All of the estimates in Table 3 assume single-lag policy timing. Attempted estimation of the no-lag model does not converge for any of error specifications in Table 3. Our estimates (reported in Table 4) of the output shock variance are quite large compared to our inflation variance estimates. This contradicts the perfect accommodation of output shocks implied by the no-lag logic, in which ξ drops out of (5). Perhaps the unreality of this restriction explains our non-convergence results and supports the inference that the no-lag timing assumption is unrealistic. We compare single-lag and double-lag timing below.

Within a group of linked economies, it is plausible that inflation, output and potential growth shocks are contemporaneously correlated with shocks in other countries. It is a simple extension to introduce covariances, $\operatorname{cov}(\varepsilon_{it}, \varepsilon_{jt})$, $\operatorname{cov}(\xi_{it}, \xi_{jt})$ and $\operatorname{cov}(\upsilon_{it}, \upsilon_{jt})$ for $i \neq j$, identical among these countries.

Comparing the log likelihoods in Table 3 without (the top rows) and with (the bottom rows) covariance strongly supports the presence of such between-country covariance.

In the first and third rows we report estimates in which shocks are assumed to be serially independent, and (3) is simplified due to $E_{t-1}\varepsilon_{it} = 0$. In the second and fourth row we consider the possibility that inflation and growth shocks are serially correlated according to an AR(1) model,

$$\begin{aligned}\varepsilon_{it} &= \rho_{\varepsilon}\varepsilon_{it-1} + \mu_{it} \\ \xi_{it} &= \rho_{\xi}\xi_{it-1} + \nu_{it}\end{aligned}$$

where μ and ν are independent normal random variables and ρ_{ε} and ρ_{ξ} measure the autocorrelation between shocks. For these models we account for the predictability of inflation shocks in (3) by setting $E_{t-1}\varepsilon_{it} = \rho_{\varepsilon}\varepsilon_{it-1}$. Although these generalizations markedly improve the statistical fit, we reject the AR(1) specification as inconsistent for reasons detailed below. Before making that argument we evaluate alternative smoothing restrictions on the potential output series.

Conventionally, potential output changes over time as technology advances and as physical and human capital is accumulated. Asserting that these influences evolve slowly and independently of business cycles, economists have applied smoothing procedures to estimate the underlying economic potential. Our smoothing method restricts the variance of the random-walk steps. The first column of Table 3 reports results for the strongly smoothed restriction that $\sigma_{\upsilon}^2 = 0.01$ (a standard deviation of 1/10% per year); the second column repeats the calculation with the restriction that $\sigma_{\upsilon}^2 = 0.16$ (a standard deviation of 4/10% per year) and for the more volatile $\sigma_{\upsilon}^2 = 0.64$ (a standard deviation of 8/10% per year) in the third. Although our results are inconclusive, the $\sigma_{\upsilon}^2 = 0.16$ restriction seems appropriate.

Table 4. Selected estimation results, 14 North Atlantic countries, 1953-2009
(z-ratios in parentheses)

model	(a)	(b)	(c)	(d)	(e)	(f)	(g)
policy timing	single-lag	single-lag	single-lag	single-lag	single-lag	single-lag	double-lag
Phillips curve slope	0.435	0.589	-0.733	0.290	0 (imposed)	26.832	0.289
	(20.144)	(22.129)	(-25.205)	(10.695)		(1.137)	(17.835)
target	4.022	4.197	4.200	4.511		2.124	3.844
	(9.851)	(3.939)	(4.877)	(1.332)		(13.100)	(1.179)
var(e_i) inflation	5.657	5.583	5.734	5.925	6.347	5.696	11.122
var(x_i) growth	4.870	5.762	13.461	0.936	5.708	5.174	6.097
var(u_i) potential	0.16 (imposed)	0.16 (imposed)	0.01 (imposed)	3.426	0.16 (imposed)	0.16 (imposed)	0.16 (imposed)
cov(e_i,e_j)		1.620	1.917	1.390	1.438	1.977	4.815
		(5.750)	(5.068)	(6.003)	(6.361)	(4.151)	(4.557)
cov(x_i, x_j)		3.150	6.356	0.064	3.518	2.114	3.805
		(5.983)	(4.772)	(0.577)	(6.386)	(1.246)	(5.931)
cov(u_i,u_j)		0.008	0.001	2.084	0.003	0.074	0.003
		(1.335)	(1.203)	(3.368)	(0.548)	(1.814)	(0.652)
autocorrelation inflation						0.680	
autocorrelation growth						0.994	
log likelihood	-3947	-3720	-3963	-3603	-3741	-3470	-3937

Table 4 reports detailed results for some of the more likely specifications, the shaded four in Table 3, plus model (d) that relaxes the smoothing restriction by letting σ_{υ}^2 be an estimated parameter, (e) which imposes a flat Phillips curve, and (g) which estimates a double-lag timing specification. Although models (d) and (f) attain the highest likelihood in Table 4, they are questionable due to their implications about growth shocks. Figure 2 suggests that model (d)'s estimate of potential growth is too volatile (with a standard deviation of almost 2% per year) for a measure of economic potential. The potential growth series forecast under the model (b) with $\sigma_{\upsilon}^2 = 0.16$ appears more like the customary estimates of this unobserved variable.

Overall we prefer model (b); however, we find that a $VAR(1)$ regression on the same two dependent variables with the same error specification (spherical with between-country covariance) achieves a log likelihood of -3538. Perhaps a more appropriate benchmark is the $\psi = 0$ restricted model where the government's preferred inflation is always the expected rate, and its preferred output is zero; this restricted estimate is (e). It removes the tradeoff between inflation and the output; the inflation target drops out; and the observable equations become separable. This restriction removes any temptation for countercyclical policy. We conclude an activist policy is more likely to have generated these data than this no-policy alternative. Although model (b) cannot be said to be the most likely to have generated these data, we nevertheless pursue it because of its theoretical interest.

We allow for between-country covariance in all models except (a). Our estimates of the between-country covariance of inflation and growth shocks are generally large and statistically significant. The exception of model (d) may be understood as connected to its very volatile potential growth. We question the plausibility of model (d), and explain its estimated potential as a misinterpretation of transitory volatility. Generally the largest of the estimated covariances is that of transitory growth shocks, validating this important mechanism of international business cycle synchronization.

Our results suggest that inflation-shock and growth-shock covariances are much more important than potential-growth-shock covariance. In light of the technological interpretation of potential output, we might expect potential growth to covary among countries, but our estimates are generally small and insignificant. The exception (d) implausibly replaces the high between-country covariance of transitory shocks with a covariance among potential ones.

The estimated inflation targets are generally around 4%. The estimated slopes of the Phillips curve are mostly statistically significant and positive, although they vary considerably. Model (c), which imposes strong smoothing on the variance of potential shocks, results in an unexpectedly negative slope; however, this model is the least likely of those reported in Table 4. On the other hand, the serially correlated model (f) gives the best fit, but estimates an unexpectedly high slope (with considerable uncertainty). We revisit model (f) below with another reason for doubt.

6. The smoothing of potential output

The natural rate literature reports other methods of estimating unobserved potential output. Figure 2 compares two of our Kalman estimates of US potential growth with two popular alternatives, the estimate published by the Congressional Budget Office (2001), and the Hodrick-Prescott filter. The popularity of the

HP filter may be due to its simple agnostic formula.[18] The CBO estimate is more complicated. It uses a growth accounting method inspired by the Solow growth model. This method combines estimates of the trends in the labor force, the capital stock and technological progress. Cyclical components of the labor supply and productivity are removed from observed statistics by constraining potential labor and productivity growth rates to be constant over the business cycle. The CBO's estimate also uses an estimate the non-accelerating inflation rate of unemployment.

Clearly the volatility of our $\sigma_v^2 = 3.43$ estimate is inconsistent with the conventional notion of smooth potential growth. Its sensitivity to the business cycle is questionable; note the implausibly large drops in this series associated with every recession. The same criticism can be made of the HP filter estimate for 2009. We prefer model (b) because potential growth series in Figure 2 looks more plausible. We restrict $\sigma_v^2 = 0.16$ for all models throughout the remainder of the paper.

Both our Kalman one-step forecasts are more volatile than the usual estimates. For the early years of our sample, Figure 2 shows that our one-step estimates are substantially below the alternatives. This reflects different potential growth assumptions as well as different methods of estimation. The HP filter and CBO estimate both impose a gradually evolving process, without large shifts. On the other hand, our assumed generating process is a random walk, typified by small random shifts that can occasionally be large. An appealing methodological feature of the Kalman filter is that potential growth is estimated recursively on past observations only, not future ones. This explains why our estimates become smoother and converge with the alternatives as more observations become available.[19] The other two methods are omniscient in the sense that both include past and future observations; in this sense they are more

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[18] It estimates of the natural rate series by minimizing the expression

$$\sum_{t=2}^{T-1}\left\{\left(g_t - g_t^*\right)^2 + \lambda\left[\left(g_{t+1}^* - g_t^*\right) + \left(g_t^* - g_{t-1}^*\right)\right]^2\right\},$$

where λ an arbitrary smoothness parameter that penalizes sharp curves in the g_{it}^* series. Conventional application recommends setting λ=100 for annual data.

[19] We specify $\hat{g}_{1|0}^* = 2$ with a variance of 9 as a plausible prior for the potential growth, and set $\ln\left(\hat{Y}_{0|-1}^*\right)$ equal to the values observed in 1951 with a variance of 0.1. We start with 1951 because our equation (3) includes the lagged output gap x_{it-1} so that the first observation is 1952.

comparable to "smoothed" Kalman predictions of the state variables conditioned on the entire data set, also plotted in Figure 2. Although this smoothed estimate is not always closer to the alternatives than the filtered estimate, it is less volatile and removes the 1950s-1960s anomaly. The difference between forward-looking and omniscient forecasts is apparent.

Figure 2. Alternatives estimates of the US potential growth rate

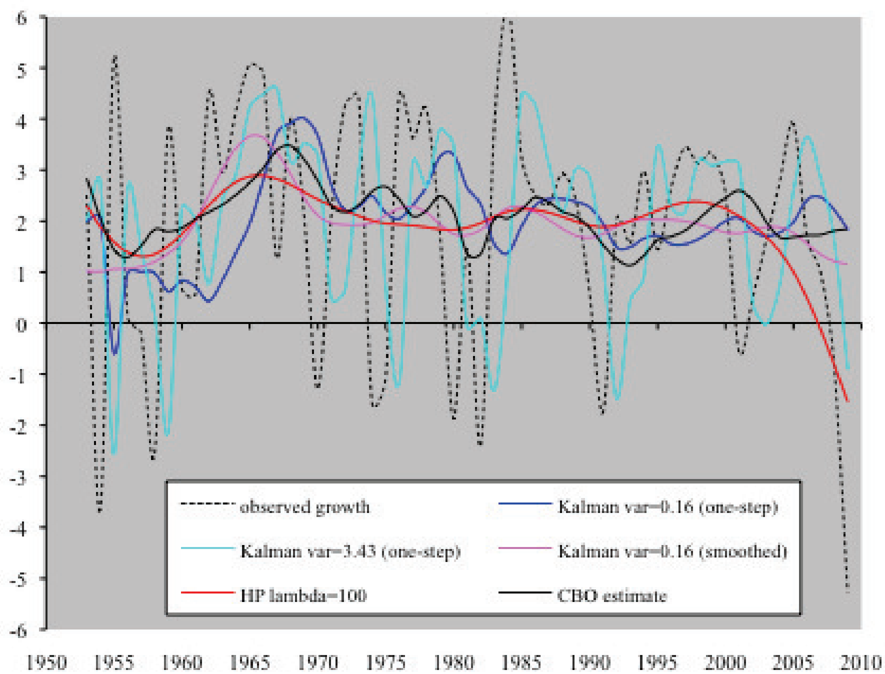
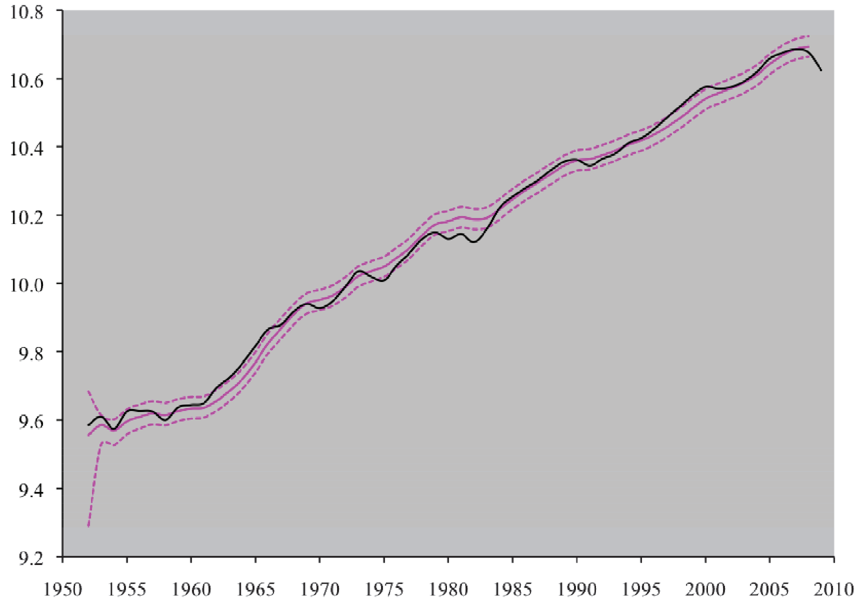


Figure 3 shows that our estimate of the potential output series is fairly smooth. Although apparently tight, its 95% confidence interval (dashed) is actually imprecise; observed *ln*(GDP/capita) is only rarely outside of this interval; note how far US 2009 performance lies outside the confidence interval. This plot also shows how quickly the observations come to dominate our prior. This method of estimating potential output is appealing because it is integrated into a macroeconomic model, and not a separate calculation.

Figure 3. Comparing observed *ln*(GDP/capita) with the model (b) prediction of the US potential level



Model (f) achieves the highest log likelihood in Table 4, but it estimates a surprisingly steep and statistically insignificant Phillips curve; furthermore, the estimated growth shock process is essentially a random walk. Inspection of our growth equation (3) suggests that both models (d) and (f) achieve their tight fit by adding a volatile random walk to growth. We question model (d) above on the grounds that its implied potential path is inconsistent with the usual interpretation, and likewise we reject (f), a similar result achieved by adding a random walk in the form of the growth shock. Although we reject these models as theoretically incoherent, their goodness-of-fit remains unexplained.

7. Double-lag timing

The rightmost column in Table 4 reports a double-lag timing specification. According to (7), this involves the government's forecast of an expectation by agents in the future. Consistent with our double-lag assumption, it would be logical to use the modified Phillips curve (6) and the $E^a_{t-1}\pi_t = \pi_{t-1}$ approximation to make this forecast based on information available in the t-2nd year,

$$E^g_{t-2}\left(E^a_{t-1}\pi_t\right) = \pi_{t-2} + \psi x_{t-2} + E^g_{t-2}\varepsilon_t$$

where we have suppressed country subscripts for convenience. Substituting this into the double-lag gap target model and assuming that shocks remain unpredictable yields,

$$\pi_t = \frac{\pi_{t-2} + \psi x_{t-2} + \psi^2 \hat{\pi}}{1+\psi^2} + \varepsilon_t$$
$$g_t = g_t^* - x_{t-1} - \psi \frac{\pi_{t-1} + \psi x_{t-1} - \hat{\pi}}{1+\psi^2} + \xi_t.$$

Comparing this with the single-lag model, the most apparent difference is in the inflation equation; single-lagged inflation is replaced the double-lagged variable. Thus it should probably not be surprising that the double-lagged version (g) does not fit the data as well as (b). The much larger inflation variance estimate for (g) also reflects the poorer fit of the inflation equation. We conclude that the data favor the single-lag timing assumption over the double-lag one, although both specifications are consistent with endogenous stabilization.

8. Inflation expectations

Backward-looking expectations fit the data well, but many may be skeptical of this approximation. The typical agent might know the government's inflation target; a rational agent would use this information to forecast inflation. To obtain a model-consistent expectation of π given this knowledge, we take the expectation of (3), finding that $E^a_{t-1}\pi_t = \hat{\pi}$. Substituting into (3) and supposing that rational expectations are typical, gives the solution[20]

$$\begin{aligned} \pi_t &= \hat{\pi} + \varepsilon_t \\ g_t &= g_t^* - x_{t-1} + \xi_t \end{aligned} \tag{8}$$

which certainly makes a strong assumption about agent sophistication. If this strongly rational model is valid, we cannot identify the slope of the Phillips curve, although we can estimate the inflation target.

Table 5 compares alternative expectation models. The first column repeats our inertial model for convenience. Model (h) estimates the strongly rational expectations specification (8). The results support the inertial approximation.

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[20] We maintain our assumption that the agent cannot predict the contemporaneous shock, so that $E^a_{t-1}\varepsilon_t = 0$.

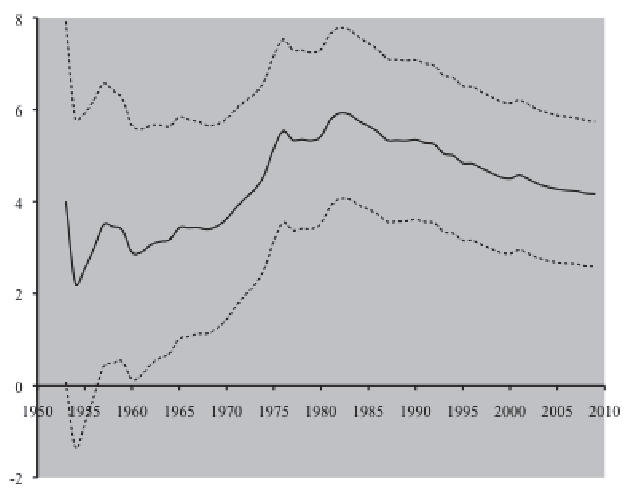
Table 5. Alternative expectations specifications: 14 North Atlantic countries, 1953-2009
(z-ratios in parentheses)

model	(b)	(h)	(i)	(j)	(k)
	inertial expectations	rational expectations	iterated expectations	evolving target, inertial expectations	sticky prices
Phillips curve slope	0.589		0.142	0.589	0.086
	(22.129)		(3.558)	(27.659)	(1.447)
inflation target $\hat{\pi}$	4.197	4.441	5.625	4.398 (ave)	13.482
	(3.939)	(6.400)	(0.432)		(0.259)
stickiness parameter η					0.619
					(6.306)
indexation parameter γ					0
					(imposed)
var(u_i) potential (imposed)	0.160	0.160	0.160	0.160	0.160
var(e_i) inflation	5.583	13.493	5.596	5.577	5.914
var(z_i) growth	5.762	5.699	5.551	5.725	5.653
cov(u_i,u_j)	1.620	7.659	1.662	1.610	2.073
	(5.750)	(2.997)	(5.795)	(4.870)	(4.553)
cov(e_i,e_j)	3.150	3.511	3.393	3.112	3.478
	(5.983)	(5.787)	(5.734)	(6.394)	(5.402)
cov(z_i, z_j)	0.008	0.003	0.681	0.008	0.004
	(1.335)	(0.467)	(1.072)	(1.351)	(0.610)
log likelihood	-3720	-3848	-3661	-3720	-3653

Model (i) invokes a different version of rational expectations; it substitutes the one-step Kalman forecast $E_{t-1}\pi_t$ from model (b) back into the observable equations, and re-estimates our state space model. This forecast is rational when the data are generated according to model (b) where the typical agent uses the inertial approximation. The parameters estimated by this method will be consistent to the extent that model (b)'s forecast is predetermined. This is partially true for the state variables, g_t^* and $\ln\left(Y_{t-1}^*\right)$; they depend only on information available during t-1. But it fails to the extent that these forecasts also depend on the inflation target and the Phillips curve slope, parameters that model (b) estimates with the entire sample period, not just with available information.

We investigate this predetermination issue further by redefining the inflation target as a state variable, $\hat{\pi}_t = \hat{\pi}_{t-1} + \omega_t$, where $\omega_t \sim N\left(0,\sigma_\omega^2\right)$. This random coefficient model is motivated by the conjecture that the target has evolved over time. As a plausible prior we specify $\hat{\pi}_{10} = 4\%$ with a variance of 4, reflecting the considerable uncertainty surrounding this parameter; and we restrict $\sigma_\omega^2 = 0.01$ to smooth the target series. The results are reported as model (j); the resulting target estimates and their 95% confidence interval are plotted in Figure 4. Starting at 4%, our estimate rises to almost 6% by 1982, and declines to around 4% near the end of the sample period, certainly a plausible result in light of the evolution of stabilization doctrine. This plot also shows that even after 50 years these data do not resolve the uncertainty about governmental targets. We also find that the fixed-target model (b) is slightly more likely to have generated the data than this random coefficient version, and that inflation forecasts using (b) are indistinguishable from those using (j). We conjecture that the results would not be significantly changed by an analogous generalization concerning the Phillips curve slope, concluding that our use of the inflation forecast from model (b) as a regressor in model (i) is unlikely to yield inconsistent estimates.[21]

Figure 4. Evolving estimates of the inflation target, model (j)



The iterated model (i) is appropriate when the typical agent uses model (b) to forecast one year ahead. It dramatically improves the fit, perhaps more than a few agents apply this logic. Repeating this iteration a second time, we find that this procedure converges quickly: the second result is virtually

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[21] Of these two parameters, the target seems more likely to vary over time than the slope. We do not attempt a varying-slope generalization because it requires an abandonment of the linear state space model; the target enters the observation equations linearly, but the slope does not.

unchanged, as are the one-year forecasts.[22] The inflation forecast (plotted in Figure 5) according to inertial model (b) is almost indistinguishable from that of model (i). The iterated results show a much flatter Phillips curve and a less precise target, suggesting that forecasters do not need to pay attention to government policy. This inference follows because a totally flat Phillips curve reduces (3) to the stipulation that inflation equals its expectation plus an unpredictable shock.

Next, we adopt a third version of rational expectations, and take a step toward microfoundations following a version of Calvo's (1983) stochastic price adjustment model. This *sticky-price* model specifies that $(1-\eta)$ is the probability that a firm can reset its price in the current year. It is assumed that the optimal price p_t^* for the typical firm varies with the aggregate price and the marginal costs. Under imperfect competition the profit-maximizing price is a markup of marginal cost.[23] Furthermore, under certain conditions it can be argued that the deviation from steady-state marginal cost is proportional to the aggregate output gap; thus the optimal price depends on the output gap.[24] Again we use the symbol ψ to specify the price-gap relation.

Since firms may not be able to change their prices for some time, resetters forecast future conditions. They average observable conditions with their forecasts, weighted according to the probability that their price will remain fixed in each year.[25] Customary derivations date expectations from the current period, but it is more appropriate to lag the expectation date,

$$p_t^* = (1-\eta)\sum_{\tau=0}^{\infty}\eta^{\tau}E_{t-1}^{a}\left(p_{t+\tau} + \psi x_{t+\tau}\right) + \varepsilon_t\,.$$

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[22] The second iteration raises the log likelihood only to –3660.

[23] Some authors (for example, Gali (2008)) develop further microfoundations at this point, assuming an economy of monopolistically competitive firms providing a continuum of differentiated consumer goods.

[24] There is doubt in the empirical literature about whether the conditions necessary for the cost-gap link hold. Gali and Gertler (1999) report consistent results for a measure of marginal cost, but not for the output gap, while neither variable can explain observed inflation in the Rudd and Whalen (2006) study.

[25] It is appropriate for firms to discount future profits. But since this complicates the result, we follow much of the literature by weighting all quarters equally, except for the probability of price resetting. Since we focus on short-run decisions here, this neglect of discounting is a reasonable simplification. Below we estimate that the average length of price fixity is about 1.6 years.

The *t*-1 date for the expectations is realistic because aggregate price indices are only made public during the following year. We redefine ε_t as an exogenous price shock added to account for all other factors affecting the pricing decision.

The aggregate price level is specified as the geometric average of those currently permitted to reoptimize with those who reset prices previously, η

$$\ln(p_t) = (1-\eta)\ln(p_t^*) + \eta\{(1+\gamma)\ln(p_{t-1}) - \gamma\ln(p_{t-2})\}.$$

Following Smets and Wouters (2003), the term in brackets allows indexation to past inflation for those agents not permitted a current reset, where $0 \le \gamma \le 1$ accounts for the degree of this indexation. Eliminating the unobserved optimum price, it can be shown that aggregate inflation is given as

$$\pi_t = \eta E_{t-1}^a \pi_{t+1} + (1-\eta(1+\eta\gamma))E_{t-1}^a \pi_t + \eta\gamma\pi_{t-1} + (1-\eta)^2 \psi E_{t-1}^a x_t + \varepsilon_t. \tag{9}$$

This new Keynesian Phillips curve involves forecasts of two inflation rates and of the output gap; and due to indexation it also includes lagged inflation. Equation (9) is unconventional; usually expectations are dated in the t^{th} quarter so that $E_{t-1}^a \pi_t = \pi_t$, $E_{t-1}^a \pi_{t+1} = E_t^a \pi_{t+1}$, and $E_{t-1}^a x_t = x_t$, and indexation is not permitted so that $0 = \gamma$. Under these assumptions simplifies to a conventional forward-looking new Keynesian Phillips curve,

$$\pi_t = E_{t-1}^a \pi_{t+1} + \frac{(1-\eta)^2 \psi}{\eta} x_t + \frac{1-\eta}{\eta} \varepsilon_t. \tag{10}$$

We estimate a new Keynesian model by a two-step procedure: first we use the backward-looking model (b) to estimate the unobserved inflation expectations, second we use these forecasts to estimate sticky-price versions of our 2-equation model, substituting (9) for the backward-looking Phillips curve. For the gap-target objective, the observable equations become[26]

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[26] The double-lag timing assumption is inconsistent with this sticky-price approach because the double-lag modification (6) is inconsistent with the sticky-price Phillips curve (9).

$$\pi_t = \frac{\eta E^a_{t-1}\pi_{t+1} + \left(1-\eta(1+\eta\gamma)\right)E^a_{t-1}\pi_t + \eta\gamma\pi_{t-1} + \left((1-\eta)^2\psi\right)^2\hat{\pi}}{1+\left((1-\eta)^2\psi\right)^2} + \varepsilon_t$$
$$g_t = g^*_t - x_{t-1} - \frac{(1-\eta)^2\psi\left(\eta E^a_{t-1}\pi_{t+1} + \left(1-\eta(1+\eta\gamma)\right)E^a_{t-1}\pi_t + \eta\gamma\pi_{t-1} - \hat{\pi}\right)}{1+\left((1-\eta)^2\psi\right)^2} + \xi_t \qquad (11)$$

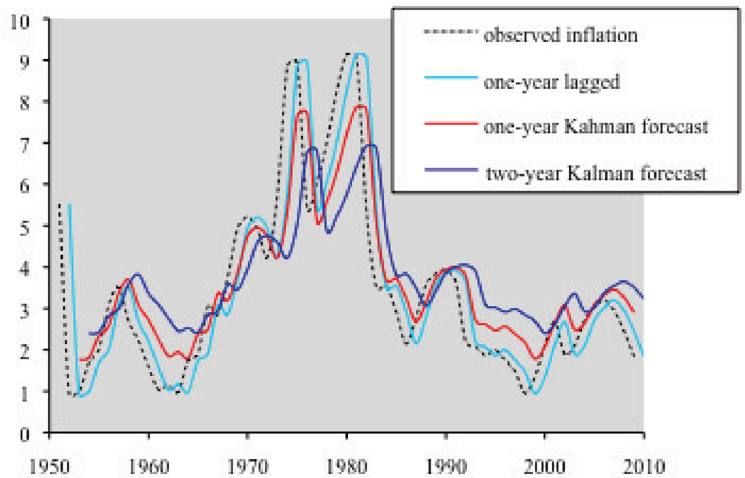
Equations (11) show that the iterated expectations model (i) can be interpreted as an approximation of the flexible-prices case, $\eta = 0$.

Figure 5 compares US inflation observations with alternative forecasts of inflation: one-year lagged inflation, the one-year and two-year forecasts (both according to model (b)). Although the backward-looking assumption $E^a_{t-1}\pi_t = \pi_{t-1}$ has often been closer to observation inflation than either of the other forecasts, sticky-price model (k) specified as (11) improves the fit compared to model (b) using only lagged inflation. This result supports the inference that prices are sticky (we estimate the probability of price resetting at 38% per year), and that agent expectations are forward looking. Of course, this model requires that $0 \le \eta \le 1$ and $0 \le \gamma \le 1$. Since our estimation results in an indexation parameter less than zero; we impose a $\gamma = 0$ restriction on model (k) implying no indexation for agents who cannot reoptimize their prices.

Taken together, these estimates give support to rational expectations in the sense of models (i) and (k), but not of model (h). However, model (k) has an implausibly high inflation target at about 13%, although it is not statistically significant. Furthermore, like model (i), (k)'s estimate of the stick-price Phillips curve slope $(1-\eta)^2\psi$ is surprisingly flat.[27]

[27] The Phillips curve slope is calculated according to (15) as $(1-\eta)^2\psi$.

Figure 5. Comparing alternative forecasts of US inflation



Our use of lagging expectations is appropriate to this method; if we use (10) instead of (9) to derive the model, we may introduce simultaneity bias because in the one-step forecast $E_t \pi_{t+1}$ assumes knowledge of the knowledge of the current dependent variables.[28] We decide above that the lagged forecasts based on model (b) are can be treated as predetermined. Several empirical studies of the new Keynesian curve have studied regressions specified according to (10). Invoking rationality, they assume that inflation forecasts are on average accurate. But since replacing $E_t^a \pi_{t+1}$ with π_{t+1} introduces an endogenous variable on the right hand side of the regression, they specify a list of lagged instruments to mitigate endogeneity bias.[29] Our method does not involve instrumental variables.

If these estimates (k) are accurate, then government behavior simplifies dramatically: its preferred inflation is always the expected rate, and its preferred output is zero.[30] This removes any motivation for leaning against the macroeconomic wind. Thus, although the sticky-price enhancement finds support for stickiness, it also suggests that the governments have not been practicing activist policy. However, there is an inconsistency in our two-step method: we find the activist assumption of (b) useful in forecasting

[28] Our methodology also differs from the econometric literature in respect of the unobserved variables; customarily the output gap is measured in a deterministic fashion, not as part of the short-run equilibrium.

[29] For example Gali and Gertler (1999).

[30] This result is consistent with other studies of the new Keynesian Phillips curve that report unexpected negative or insignificant slope estimates; for example see Rudd and Whalen (2006).

expected inflation, but having made these forecasts, we now find that this assumption is not useful in explaining outcomes. If true, a consistent methodology would remove the activist terms throughout: it would start by imposing $\psi = 0$; this is model (e). Accordingly, the Kalman forecasts (both one-year and two-year) are simply lagged inflation, and both the iterated-expectations (i) and the sticky-prices (k) simplify to (e). Since this internally consistent procedure does not fit the data nearly as well, we remain uncertain about the $\psi = 0$ conclusion.

9. Conclusion

We develop a standard theory of macroeconomic stabilization in the state space framework, and test its relevance to recent macroeconomic history using a panel of interconnected countries. Starting with inertial expectations, we conclude that the Keynesian model of asymmetric information and backward-looking expectations are consistent with the data. It results in a plausible estimate of potential GDP, a positive Phillips curve slope, and an inflation target of about 4%. We find strong evidence of between country covariance of macroeconomic shocks, especially transitory output shocks, but not potential ones. We also find that a one-year lag in policy effectiveness is more likely than alternative no-lag or double-lag models.

We compare a number of alternative econometric models of inflation expectations. Although the strongly rational hypothesis is poorly supported by these data, an alternative definitions of rationality (using Kalman forecasts iteratively) dramatically improve the fit. Calvo's sticky-price model invokes forward-looking rationality based on a microeconomic derivation of the Phillips curve. A two-step implementation of the sticky-price Phillips curve further improves our fit, but its flat Phillips curve estimate casts doubt on activist stabilization.

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