Do expectations matter? The Great Moderation revisited

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Abstract

We examine the role of expectations in the Great Moderation episode. We derive theoretical restrictions in a New-Keynesian model and test them using measures of expectations obtained from survey data, the Greenbook and bond markets. Expectations explain the dynamics of inflation and interest rates but their importance is roughly unchanged over time. Systems with and without expectations display similar reduced form characteristics. Including or excluding expectations hardly changes the economic explanation of the Great Moderation. Results are robust to changes in the structure of the empirical model.

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1 Introduction

Many authors have examined the "Great Moderation" episode in the US (see Clarida, et. al. (2000), Blanchard and Simon (2001), Cogley and Sargent (2001) (2005), Stock and Watson (2002), Gordon (2005) Primiceri (2005), Arias, et. al. (2006), Sims and Zha (2006), Gambetti et. al. (2008) among others) and its international features are currently investigated (see Stock and Watson (2004), Canova, et. al. (2007) or Benati (2008)). Most analyses agree on the observation that the volatility and the persistence of output and inflation declined since the late 1970s but explanations differ. The literature is mainly divided into two fronts - those who support the "bad policy" hypothesis (failure of the Fed to appropriately respond to inflation) and those who lean toward the "bad luck" hypothesis (shocks are drawn from a time varying distribution) - with a few authors claiming that changes in the private sector (see e.g. McConnell and Perez Quiroz (2001), Canova (forthcoming), Campbell and Herkovitz (2006), Gali and Gambetti (2009), Jerman and Quadrini (2006)) or reduced activism combined with decreased misperceptions (Orphanides (2004), Orphanides and Williams (2005)) may be responsible for the phenomenon. The division appears to be linked, in part, to the type of data used (real time vs. historical) and, in part, to the type of empirical analysis conducted: while narrative and reduced form approaches consistently point to "bad policy" as key to explain the facts, structural VARs favor the "bad luck" conclusion. Given the strong prior of many commentators, some have questioned the ability of structural VARs to detect true sources of variations in the data (see Benati and Surico (2006)).

The most convincing formalization of the " bad policy" hypothesis appears in Lubik and Schorfheide (LS) (2004) who, building on the work of Clarida, et. al. (2000), estimate a three-equations New-Keynesian model with Bayesian methods over subsamples and find an indeterminate equilibrium in the first subsample (up to the end of the 1970s) but not in the second one (from the beginning of 1980s up today). Boivin and Giannoni (2006) confirm this conclusion with an alternative estimation technique. One important consequence of this finding is that expectations were driven by non-fundamental forces in the 1970s, and became function of fundamental factors when the Fed strengthened the reaction of the nominal rate to inflation. Despite the fact that the dynamics of expectations are crucial to understand the facts and to assess the credibility of the explanation, no one has formally examined whether expectations fit the role that the indeterminacy-determinacy story of the Great Moderation has given to them. Leduc et. al (2007) studied how much the nominal rate moves in response to expected inflation shocks and whether there has been a change in the magnitude and the persistence of expected inflation shocks, but they do not directly examine the importance of inflation expectations in the two regimes.

In this paper, we study the role of expectations in the Great Moderation episode using reduced form techniques. To start with we take a simple New-Keynesian model, parameterized so as to replicate the most salient aspects of LS estimates, and show that there is a state variable entering the solution in the indeterminate regime which fails to appear when the equilibrium is determinate. If expectations play the role of this additional state variable, they should help to predict other endogenous variables in the indeterminate sample and there should be a break in the significance of predictive tests, as we move from the indeterminate to the determinate regime. Moreover, omitting expectations from the empirical model causes the variance of the shocks to be overestimated in the indeterminate regime but not in the determinate one.

We show that these two implications are the only testable ones the theory imposes and that existing approaches may be unable to detect regime switches. For example, the standard counterfactuals conducted in the literature are uninformative because variations in the policy rule imply changes in both the impact coefficients and the lagged responses to shocks, regardless of whether policy changes occur within or across regimes. Moreover, we show that certain structural methods are unlikely to be more informative than reduced form ones about the type of regime in place because regimes may have dynamics which are "local" to each other.

In our analysis we proceed as follows. We collect alternative measures of one year ahead expectations using survey data (Michigan, Professional, Livingstone), the Greenbook, and the term structure of nominal interest rates. Then, we run several VARs which include output growth, inflation, the nominal interest rate, and a proxy measure of expectations and examine: (i) whether the coefficients on lagged expectations are significant and whether their significance changes over time; (ii) whether omitting expectations from the estimated system causes time varying biases in the variance of reduced form shocks. We complement this statistical evidence analyzing whether the absence of expectations from the estimated system alters the interpretation of the Great Moderation. Since expectations have been systematically excluded from empirical models, we want to know whether and how such an omission matters. Finally, we measure the importance of sunspot shocks and examine whether their elimination could be responsible for the Great Moderation.

Our results suggest that the role of expectations differs from that postulated by the indeterminacy-determinacy story. In particular, regardless of the specification of the empirical model and the statistics used, we find that (i) lags of expectations are either always significant or always insignificant and there is no clear switch over time in their importance in any equation of the system; (ii) reduced form variances estimated in systems with and without expectations display similar features and little evidence of time varying biases; (iii) the economic interpretation of the Great Moderation is largely independent of the exclusion of expectations from the empirical system; (iv) sunspot shocks matter for output growth and inflation volatility and persistence but changes in their contribution over time do not line up well with the time variations in these statistics.

The rest of the paper is organized as follows. The next section examines the implications of the theory. Section 3 describes our expectation measures. Section 4 presents the empirical evidence. Section 5 discusses the causes of the Great Moderation. Section 6 measures the importance of sunspot shocks. Section 7 concludes.

2 What does the theory tell us?

2.1 A simple example

To set up ideas, it is useful to consider a simple univariate example. Suppose

$$y_t = \frac{1}{\theta} y^e_{t+1} + e_t \tag{1}$$

where $e_t = \phi e_{t-1} + \eta_t$, $0 < \phi \leq 1$, η_t is iid $(0, \sigma^2)$. and y^e_{t+1} are expectations at t of y_{t+1}. Suppose expectations are rational, i.e $y^e_{t+1} = E_t y_{t+1}$. If $|\theta| > 1$ (the determinate regime), the solution for y_t is $y_t = \frac{\theta}{\theta+\phi} e_t = \phi y_{t-1} + \frac{\theta}{\theta+\phi}\eta_t$. Since $E_{t-1}y_t = \phi y_{t-1}$ time $t-1$ expectations of y_t are irrelevant in predicting y_t if y_{t-1} is available. In other words $E_{t-1}y_t$ does not Granger-cause y_t in this regime.

When $|\theta| < 1$ (the indeterminate regime), equation (1) can be rewritten, shifting the time index by one period, as

$$y_t = \theta y_{t-1} - \theta e_{t-1} + v_t \tag{2}$$

where $v_t \equiv y_t - E_{t-1}y_t$. Clearly, if $v_t = \eta_t$, the solution for y_t still is $y_t = \frac{\theta}{\theta+\phi} e_t$ and, conditional on y_{t-1}, expectations play no role also in this regime. Suppose instead that v_t is a iid (pure sunspot) shock orthogonal to e_{t-1}. Since $E_{t-1}y_t = \theta y_{t-1} - \theta e_{t-1}$, time $t-1$ expectations of y_t will help to forecast y_t, given y_{t-1}, because they contains information about e_{t-1} that is not included in y_{t-1}.

This discussion indicates that two basic features distinguish indeterminate from determinate regimes: (i) conditional on y_{t-1} past expectations should help to predict y_t in the former but not in the latter regime; (ii) excluding expectations from an empirical model should make prediction errors larger in the indeterminate regime but not in the determinate one. These two implications of the theory constitute the null hypotheses of the reduced form tests we conduct below.

As the editor has pointed out to us, it is unclear whether rational expectations is a reasonable working assumption when the economy drifts into an indeterminate regime. Since our empirical analysis may have stronger appeal if the tests we propose have power when the rational expectation assumption fails hold in this regime, we next examine whether the implications we emphasize holds under an alternative expectation formation mechanism. Suppose that expectations are formed using a constant gain learning scheme:

$$y_{t+1}^e = y_{t-1}^e + \gamma(y_{t-1} - y_{t-1}^e) \tag{3}$$

Using equation (3) into (1) we obtain

$$y_t = \frac{1-\gamma}{\theta} y_{t-1}^e + \frac{\gamma}{\theta} y_{t-1} + e_t \tag{4}$$

Hence, given y_{t-1}, past expectations help forecasting y_t, so long as $\gamma \neq 1$. Intuitively, expectations matter because they proxy for lags of y_t which are important to characterize current values of y_t.

It is relatively easy to show that the above result holds if, instead of a constant learning scheme, agents use a Kalman filtering scheme $y_{t+1}^e = y_{t-1}^e + \kappa_{t-1}\epsilon_{t-1}$, where κ_{t-1} is the time varying gain, $\epsilon_{t-1} = y_{t-1} - y_{t-1|t-2}$ is the time $t-1$ forecast error and the notation $y_{t|t-1}$ indicates the best predictor of y_t using information available at $t-1$, and if more complicated learning schemes are considered. Nevertheless, as the above derivation clearly indicates, under learning y_{t-1}^e will help to predict y_t in both regimes. Hence, the basic tests we perform in section 4 are meaningful if rational expectations hold at least in the determinate regime - the expectation formation in the indeterminate regime could be any of the three we have considered.

If one it is not willing to assume that expectations are rational even in the determinate regime, a weaker version of our tests would be meaningful, provided θ is sufficiently away from one. In fact, when $\gamma \neq 1$, and again conditional of y_{t-1}, y_t^e will have a (much) larger coefficient under indeterminacy than under determinacy and the difference will be significant if $|\theta| >> k > 0$, some k. Therefore, even though the distinction across regimes is not as sharp as under rational expectations, there is a sense in which, under learning, expectations are more important in an indeterminate regime than a determinate one. The exercise with a time varying coefficient model we report in section 5, will be able to detect these differences if they are present in the data.

2.2 The basic model

To show that the two basic implications we care about, carry over to more interesting setups, consider a standard three-equation New-Keynesian model, which includes a log-linearized Euler condition, a log-linearized Phillips curve, and a log-linearized policy rule. In deviation from a non-stochastic steady state, the equations are:

$$R_t = \phi_r R_{t-1} + (1-\phi_r)(\phi_\pi \pi_t + \phi_x(x_t - z_t)) + e_{R,t} \quad (5)$$

$$\pi_t = \beta \pi_{t+1|t} + \kappa(x_t - z_t) \quad (6)$$

$$x_t = x_{t+1|t} - \tau(R_t - \pi_{t+1|t}) + g_t \quad (7)$$

where $g_t = \rho_g g_{t-1} + e_{g,t}$, $z_t = \rho_z z_{t-1} + e_{z,t}$, x_t is the output gap, π_t the inflation rate, R_t the nominal rate, and the notation $t+1|t$ denotes conditional expectations. Here, g_t is a demand shifter, z_t exogenously shifts the marginal cost of production while $\beta, \kappa, \tau, \phi_r, \phi_\pi, \phi_x, \rho_g, \rho_x, \sigma_{eR}$, σ_g, σ_z and ρ_{gz}, the contemporaneous correlation between g_t and z_t, are structural parameters.

Table 1: Model Parameterization

Parameter	Regime 1 Indeterminate	Regime 2 Determinate	Regime 1 Estimates 1	Regime 1 Estimates 2
ϕ_π	0.77	2.19	1.75	1.51
ϕ_x	0.17	0.30	0.82	0.87
ϕ_R	0.60	0.84	0.81	0.86
β	0.99	0.99	0.99	0.99
τ	1.45^{-1}	1.45^{-1}	1.75^{-1}	1.45^{-1}
κ	0.77	0.77	0.58	0.77
ρ_g	0.68	0.68	0.74	0.74
ρ_z	0.82	0.82	0.74	0.77
σ_g	0.27	0.27	0.29	0.33
σ_z	1.13	1.13	1.05	1.31
σ_{eR}	0.23	0.23	0.15	0.15
ρ_{gz}	0.14	0.14	0.14	0.14

The first two columns report the parameters used to characterize the two regimes. The last two columns report point estimates obtained with a minimum distance estimator using data from the regime 1 (indeterminate) but assuming that the equilibrium is determinate. The third column leaves all parameters but β unrestricted, the last column fixes β, τ and κ.

To describe the population features of this model in different regimes we use a parameterization similar in spirit to the estimates of Lubik and Schorfheide (2004) (see table

1, columns 1 and 2), which they obtained with US data and Bayesian methods over the subsamples (1960:1-1979:2, 1982:4-1997:4). None of the points we make, however, depends on the exact parameter selection. Note that these two columns differ only in the coefficients of the policy rule, $(\phi_\pi, \phi_x, \phi_R)$. As in the univariate example, when the reaction of the nominal rate to inflation is weak ($\phi_\pi < 1$) an indeterminate equilibrium is obtained; when the reaction is strong ($\phi_\pi > 1$), a determinate equilibrium emerges. Since in the indeterminate regime there is a continuum of solutions, we consider also in this case two special situations where the forecast error is either a function of the structural errors - the "continuity" solution - or a pure sunspot shock - the "orthogonality" solution (see Lubik and Schorfheide (2003). Also, since the model is sufficiently complex and no analytical expression for the solution is available, we present the log-linearized decision rules for the nominal rate, the inflation rate and the output gap the model delivers. The continuity solution of the indeterminate regime produces:

$$\begin{bmatrix} \widehat{R}_t \\ \widehat{\pi}_t \\ \widehat{x}_t \end{bmatrix} = \begin{bmatrix} 0.61 & -0.06 & 0.05 & 0.36 \\ 0.001 & -0.001 & 0.001 & 0.99 \\ 0.28 & -0.99 & 0.84 & 0.81 \end{bmatrix} \begin{bmatrix} \widehat{R}_{t-1} \\ \widehat{\pi}_{t-1} \\ \widehat{x}_{t-1} \\ \widehat{\zeta}_{t-1} \end{bmatrix} + \begin{bmatrix} \widehat{u}_{1t} \\ \widehat{u}_{2t} \\ \widehat{u}_{3t} \end{bmatrix}, \Sigma_u = \begin{bmatrix} 3.57 & & \\ 8.18 & 24.86 & \\ 5.30 & 17.52 & 20.57 \end{bmatrix}$$

where $\widehat{\zeta}_{t-1}$ represents $t-1$ expectations of inflation or of output or a combination of the two, while the orthogonality solution delivers:

$$\begin{bmatrix} \widehat{R}_t \\ \widehat{\pi}_t \\ \widehat{x}_t \end{bmatrix} = \begin{bmatrix} 0.61 & -0.06 & 0.05 & 0.36 \\ 0.001 & -0.001 & 0.001 & 0.99 \\ 0.28 & -0.99 & 0.84 & 0.81 \end{bmatrix} \begin{bmatrix} \widehat{R}_{t-1} \\ \widehat{\pi}_{t-1} \\ \widehat{x}_{t-1} \\ \widehat{\zeta}_{t-1} \end{bmatrix} + \begin{bmatrix} \widehat{u}_{1t} \\ \widehat{u}_{2t} \\ \widehat{u}_{3t} \end{bmatrix}, \Sigma_u = \begin{bmatrix} 1.31 & & \\ 0.92 & 2.04 & \\ -1.13 & -2.50 & 3.07 \end{bmatrix}$$

In the determinate regime, instead we have:

$$\begin{bmatrix} \widehat{R}_t \\ \widehat{\pi}_t \\ \widehat{x}_t \end{bmatrix} = \begin{bmatrix} 0.86 & 0.17 & 0.02 \\ 0.06 & 0.57 & -0.04 \\ 0.11 & -0.59 & 0.81 \end{bmatrix} \begin{bmatrix} \widehat{R}_{t-1} \\ \widehat{\pi}_{t-1} \\ \widehat{x}_{t-1} \end{bmatrix} + \begin{bmatrix} \widehat{u}_{1t} \\ \widehat{u}_{2t} \\ \widehat{u}_{3t} \end{bmatrix}, \Sigma_u = \begin{bmatrix} 0.80 & & \\ 0.80 & 4.89 & \\ -0.44 & 2.61 & 10.94 \end{bmatrix}$$

Thus, regardless of the solution one considers, there is an additional state variable under indeterminacy when sunspots are present [1]. Hence, $\widehat{\zeta}_{t-1}$ should help predicting $(\widehat{R}_t, \widehat{\pi}_t, \widehat{x}_t)$, given lags of these variables, in the indeterminate regime but not in the determinate one. Moreover, omitting $\widehat{\zeta}_{t-1}$ from the estimated equations would cause the variance of the reduced form shocks to be larger than the true one in the indeterminate but not in the determinate regime.

[1] We are not the first ones to point out this fact, see Lubik and Schorfheide (2004) or Benati and Surico (2006), but neither use it to derive testable reduced form restrictions.

We want to stress that these implications are conditional on the inclusions of lags of the endogenous variables. Hence, we are not saying that the importance of $\widehat{\zeta}_{t-1}$ should change *unconditionally* across regimes, and that the variance of the shocks in the indeterminate regime is larger than in the determinate one. Unconditionally, several authors have documented that variables which proxy for $\widehat{\zeta}_{t-1}$ loose their predictive ability for output and inflation after 1984 (see e.g. Campbell (2004)), but these results have little to say about the implications we care about. Furthermore, the magnitude of the variance of the shocks in the two regimes depends on the parameterization and the choice of solution. For example, two of the three diagonal elements of Σ_u are larger in the determinate than in the indeterminate regime under orthogonality. Rather than comparing unconditional variances across regimes, we emphasize that omission of $\widehat{\zeta}_{t-1}$ should induce biases in the variance of the reduced form disturbances in the indeterminate regime.

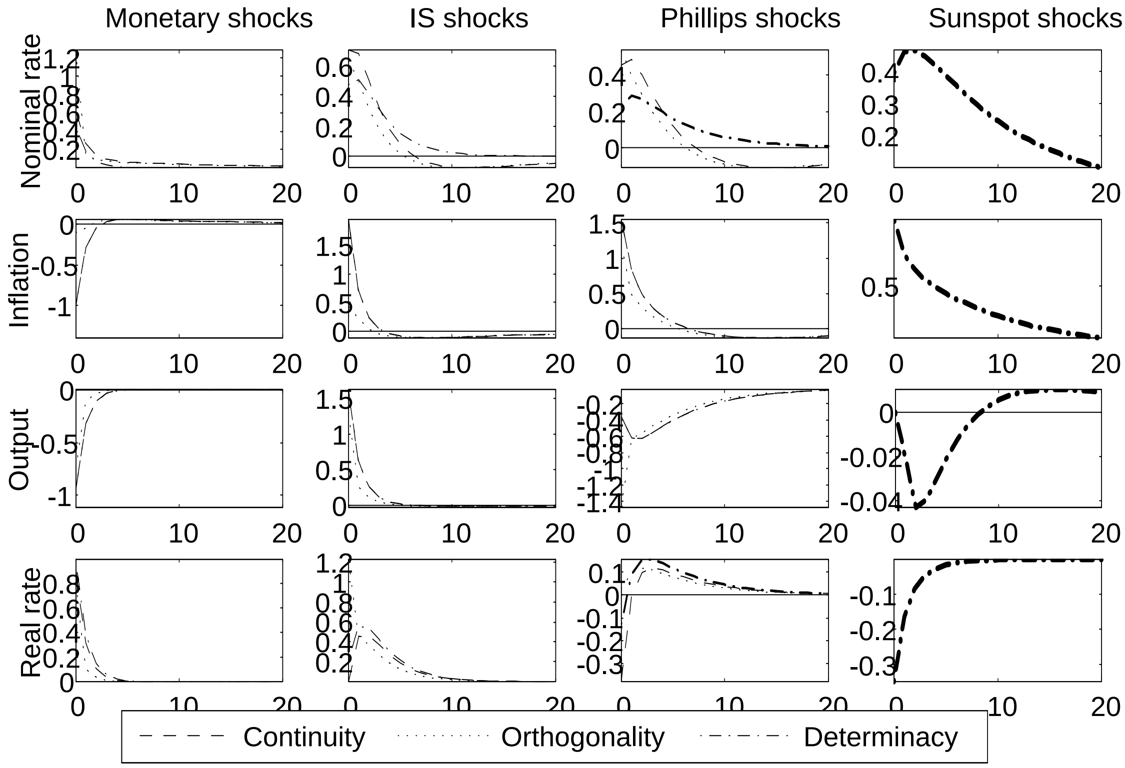

Figure 1: Impulse responses, Determinacy and Indeterminacy

We would like to emphasize three additional points. First, the model we consider is stark but the conclusions it delivers about regime switches are the same as those obtained in more complex models with additional shocks or frictions. Second, while the structural model differs across regimes only in the coefficients of the policy equation, the solution is such that lagged dynamics as well as the variance of the reduced form shocks change. Hence, standard reduced form counterfactuals conducted in the literature switching coefficients and variances across subsamples are not useful to check what regime is in place. Third, changes in the structural parameters within or across regimes, produce changes in the lagged dynamics and in the variance parameters and the magnitude of the changes is roughly similar. Thus, the size of the relative changes in the lagged coefficients and the variances is uninformative about regime switches.

Figure 1 presents the dynamics in response to the shocks in the two regimes where, in the case of indeterminacy, we plot both the continuity and the orthogonality solutions. While there are quantitative differences, especially in the impact period, the sign and the shape of the responses are very similar across regimes.

It is often presumed that structural estimation methods have an edge relative to less structural ones in detecting regimes, because they take expectation formation into account. To illustrate the fallacy of such a presumption in our specific case, we take the population dynamics generated by the model under indeterminacy (the continuity solution) as given and ask: are there parameter values which make the dynamics under determinacy "close" to those produced under indeterminacy?

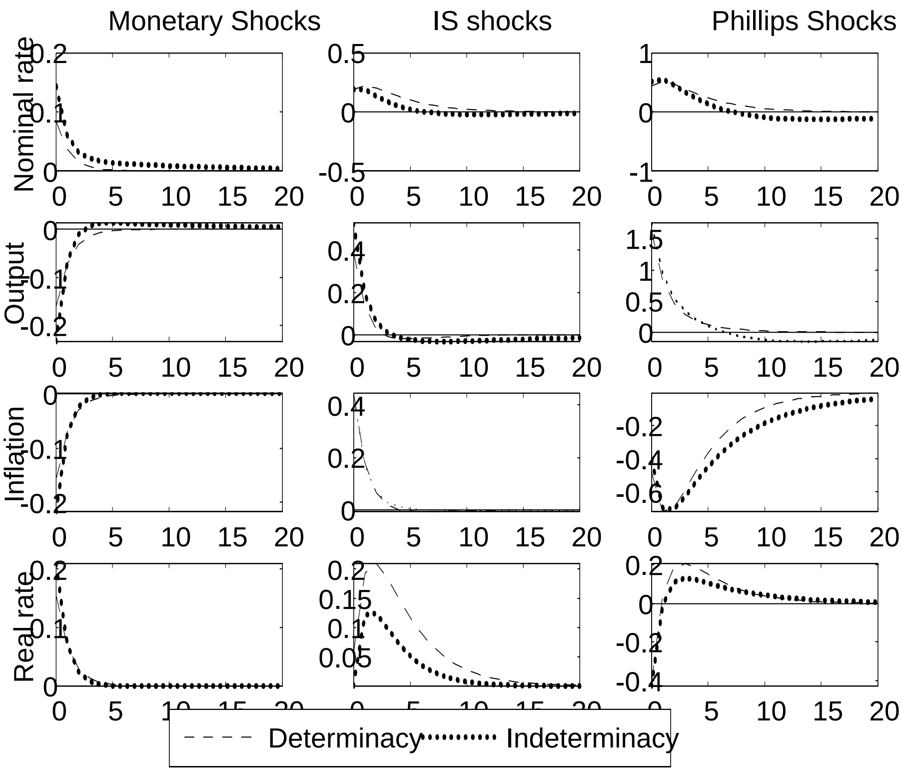

Figure 2: Alternative dynamics for regime 1

Figure 2, which uses a formal minimum distance estimator to try to replicate the dynamic responses of output, inflation and the nominal rate generated by the structural shocks, shows that this is indeed possible. If rather than taking one parameterization, we take estimated uncertainty seriously and construct response bands for the indeterminate regime using Monte Carlo simulations, these bands would always include the point estimate of the responses under determinacy. Thus, even in the unlikely case that a very large number of observations were available, structural methods focusing on the dynamics induced by structural shocks will find it hard to detect regime switches.

The parameters generating figure 2 are in the third column of table 1. Note that, it is impossible to simply change the variance of the shocks to make the dynamics of the indeterminate and of the determinate solutions close; that is, the "bad luck" hypothesis is not local to the indeterminacy/determinacy story. However, alternative explanations in which private sector parameters change together with the structural variances, or in which the parameters of the policy rule change together with the structural variance, keeping private sector parameters fixed (see fourth column of table 1) have this feature. Thus, the near observational equivalence of various hypotheses makes certain structural estimation exercises incredible.

Table 2: F-tests, p-values, simulated data

	Continuity Solution							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	0.06	0.04	0.44	0.90	0.60	0.47	0.70	0.65
π	0.08	0.08	0.39	0.57	0.52	0.51	0.49	0.40
R	0.53	0.54	0.82	0.22	0.99	0.99	0.93	0.93
	Orthogonality Solution							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	0.04	0.04	0.08	0.22	0.60	0.60	0.70	0.65
π	0.00	0.00	0.12	0.81	0.36	0.39	0.49	0.40
R	0.90	0.90	0.71	0.44	0.84	0.82	0.93	0.93

The table reports the p-value for the F-test that the coefficients on the expectation variable in the equation are all equal to zero in a 4 variables VAR(2). Data from 1960:1 to 1979:4 are from the indeterminate solution, data from 1980:1 to 1999:4 from the determinate solution.

It is important to know whether the type of reduced form tests we suggest have reasonable power to detect regimes in the typical samples used in macroeconomics. As it will be clear below, we have only about 80 data points on each side of the potential break date, making small sample problems an issue. To check whether our approach is able to detect regime breaks in this situation, we have simulated data from each of the two regimes, using the parameter values reported in the first two columns of table 1, employing either the continuity or the orthogonality solution when generating data from the indeterminate regime.

We then constructed two samples of 160 data points (one with 80 data from the continuity regime and 80 from the determinate regime, the other with 80 data from the orthogonality regime and 80 from the determinate regime), run a VAR(2) including experimental data for output, inflation and the nominal rate and one of the expectational variables, tested the hypothesis that lags of the expectational variables significantly enter the first three equations and measured the differences in the covariance matrix of the reduced form shocks when the expectational variable is included or excluded from the VAR.

Tables 2 and 3 show that our tests do have power to detect regime changes even in these relatively small samples. In particular, i) one of the expectational variables is significant in some equations when up to the first 80 data points are used but not if either more data is included or if estimation starts at a later date; and ii) the variance of the reduced form shocks in a system without inflation expectations is larger than in a system which includes them only if the first 80 data points are used. Benati and Surico (2006) have argued that VARs may be unable to correctly capture regime switches with this DGP. Tables 2 and 3 show that such a claim is generally invalid.

Table 3: Variances of reduced form shocks, simulated data

	Continuity solution							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	3.32	3.22	3.27	3.26	1.05	0.99	0.96	0.89
π	1.63	1.58	1.56	1.54	0.38	0.36	0.37	0.34
R	0.87	0.84	0.83	0.89	1.07	1.11	1.16	1.09
	Orthogonality Solution							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	1.01	1.02	1.04	1.15	0.99	0.93	0.96	0.89
π	0.16	0.16	0.19	0.25	0.37	0.36	0.37	0.34
R	0.08	0.08	0.08	0.17	1.08	1.12	1.16	1.09
	Without inflation expectations, Continuity solution							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	3.48	3.40	3.29	3.26	1.05	0.99	0.96	0.89
π	1.68	1.63	1.56	1.54	0.38	0.36	0.37	0.35
R	0.88	0.88	0.83	0.90	1.08	1.11	1.09	1.10
	Without inflation expectations, Orthogonality solution							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	1.04	1.04	1.06	1.12	0.98	0.87	0.93	0.84
π	0.18	0.19	0.19	0.24	0.35	0.34	0.34	0.32
R	0.09	0.09	0.08	0.17	1.00	1.04	1.08	1.04

The table reports the variances of the reduced form shocks in a 4 or 3 variables VAR(2). Data from 1960:1 to 1979:4 are from the indeterminate solution, data from 1980:1 to 1999:4 from the determinate solution.

In sum, regime changes may be hard to detect with standard methods. However, if the indeterminacy/determinacy story is correct expected inflation, expected output, or a combination of the two must behave as a state variable up to the end of the 1970s but not afterward; that is, lags of these variables must help in predicting output, inflation, and the interest rates, given their lags, up to the end of the 1970s but not afterward, and the change should be a permanent one. Furthermore, omitting expectations from the system should change the variance of reduced form shocks only for samples up to the end of the 1970s. Clearly, if the story is correct and expectations are excluded from the empirical system, one should also expect the interpretation of the Great Moderation to be significantly affected.

In the next sections, we focus attention on the role of inflation expectations as a state variable. Later, we examine how our conclusions change if a measure of output expectations is used in place or in addition to an inflation expectation measure, or if the first principal component of all the available measures of inflation and output expectations is used in the empirical model.

3 Measures of expectations

Expectations are not observable but there are proxies one could use. Since they differ in the time coverage and in their reliability as predictors of future variables, we dedicate this section to describe their properties and motivate our selection of expectation measures.

The Michigan survey reports average expected changes in consumer prices for the incoming year and is available quarterly since 1960:1. This survey has 100 respondents each period, covers primarily households, and is conducted before the inflation figure of the middle month of the quarter are available. We assign the forecast to the end of the quarter, giving the survey a bit more information than it actually has. We use the mean forecast as our measure, since median estimates are available only since 1978, despite the fact that Kilian and Inoue (2005) have raised doubts about its reliability.

The Survey of Professional Forecasters, constructed by the Federal Reserve Bank of Philadelphia, has data on the implicit price deflator and real GDP expected yearly changes since 1970:1 (1968:1 for real GDP growth) while CPI forecasts are available only since 1981. The number of respondents changes somewhat with the quarter and the year in which the survey is run, and respondents are primarily members of the business community. As the Michigan survey, it is conducted in the middle of each quarter, but we assign the reported value to the end of the quarter. In this case, we use median forecast as our measure.

The Livingstone survey is biannual - it is conducted in April and October since 1955:1

- and reports eight months ahead level of the non-seasonally adjusted CPI. The number of respondents is smaller than the other two surveys (it covers about 50 economists from industry, government and academia per time period) and this may produce larger or more persistent biases. To make it comparable to the other survey measures, the 8 months expected rate of change is annualized. The median value is used as our estimate.

The Greenbook contains projections of inflation and real GDP growth produced by the staff at the Federal Reserve Board for FOMC meetings. The projections measure the annualized quarter-on-quarter changes of the implicit price deflation and real GDP up to 1996 and of the chain-weighted indices after that date. One year ahead forecasts are available only since 1975:1. Irregularly sparsed annualized two and three quarters ahead forecasts are available since 1968:1 and annualized one quarter ahead forecasts since 1965:4. We fill in missing data using regression methods and use annualized three quarters ahead projections as our basic measure. Also, since FOMC meetings are irregularly spaced, quarterly data are constructed using the projections produced by the report which is closest to the middle of each quarter. As with survey measures, we assign this value to the end of the quarter.

The term structure of nominal interest rates also provides an implicit measure of inflation. To construct it, let $f_{t,p,k-p} \equiv \frac{R_{t,p}}{R_{t,k}}$ be the forward rate quoted at t, for p holding periods, on a bond with maturity k, where $R_{t,p}$ and $R_{t,k}$ are the time t returns on nominal bonds of p and k maturities. Thus, for example, the (quarterly) forward rate quoted at t, on a ten year bond held for one year, is denoted by $f_{t,4,116}$. The one year forward rate can be decomposed as:

$$f_{t,4,k-4} = r^e_{t,4,k-4} + \pi^e_{t,4,k-4} + [f_{t,4,k-4} - E_t \ln R_{4,t+k-4}] + [E_t \ln R_{4,t+k-4} - r^e_{t,4,k-4} - \pi^e_{t,4,k-4}] \tag{8}$$

where the first term represents the expected one year real rate, the second the one year expected inflation, the third the nominal term premium (the difference between the forward rate and the expected future nominal rate) and the last the real excess return of the expected nominal rate over the expected real rate. While it is typical to assume that the first, the third and the fourth terms of the expression are time invariant - this would allow us to identify the dynamics of expected inflation with those of the forward rate - such an assumption is too heroic for the sample we consider to be credible. As an alternative, we use the rational expectation assumption, regress realized inflation on a constant and the forward rate and take the predicted value as a measure of inflation expectations. This procedure is relatively common in the literature (see e.g. Svensson (1994), or Soderlin (1995)) and makes the resulting expectations close to actual inflation. To take into account potential breaks in the path of inflation the regression is actually run on two separate subsamples (up to

1980:2, after 1980:2). An alternative signal extraction approach, where expected inflation is treated as unobservable random walk while the other components in (4) have stationary AR(1) dynamics, produces similar results.

Data on the term structure of the nominal interest rates is available at the FRED databank of the Fed of Saint Louis. However, the data reports rates for non-zero coupon bonds. We have managed to recover a comparable data set for zero coupon bonds but only for the period 1974:1-2001:4, which makes it too short for our purposes. It turns out that the forward rates implied by the two term structures are very similar in the overlapping sample (contemporaneous correlation 0.98) and the measures of expectations we obtain from the two different series are practically indistinguishable. To maximize the length of the sample, we therefore work with inflation expectations obtained from non-zero coupon bonds, even though the above decomposition is only approximately valid.

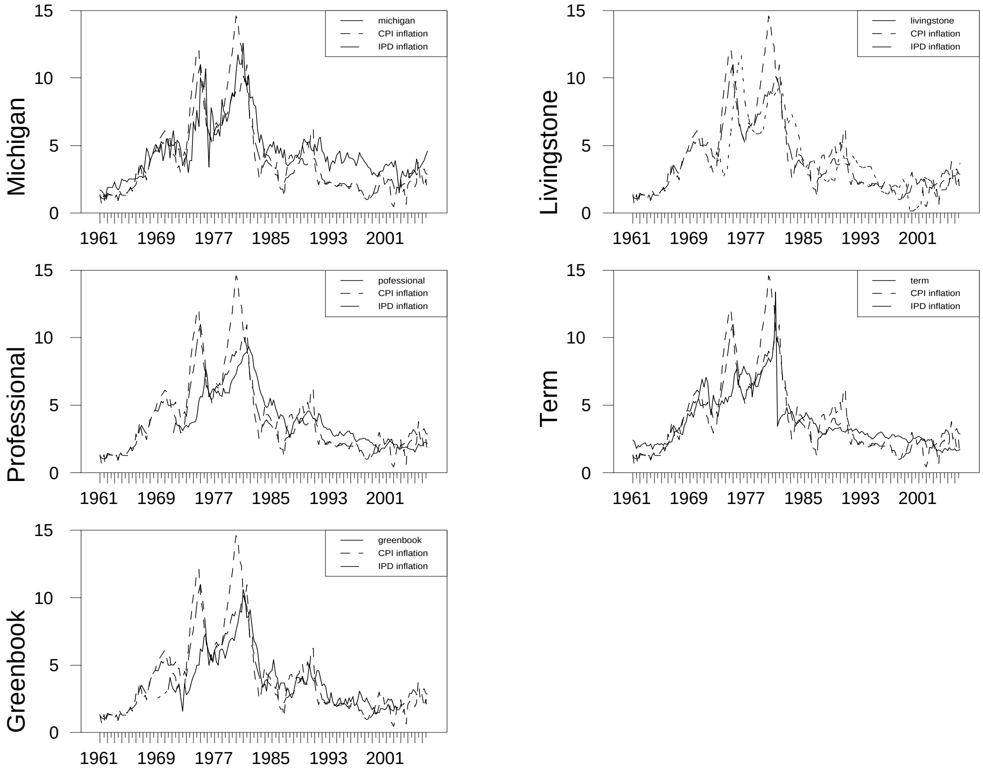

Figure 3: Actual and expected inflation.

While inflation expectations backed out from financial market data are probably more reliable, survey data are publicly available and do not require any statistical model or possibly controversial assumption to back them out. To compare their properties, we plot in figure 3 the time path of the five expected inflation series together with actual inflation computed using the implicit price deflator (IPD) and the CPI (measured here by the seasonally adjusted index for all items). Confirming Merha (2002), Michigan expectations are a good predictor of actual inflation up to 1980. The tracking performance deteriorates somewhat over the 1980s, and over the 1990s the reported mean systematically overestimates actual inflation. Professional expectations are better over the whole sample, but in particular episodes (for example, the beginning of the 1980s), they are less reliable than Michigan expectations. Livingstone expectations appear to be free of large or persistent biases, except perhaps in the latest part of the sample. Greenbook projections closely track IPD dynamics, are highly correlated with Professional and term structure expectations, and replicate actual inflation well, except for the early 1980s.

Table 4 shows that Michigan and Term structure expectations are those most highly correlated with actual inflation (regardless of whether it is measured by IPD or CPI) and with each other. In terms of moments of the empirical distribution, Term structure expectations closely replicate those of actual inflation. Finally, Michigan expectations have the smallest in-sample MSE, both relative to IPD and CPI inflation. Hence, we initially focus on Michigan and Term structure expectations in our exercises and use other measures for robustness checks [2].

Table 4: Statistics and contemporaneous correlations

	Correlations						Statistics				MSE	
	Professional	Livingstone	Greenbook	Term	IPD	CPI	Mean	St. Err.	Min	Max	IPD	CPI
Michigan	0.78	0.50	0.77	0.79	0.86	0.82	4.66	2.20	1.2	12.60	2.12	3.48
Professional		0.63	0.88	0.70	0.73	0.69	4.05	1.97	1.54	9.37	2.33	5.11
Livingstone			0.54	0.47	0.50	0.46	4.12	2.66	0.15	11.62	2.97	6.16
Greenbook				0.60	0.75	0.71	4.04	2.03	1.40	10.60	1.95	4.86
Term					0.83	0.80	3.80	2.20	0.95	13.07	5.51	9.64
IPD							3.80	2.39	0.94	10.99		
CPI							4.05	3.06	0.45	14.59		

The table reports the correlation, some sample statistics (mean, standard error, minimum and maximum) and the in-sample mean square error. Data from for Michigan expectations is from 1960:1 to 2005:4; data for Professional expectations is from 1970:1 to 2005:3, data for Livingstone expectations is from 1955:2 to 20005:2, data for Greenbook projections is from 1965:4 to 2005:4; and data for Term structure expectations

[2] When comparing survey measures to actual inflation data one should be aware that they are not measuring the same thing. First, the reported expected rate is an average over quarters rather than an end of the period measure. Second, apart from Professional forecasts, it is not clear if agents forecast CPI levels/changes or headline CPI level/changes. Third, it is not clear if simple or compounded rates are used to construct yearly measures. Fourth, forecasts are typically for non-seasonally adjusted data, while seasonally adjusted data will be used in the exercise. Ang et. al. (2006) have shown that these measurement biases are small and account for none of their forecasting comparison results.

is from 1960:1 to 2005:4. IPD is annualized inflation computed using the implicit price deflator and CPI the annualized inflation computed using all item CPI.

4 The evidence

We estimate a number of reduced form VAR models and examine whether lags of inflation expectations matter in a system including real output growth (ΔGDP), the inflation rate (π), and a short term nominal rate (R). Data is from the FRED data bank. Output growth is measured by the year-to-year change in GDP, inflation by the year to year change in CPI, all items and the interest rate by the Federal funds rate. While the implications we have derived in section 2 hold for a system where real activity is proxied by the output gap, it can be easily shown that they also hold when output growth is used.

To start with, we use the traditional device of breaking the sample in two, even if such approach is problematic for two reasons: since inflation and the nominal interest rate display an inverted U-shaped pattern, it is not clear which break date should be used and whether a subset of the data (the 1979-1982 period) should be omitted or not; using subsamples forces a simultaneous break in all the relationships while the moments of these variables display breaks at different dates.

Table 5: F-tests, p-values

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.73	0.70	0.81	0.91	0.70	0.55	0.99	0.92
π	0.00	0.01	0.01	0.00	0.02	0.00	0.04	0.05
R	0.07	0.00	0.11	0.24	0.00	0.01	0.10	0.05
	With term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.69	0.82	0.52	0.29	0.02	0.03	0.10	0.67
π	0.58	0.51	0.10	0.00	0.00	0.00	0.59	0.24
R	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02

The table reports the p-value for the F-test that the coefficients on the expectation variable in the equation are all equal to zero in a 4 variables VAR(4) which includes the growth rate of output Δ GDP, inflation π, the nominal interest rate R and an expectation proxy, in various subsamples.

Table 5 reports the p-value of an F-test for the exclusion of lags of inflation expectations in a VAR with 4 lags. When Michigan expectations are employed, lags of inflation expectations are never important in the output growth equation, always important in the inflation equation and usually important in the nominal rate equation (the exceptions are the samples 1960:1-1981:2 and 1960:1-1982:1). When term structure expectations are used, lags of inflation expectations are always significant in the nominal rate equation; significant in the output growth equation in the samples 1979-2005 and 1980-2005, and significant in the inflation equation, if the years 1979-1980-1981 are jointly included.

Table 6, which reports the estimated variance of the VAR residuals when the two proxies for expectations are used and when inflation expectations are excluded from the system, confirms the outcomes of table 5. For appropriately selected samples, the variances of reduced form shocks in a system where inflation expectations are included decreases over time and a system which excludes inflation expectations has reduced form shocks with marginally higher variability. More importantly, a system where inflation expectations are excluded displays the same qualitative features as systems which include them: for appropriately chosen samples, the variance of all shocks declines.

Hence, tables 5 and 6 do not support the main implications of the theory: the data tells us that if inflation expectations matter, they matter for the whole sample and when they don't, changes are temporary and primarily related to the Volker experiment of the late 1970s.

Table 6: Variances of reduced form shocks

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.80	0.81	0.86	1.06	0.60	0.58	0.56	0.34
π	0.07	0.08	0.09	0.10	0.05	0.04	0.03	0.03
R	0.50	0.75	1.47	1.96	0.93	0.92	0.46	0.15
	With term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.80	0.81	0.83	1.00	0.55	0.53	0.51	0.34
π	0.10	0.10	0.10	0.10	0.04	0.04	0.04	0.03
R	0.43	0.52	1.03	1.35	0.64	0.64	0.46	0.15
	Without inflation expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.83	0.83	0.88	1.07	0.62	0.60	0.56	0.35
π	0.10	0.10	0.11	0.13	0.06	0.05	0.04	0.04
R	0.57	0.89	1.65	2.12	1.15	1.06	0.50	0.17

The table reports the variances of reduced form shocks in a VAR(4), which includes the growth rate of output Δ GDP, inflation π, the nominal interest rate R and in the first two panels an expectation proxy, in various samples.

5 Is the empirical evidence reliable?

There could many reasons for why the empirical evidence fails to conform to the predictions of the theory. In this section, we examine six alternative possibilities. Tables documenting the results we discuss are in the appendix available as additional material to the paper.

First, we may be unable to detect a permanent break in the importance of inflation expectations because the lag length of the VAR is misspecified. Note that, given overlapping nature of all expectations measures, a generous lag length is needed to whiten VAR residuals. However, if too many lags are included, lags of other variables could proxy for lags of inflation expectations weakening our tests. Since the model of section 2 has a VAR(2) format and since inflation expectation measures induce an MA component of order three, a lag length of 4 strikes a balance between the two opposing forces. However, changing the lag length from 2 to 8, has no effect on the conclusions we reach.

Second, as we have mentioned, several expectation measures forecast IPD inflation rather than CPI inflation. Therefore, we have rerun our tests using IPD inflation in the VAR. While there is weak evidence that term expectations matter in the right way for inflation, the basic conclusions we have derived hold also in this case.

Third, our tests may fail because the proxies for expected inflations we employ are plagued by measurement or estimation errors. Since Thomas (1999), Merha (2002), and Ang, et. al. (2006)) have shown that these proxies capture important information about future developments of inflation, it is hard to believe that this is the case. Nevertheless, Faust and Wright (2006) have shown that Greenbook projections are superior to other expectation measures, while Leduc et. al. (2007) claim that Livingstone expectations contain information which is relevant to capture shocks to expectations. We have repeated the estimation using Greenbook forecasts - in this case the sample starts in 1968:4 - and Livingstone survey data - in this case data for output growth, inflation and the nominal rate is sampled bi-annually - but the same conclusions. If anything, the evidence for a structural break is even weaker with Livingstone data, while Greenbook projections become more important for output growth and inflation after 1982.

It is also possible that our inflation expectation measures are not really forward looking making the test weak. To check for this possibility we have constructed an expected inflation measure using the VAR. This measure, which is internally consistent but completely backward looking, is correlated with survey and term structure measures, but not perfectly (roughly 0.6). Therefore, inflation expectations measures do contain an independent forward looking component.

Fourth, as argued in section 2, the theory implies that there is an additional state variable under indeterminacy with sunspots. So far we have associated this variable with inflation expectations, but any variable correlated with sunspot shocks may do the job. We have repeated estimation using output growth expectations in place of, or jointly with, inflation expectations or when using the first principal component of all output and inflation expectation measures in place of inflation expectation - since measures of output growth expectations start only in the mid-late 1960's, the size of the first subsamples is now shorter. None of the results we have presented is affected by the addition of output growth expectations to the empirical model, or the substitution of inflation expectations with output growth expectations or with the first principal component of all expectations.

Campbell (2004) documented that the predictive power of the expectation measures contained in the Survey for Professional Forecasts (SPF) for output growth has declined since 1984. As mentioned, SPF can not be used for our purposes because the data starts too late to make estimation credible. Nevertheless, it should be pointed out that our conclusions are different because the exercise we conduct is different. First, we are looking for a change in predictive power of output expectations, once lags of the endogenous variables are used. Second, we are looking for changes in the predictive power of lagged rather than current expectations. Tulip (2005) has found that the short term predictability of output growth has increased using Greenbook forecasts. Our results agree with this evidence.

Fifth, one can argue that a four variable VAR is misspecified. If a large scale model were the true data generating process and a four variable system was used, many important variables would be omitted and their presence in VAR residuals could make the detection of regime changes hard. We therefore repeated the estimation using a VAR which, in addition to the previous four variables, includes the first principal component obtained from a large data set composed of 102 quarterly macroeconomic variables (and described in Stock and Watson (2007)). Two lags are sufficient to whiten the residuals of this system. With this empirical model, the results still hold, except that now Michigan expectations explain output growth in some samples but not others. However, the change in predictive performance is neither permanent nor timewise related to the event of interest. Interestingly, inflation expectations have no predictive power for the principal component of this large set of data in any of the samples we consider.

Finally, we have argued that arbitrarily splitting the sample and forcing the break to be common to all equations is less than ideal to examine the role of expectations over time. Time varying coefficient models are particularly suited for our purpose because they avoid strong restrictions on the nature of the breaks and because they can track the time evolution of the relationships. A time-varying coefficients specification also allows us to examine the weaker hypothesis that the importance of expectations has declined as we move from the 1970s to the later part of the sample. The model we consider is

$$y_t = X_t'\theta_t + \varepsilon_t \tag{9}$$

where y_t is a 4×1 vector, X_t is a matrix including lags of y_t and a constant, θ_t is a $4(4p+1) \times 1$ vector, p is the number of lags and $\varepsilon_t \sim N(0, \Sigma_t)$. We assume that

$$\theta_t = \theta_{t-1} + u_t \tag{10}$$

where u_t is a normal $4(4p+1) \times 1$ white noise with zero mean, covariance Ω, and we discard draws for θ_t producing diverging paths for y_t. Let $\Sigma_t = FD_tF'$, with F a lower triangular matrix and D_t a diagonal matrix, and let σ_t be the vector of the diagonal elements of D_t. We assume:

$$\log \sigma_{it} = \log \sigma_{it-1} + \xi_{it} \tag{11}$$

where $\xi_{it} \sim N(0, \Xi_i)$ and ξ_{it}, u_t and ε_t are mutually independent.

We estimate the model with Bayesian techniques and non-informative but proper priors setting $p = 2$. The details of the implementation are described in the appendix. Since both θ_t and Σ_t are time varying rather than using classical F-tests for the significance of lags of inflation expectations at each date, we present the evolution of the median and of the 68% central posterior credible interval for the statistics of interest.

Figures 4 and 5, which plot the evolution of the median and the posterior credible intervals for the lags of inflation expectations and for their long run value in each equation, when Michigan and Term expectations are used, broadly agree with table 5. When Michigan expectations are used, inflation expectations are practically never significant in the output growth equation, and almost always significant in the inflation equation, at least in the long run. The significance of inflation expectations in the interest rate equation depends on the sample, but changes over time in the long run effects are statistically insignificant.

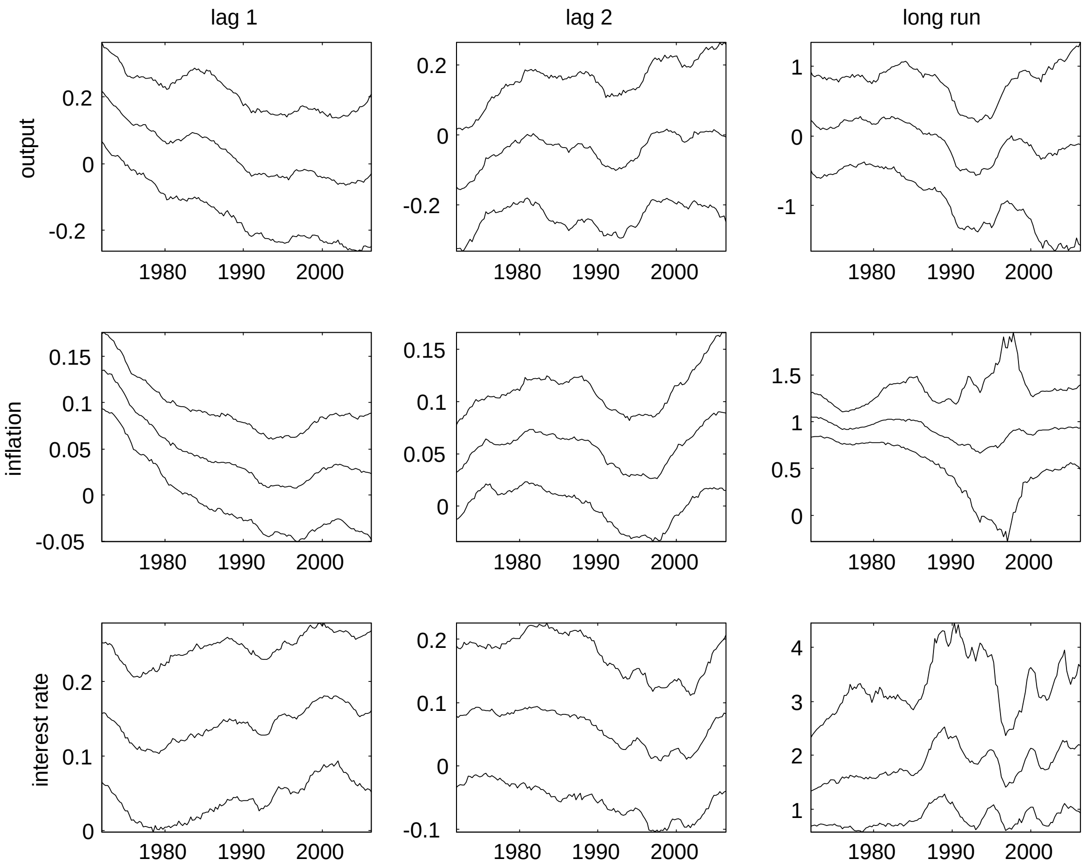

Figure 4: 68 percent posterior intervals for coefficients on lagged inflation (Michigan) expectations.

When Term expectations are used the evidence is more mixed. Nevertheless, it is still true that the importance of inflation expectations in the output growth equation is small and somewhat increasing since the early 1980s, while for the other two equations the effect is time varying but inconsistent with the hypothesis of interest. For example, decreases in the median value of the coefficient of the first lag in the interest rate equation are compensated by increases in the median value of the coefficient of the second lag. Overall, inflation expectations are more important after 1982.

Figure 6, which reports the posterior median of the variance of the reduced form shocks with inflation expectations (Michigan solid line, Term dashed line) and without them (dotted line), also broadly agrees with table 4.

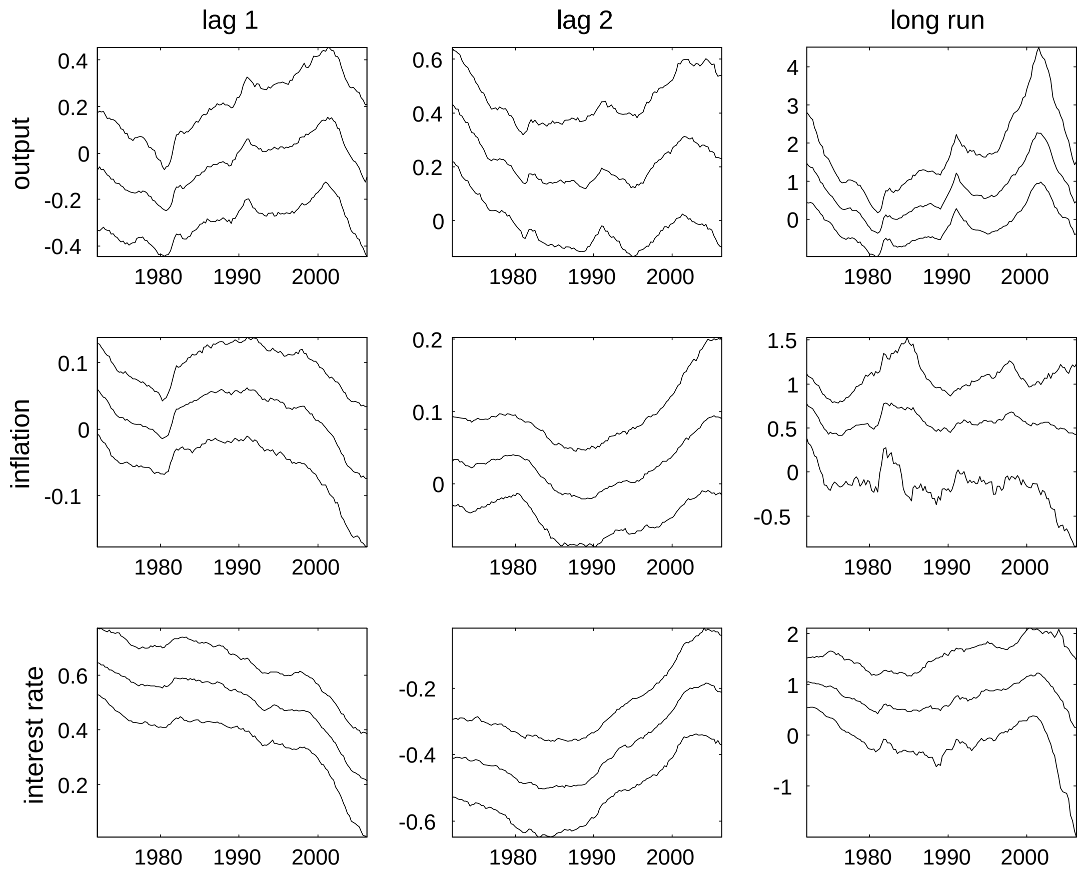

Figure 5: 68 percent posterior intervals for coefficients on lagged inflation (Term) expectations.

For instance, there is a general decline in the variability of the reduced form shocks over time which is similar in magnitude and timing across measures of inflation expectations; including or excluding inflation expectations from the system hardly changes the time path of the reduced form variances. Furthermore, given the considerable uncertainty associated with point estimates, differences in systems with and without inflation expectations are a-posteriori insignificant at any date in the sample.

To conclude, regardless of the proxies employed, of the specification of the VAR and the horizon where we measure the effect, of whether we allow coefficients to be time varying or not, and of other specification choices, the importance of expectations does not decline as we move from the 1970s to the end of the sample, neither in the sense of a structural break nor in the sense of a slow moving but unidirectional change.

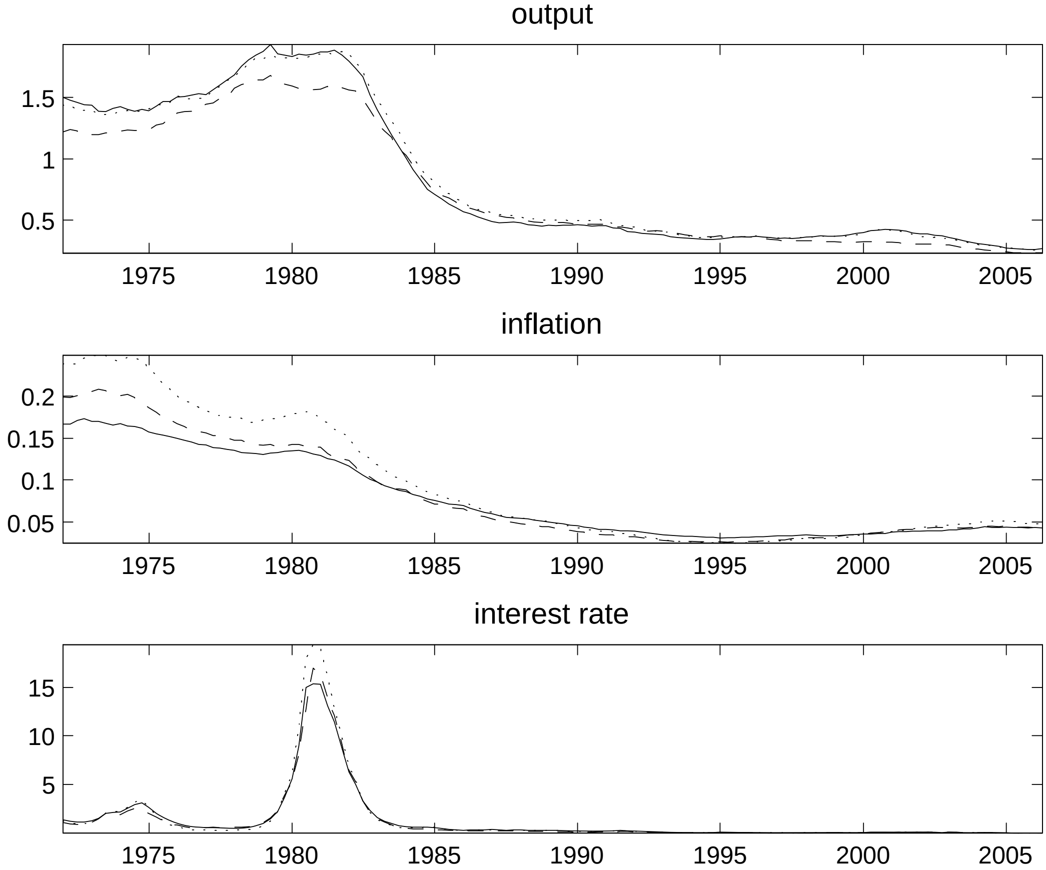

Figure 6: Variances of VAR shocks, solid Michigan expectations, dashed Term expectations, dotted no expectations.

6 Explaining the Great Moderation

The statistical analysis we have presented is silent about whether the absence of inflation expectations from an empirical model alters our understanding of the Great Moderation episode. If inflation expectations truly mattered up to a certain date, existing analyses, which systematically exclude them from the empirical system, are likely to be flawed.

To study the sources of the Great Moderation we need to identify structural shocks. The restrictions we use are in table 7. Gambetti et. al. (2008) showed how they can be obtained from a DSGE model featuring monopolistic competitive firms, rational consumers and rules for monetary and fiscal policy, and that they are robust, in the sense that they hold as the structural parameters drift within a reasonable range.

Table 7: Identification restrictions

	GDP	π	R
Supply/sunspot	≥ 0	≤ 0	≤ 0
Real Demand	≥ 0	≥ 0	≥ 0
Monetary	≥ 0	≥ 0	≤ 0

The table reports the restrictions used to identify the shocks in a VAR(2) which includes the growth rate of output Δ GDP, inflation π, the nominal interest rate R and an expectation proxy. The restrictions are from Gambetti et al. (2008).

The restrictions in table 7 are satisfied in the model of section 2 and robust, not only to the parameterization of the model, but also to the horizon at which the analysis is conducted. We impose restrictions at horizons zero and one and collect 500 draws for the posterior density of the impulse response functions for each year in the sample.

In the introduction we have characterized the "Great Moderation" phenomena as a considerable fall in the volatility and the persistence of output growth and inflation. We measure persistence as the height of the structural spectrum of output growth and inflation at frequency zero and volatility as the area under the structural spectrum of the two variables. These statistics, computed using the median estimates obtained in a four-variable TVC-VAR(2) when Michigan expectations are used, are reported as continuous lines in figure 7. They display two sharp peaks, around 1974 and 1981; a considerable decline after the second peak; and since 1985, the persistence and the volatility of both output and inflation have been stable and low relative to the 1970s. Figure 7 also presents the individual contribution of the three identified shocks: starred lines represent the contribution of supply/sunspot shocks, dotted lines the contribution of real demand shocks and dashed lines the contribution of monetary shocks. These lines report the persistence and volatility of output growth and inflation that would emerge if only one type of structural shocks was present at each date.

Supply/sunspot and real demand shocks are the largest contributors to both the 1974 and 1981 peaks in the persistence and volatility in output growth. Monetary shocks contribute little to the 1974 peak, but become more important for the 1981 peak. Supply/sunspot shocks contribute most to the peaks in inflation persistence and volatility in 1974, while monetary shocks are the sole contributor to the 1981 peak - the contributions of supply/sunspot and real demand shocks consistently decline since 1975 for all the statistics. Hence, our structural VAR indicates that i) inflation volatility (and persistence) would have been lower since the mid 1970s, had not been for the Volker experiment and ii) the fall in inflation volatility (and persistence) predates the adoption of a more aggressive monetary policy stance.

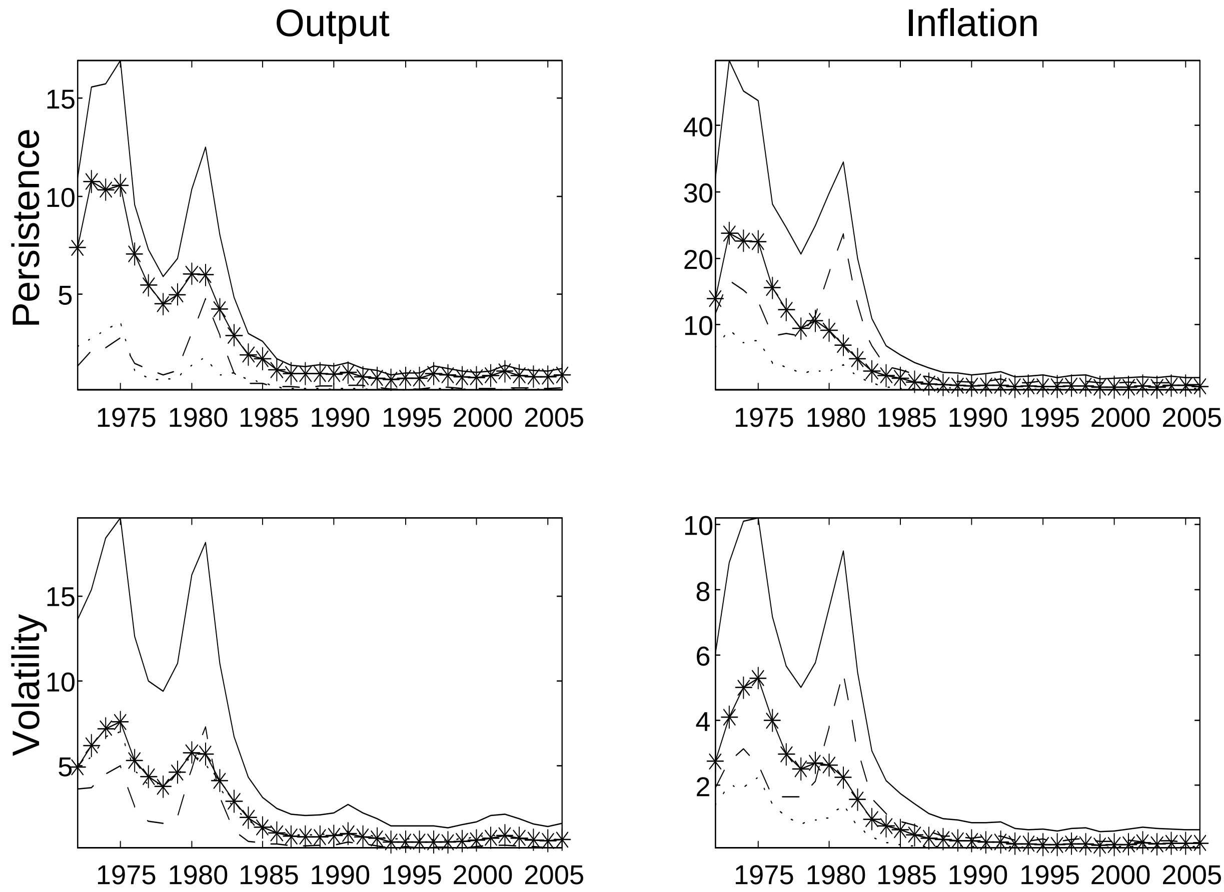

Figure 7: Contribution of supply (stars), real demand (dotted), and monetary (dashed) shocks to inflation and output growth persistence and volatility.

Would our conclusions change if we exclude inflation expectations from the VAR? Figure 8 reports the proportion of inflation and output growth volatility and persistence explained by the three identified shocks at each date in a TVC-VAR with Michigan expectations (first column), Term expectations (second column) and no expectations (third column). Our conclusions are unchanged if inflation expectations are absent from the system. For example, both supply and real demand shocks are crucial to characterize the time profile of output growth volatility and monetary policy shocks became important to explain the dynamics of inflation only from early 1980s.

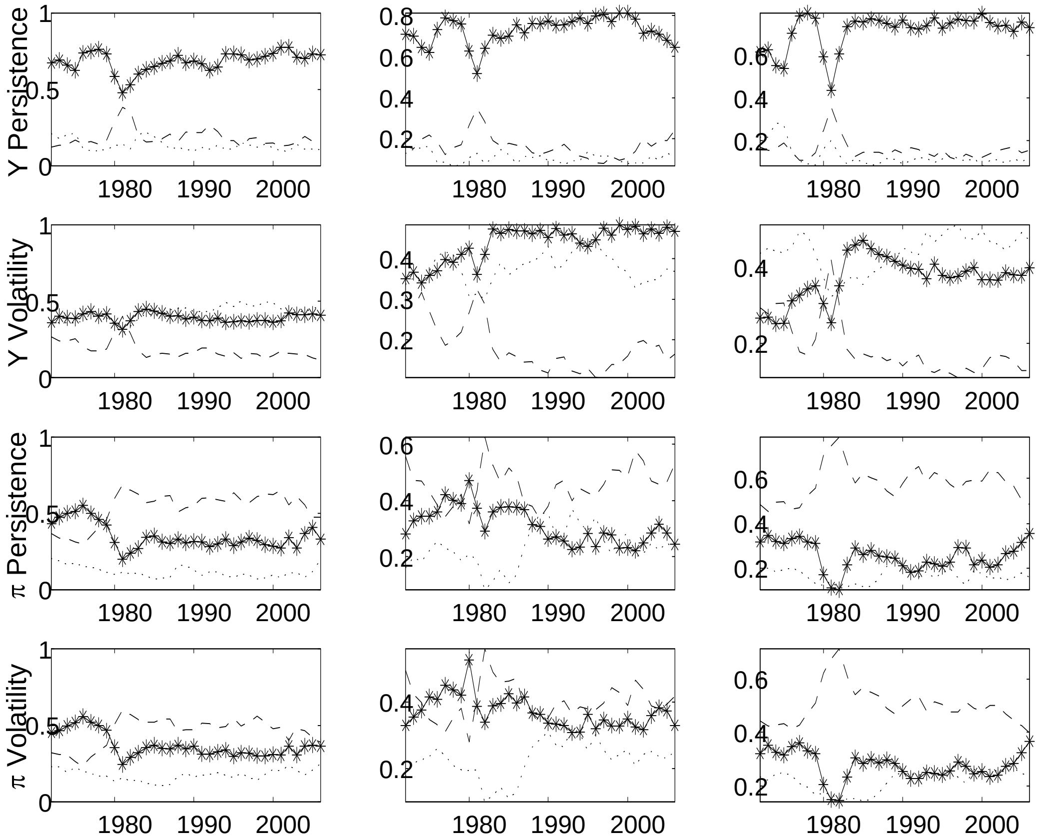

Figure 8: Share contribution of shocks: star supply shocks, dotted real demand shocks, dashed monetary shocks; colomn 1 Michigan, colomn 2 term, colomn 3 no expectations.

7 Do sunspot shocks matter?

The analysis of section 6 has not tried to separately identify the contribution of sunspot shocks to variations in output growth and inflation volatility and persistence. One reason is that, as figure 1 shows, the dynamics of output, inflation and the nominal rate induced by an orthogonal sunspot shock are qualitatively similar to those induced by a Phillips curve shock. However, figure 7 showed that what we called supply/sunspot shock has an important role in explaining the volatility and persistence bursts of 1974 and 1981 and that the time path of the volatility and persistence due to these shocks is declining over time. Could it be that what we call supply shocks are really shocks to expectations? Could it be that even if the absence of inflation expectations causes minor changes to the interpretation of the Great Moderation, sunspot shocks matter for output growth and inflation volatility and persistence up to a certain date but not afterwards? Trying to separate the two types of shocks is difficult in a four variable system. In theory, the real rate responds differently to the two shocks - it converges to zero from below in response to sunspot shocks and from above in response to Phillips' curve shocks (see figure 1), but changes in the parameterization and in the model specification change the dynamics induced by these shocks.

Conditional on the model and its parameterization, we impose the theoretical shape restrictions on the real rate implied by the VAR and ask: what is the contribution of sunspot shocks to the statistics presented in figure 7? Figure 9 reproduces the combined effect of supply and sunspot shocks reported in figure 7 (line with stars) and shows the contribution of the two components (sunspot dotted, supply dashed) when orthogonality between structural and sunspot shocks is assumed. Output growth and inflation persistence would have been much lower in the 1970s and the change much more contained if only sunspot shocks where present. Also, the fall in output growth persistence would have occurred only since the mid-1980s. Similarly, output growth and inflation volatility would not display the two peaks in 1974 and 1981 had there been only sunspot shocks and the decline in the 1980s and 1990s would have been minor. One could argue that the truly important feature here is whether sunspots shocks were present in the 1970s and absent in the 1980s. Our evidence suggests that sunspot shocks are less important in absolute terms now than they were in the past. However, relatively speaking, sunspot shocks are more important than identified supply shocks now than in the 1970s and this does not square very well with the indeterminacy/determinacy story the Great Moderation.

We want to stress that the evidence in figure 9 is suggestive: in a three equation model it is difficult to find sharp implications to extract sunspot shocks and the restrictions on the real rate we have used are not entirely robust: there are parameter combinations which imply that sunspot shocks look like demand shocks. These parameterizations, however, have the disadvantage that sunspot shocks can not be interpreted as stagflation shocks.

It is worth contrasting our evidence on sunspots with what is available in the literature. Leduc et. al. (2007) identify shocks to expectations using delay restrictions and found that the response of the nominal interest rate is quite different in the 1970 and afterwards. However, the shocks they identify do not induce the same dynamics as the sunspot shocks of figure 1 and this makes the comparison difficult. Lubik and Schorfheide (2004) and Boivin and Giannoni (2006) have estimated the model of section 2 with structural methods, but they do not address the question of how much sunspots matter. Boivin and Giannoni conduct some counterfactuals but, as indicated in section 2, these are not informative about regime switches. Also, the conclusions of all three papers are based on subsample analysis, which, as we have argued, may give a distorted view about the role of sunspots when the data displays U-shaped patterns.

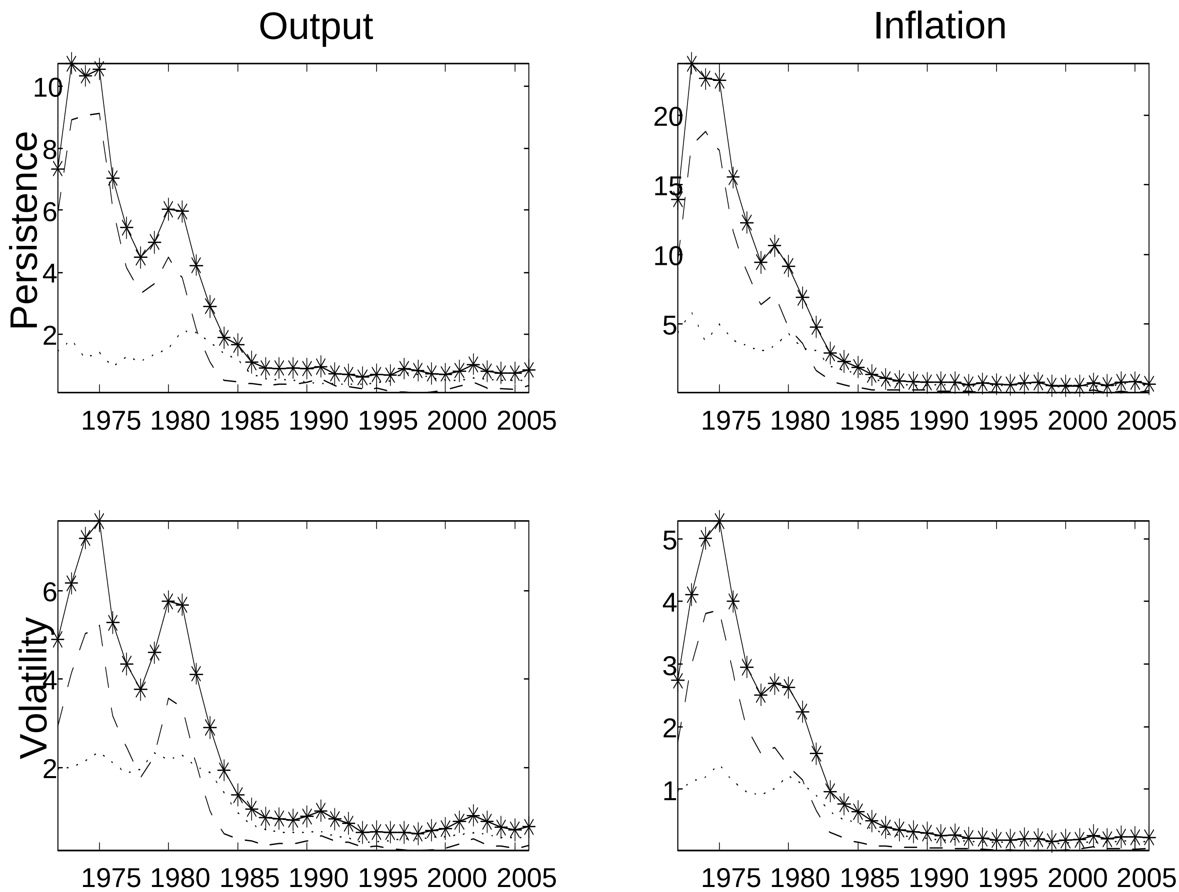

Figure 9: Contribution of sunspot (dotted) and supply (dashed) shocks to output and inflation volatility and persistence.

8 Conclusions

This paper examines whether the restrictions imposed by a simple indeterminacy-determinacy story of the Great Moderation are satisfied. We show that there is an additional state variable in the indeterminate regime which fails to appear in the determinate one; that standard counterfactuals may have hard time to detect regime changes; and that several explanations are "locally" indistinguishable from the indeterminacy-determinacy story. Using several VAR models, we study whether the significance of lagged expectations changes over time; whether omitting expectations from the estimated system causes time varying biases in the variance of reduced form shocks; and whether the absence of expectations alters the interpretation of the Great Moderation.

We find that (i) there is no clear switch over time in the importance of lags of expectations in any equation of the system; (ii) reduced form variances estimated in systems with and without expectations display similar paths and little evidence of time varying biases; (iii) the economic interpretation of the Great Moderation episode is roughly independent of the inclusion or the exclusion of expectations from the system; (iv) the contribution of sunspot shocks to output growth and inflation volatility and persistence over time do not line up well with the time variations in these statistics.

We show that the empirical results we obtain are robust to a number of potential empirical problems. Therefore, if one insists on taking the bad policy hypothesis as a benchmark, one has to conclude that the model we have used to derive restrictions is inappropriate. While the implications we emphasize hold in larger system with additional frictions (such as habit in consumption or wage stickiness), some omitted features which could matter.

First, if regimes change in a Markov chain fashion and agents are aware of the law of motion of the switches (as in Davig and Leeper (2007)), the equilibrium is either determinate or indeterminate for the whole sample but bad policy can contribute to volatility and persistence bursts even in a globally determinate regime. The fact that i) the role of expectations is unchanged over time, and ii) the volatility and in the explanatory power of structural shocks falls over time is consistent with an explanation of the Great Moderation where the equilibrium is always determinate but bad policy prevailed in the 1970s.

Empirical evidence suggesting that the case for bad policy in the 1970s is overstated comes from the work of Orphanides and Williams (2005), who find little evidence of violation of the Taylor principle in the 1970s, once real time data are used; and by Duca and Wu (2007), who pointed out that the presence of regulation-Q made the effective real interest rate very different from the ex-post real rate and that, with the effective rate, the Taylor principle is almost never violated in the 1970s.

Second, we have seen that under learning, expectations become a state variable, regardless of the monetary regime in place. Therefore, our results are not necessarily inconsistent with a indeterminate-determinate story were agents learn over time about changes in the economy (see Schorfheide (2005)). Furthermore, with learning the coefficients of the reduced form representation of the model will be time varying - which is what we find when we allow the coefficients to drift over time.

Third, the model assumes that there is no frictions in the flow of information. In models where information is sticky, such as Mankiw and Reis (2006), the role of inflation expectations does not necessarily change with the regime. Sticky information models, however, have one counterfactual implication: inflation expectations should be almost perfectly correlated with lagged inflation. In our data, the correlation is small.

Hence, while the theoretical restrictions implied by the model of section 2 are rejected, it is difficult to draw general conclusions about more sophisticated versions of the bad policy hypothesis which allows for learning, misperception or informational frictions. Future work in the area needs to examine these situations in more details.

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Complementary Material

Appendix A: The estimation of the TVC- VAR models

I. Priors

Let z^T denote the sequence of z's up to time T. Let γ be the vector containing the non-zero non-one elements of F^{-1} stacked by rows and Ξ a vector including all the Ξ_i. The transition density of the state is assumed to be

$$\begin{aligned} p(\theta_t|\theta_{t-1},\Omega) &\propto I(\theta_t)f(\theta_t|\theta_{t-1},\Omega) \\ f(\theta_t|\theta_{t-1},\Omega) &= N(\theta_{t-1},\Omega) \end{aligned}$$

where $I(\theta_t)$ is an indicator function which discard draws for θ_t implying explosive paths for y_t. We assume that the hyperparameters and the initial states are independent so that the joint prior is simply the product of the marginal densities. Following Cogley and Sargent (2005) we assume:

$$\begin{aligned} P(\theta_0) &\propto I(\theta_0)N(\bar{\theta},\bar{P}) \\ P(\Omega) &= IW(\bar{\Omega}^{-1},T_0) \\ P(\log\sigma_{i0}) &= N(\log\bar{\sigma}_i,10) \\ P(\gamma) &= N(0,10000*I_4) \\ P(\Xi_i) &= IG(\frac{0.01^2}{2},\frac{1}{2}) \end{aligned}$$

where $\bar{\theta}$ and $\bar{P}$ are the OLS estimates of the VAR coefficients and their variances obtained with the initial sample, $\bar{\Omega}=\lambda\bar{P}$, T_0 is the number of observations in the initial sample (1960:I-1971:IV, 48 observations), $\bar{\sigma}_i$ is the estimate of the variance of the residual in equation i obtained using the initial sample. The hyperparameter λ is set to 0.0005 for all the parameters except for the constant terms of inflation, inflation expectations and the interest rate. For these constants it is set to 0.001.

II. Posteriors

To draw realizations from the posterior density we use the Gibbs sampler. Each iteration is composed of four steps and, under regularity conditions and after a burn-in period, iterations on these steps produce draws from the joint density.

- Step 1: $p(\theta^T|y^T, \gamma, \sigma^T, \Xi, \Omega)$

  Conditional on $y^T, \gamma, \sigma^T, \Xi, \Omega$, the unrestricted posterior of the states is normal. To draw from the conditional posterior we employ the algorithm of Carter and Kohn (1994). The conditional mean and variance of the terminal state θ_T is computed using standard Kalman filter recursions while for all the other states the following backward recursions are employed

$$\begin{aligned} \theta_{t|t+1} &= \theta_{t|t} + P_{t|t}P_{t|t+1}^{-1}(\theta_{t+1} - \theta_{t|t}) \\ P_{t|t+1} &= P_{t|t} - P_{t|t}P_{t+1|t}^{-1}P_{t|t} \end{aligned} \tag{12}$$

where $p(\theta_t|\theta_{t+1}, y^T, \gamma, \sigma^T, \Xi, \Omega) \sim N(\theta_{t|t+1}, P_{t|t+1})$.

- Step 2: $p(\gamma|y^T, \theta^T, \sigma^T, \Xi, \Omega)$

  Given that σ^T and y^T are known ε_t is known and since u_t is a standard Gaussian white noise, we have $D_t^{-1/2}F^{-1}\varepsilon_t = u_t$ or $D_t^{-1/2}\varepsilon_t = -D_t^{-1/2}F^*\varepsilon_t + u_t$ with $F^* = F^{-1} - I$. We can rewrite the ith equation as $z_{it} = -w_{it}\gamma_i + u_{it}$ where $z_{it} = \varepsilon_{it}/\sqrt{\sigma_{it}}$, $w_{it} = [\varepsilon_{1t}/\sqrt{\sigma_{it}}, ..., \varepsilon_{i-1t}/\sqrt{\sigma_{it}}]$ and γ_i is the column vector formed by the non-zero elements of the ith row of F^*. Given the normal prior, the posterior is $\gamma_i = N(F_{1i}, V_{1i})$ where $F_{1i} = V_{0i}(V_{0i}^{-1}\gamma_{0i} + w_i'z_i)$ and $V_{1i} = (V_{0i}^{-1} + w_i'w_i)^{-1}$ with V_{0i} and γ_{0i} the prior variance and mean respectively. Drawing for $i = 2, 3, 4$ we obtain a draw for γ.

- Step 3: $p(\sigma^T|y^T, \theta^T, \gamma, \Xi, \Omega)$

  The elements of σ^T are drawn using the univariate algorithm by Jacquier, Polson and Rossi (2004) along the lines described in Cogley and Sargent (2005) (see Appendix B.2.5 for details).

- Step 4: $p(\Xi_i|y^T, \theta^T, \gamma, \sigma^T, \Omega)$, $p(\Omega|y^T, \theta^T, \gamma, \sigma^T, \Xi)$

  Conditional on $y^T, \theta^T, \gamma, \sigma^T$ and under conjugate priors, all the remaining hyperparameters, can be sampled in a standard way from Inverted Wishart and Inverted Gamma densities (see Gellman et al., 2001)).

We perform 20000 repetitions, we discard the first 5000 draws and, for inference, we keep one every 10 of the remaining draws to break the autocorrelation of the draws.

Appendix B: Additional Results

This appendix reports tables with additional material discussed but not reported in the text. We also present in tables A.15 and A.16 the results obtained using an eight variable VAR which includes output growth, inflation, the nominal rate an expectation measure and consumption growth, investment growth, hours and the growth rate of money. Consumption growth is measured by the year-to-year change in real nondurable private consumption, investment by the year to year change in fixed private investments, hours by total hours in the non-farm business sector and money growth by the year to year change in M2. Two lags are sufficient to whiten the residuals of this system. In the larger scale VAR inflation expectations have an even smaller predictive role in the first part of the sample. Hence, it is harder to find a break in the importance of inflation expectations over time.

Orphanides (2004) and Orphanides and Williams (2005) have pointed out that policy decisions are typically taken when preliminary estimates of the relevant quantities are available while empirical analyses trying to understand how policymakers historically behaved, typically employ final estimates. For our exercises, this is a relevant concern since the presence of measurement errors could reduce the ability of our tests to detect breaks. To examine the relevance of this problem we have simulated data from the model assuming that private agents take decisions using the correct data while the central bank rule is

$$R_t = \phi_r R_{t-1} + (1-\phi_r)[\phi_\pi(\pi_t + u_{1t}) + \phi_x(x_t - z_t + u_{2t})] + e_{R,t}$$

where u_{1t} and u_{2t} are measurement errors. With the same parameterization we have used in tables 5 and 6, we have simulated two samples with 160 data points (one with 80 data from the continuity regime and 80 from the determinate regime, the other with 80 data from the orthogonality regime and 80 from the determinate regime) and applied our tests to the simulated data. We have considered two situations: classical iid and highly serially correlated measurement errors. Clearly, if measurement error is large anything can happen. Therefore, it is important to appropriately calibrate the variance and the persistence of these errors to make the simulations realistic. The size of the revision error between initial and final estimates of output growth and inflation over the last 40 years shows a small declining trend and its standard error around this trend never exceeds 10 percent of the standard error of the actual series. Therefore, it is conservative to assume that an upper bound for the standard deviations of the two measurement errors is 10 percent of the standard errors of the largest structural shocks. We find that measurement error of both types (see tables A.17 and A.18) can not cover up structural changes if they were present.

Table A.1: F-tests, p-values, different lag length

1 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.44	0.30	0.57	0.81	0.77	0.64	0.71	0.68
π	0.00	0.07	0.04	0.00	0.02	0.01	0.41	0.50
R	0.38	0.09	0.02	0.08	0.01	0.00	0.02	0.01

	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.25	0.28	0.10	0.18	0.10	0.19	0.11	0.14
π	0.44	0.52	0.37	0.01	0.00	0.00	0.44	0.06
R	0.01	0.01	0.01	0.00	0.00	0.00	0.12	0.01

2 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.49	0.35	0.76	0.85	0.96	0.67	0.90	0.49
π	0.01	0.08	0.01	0.00	0.00	0.00	0.36	0.49
R	0.41	0.01	0.05	0.12	0.00	0.05	0.03	0.01

	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.31	0.26	0.09	0.22	0.15	0.24	0.08	0.12
π	0.50	0.51	0.45	0.02	0.00	0.00	0.37	0.04
R	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00

3 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.62	0.55	0.95	0.98	0.69	0.72	0.97	0.91
π	0.60	0.08	0.00	0.00	0.00	0.00	0.10	0.08
R	0.16	0.07	0.20	0.18	0.00	0.01	0.05	0.02

	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.48	0.49	0.14	0.21	0.01	0.02	0.12	0.39
π	0.52	0.50	0.16	0.00	0.00	0.00	0.72	0.27
R	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00

8 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.06	0.24	0.02	0.00	0.26	0.13	0.16	0.22
π	0.00	0.03	0.01	0.02	0.02	0.00	0.00	0.01
R	0.11	0.10	0.53	0.42	0.01	0.06	0.18	0.05

	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.84	0.71	0.14	0.31	0.00	0.01	0.18	0.14
π	0.10	0.04	0.13	0.25	0.00	0.01	0.67	0.34
R	0.44	0.00	0.00	0.00	0.00	0.00	0.01	0.03

The table reports the P-value for the F-test that expected inflation coefficients in the equation are all equal to zero in a VAR with 4 variables and varying lags.

Table A.2: Variances of reduced form shocks, different lag length.

1 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.12	1.11	1.21	1.39	0.79	0.69	0.67	0.52
π	0.09	0.12	0.12	0.13	0.07	0.05	0.05	0.05
R	0.67	0.89	2.44	2.61	1.42	1.28	0.62	0.23
	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.12	1.07	1.14	1.33	0.77	0.69	0.62	0.48
π	0.12	0.12	0.14	0.14	0.06	0.06	0.05	0.04
R	0.57	0.71	1.93	2.06	1.18	1.15	0.58	0.21
	Without inflation expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.15	1.14	1.28	1.21	0.81	0.71	0.67	0.53
π	0.15	0.15	0.15	0.14	0.08	0.07	0.06	0.05
R	0.69	0.99	2.45	2.61	1.44	1.30	0.62	0.24

2 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.03	1.01	1.17	1.31	0.71	0.65	0.62	0.45
π	0.08	0.10	0.11	0.11	0.05	0.04	0.04	0.04
R	0.62	0.86	2.03	2.33	1.24	1.22	0.51	0.18
	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.01	1.00	1.11	1.26	0.69	0.64	0.59	0.44
π	0.10	0.11	0.12	0.12	0.05	0.05	0.04	0.03
R	0.52	0.64	1.78	1.99	1.09	1.11	0.52	0.18
	Without inflation expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.05	1.04	1.18	1.31	0.71	0.66	0.62	0.46
π	0.10	0.11	0.11	0.11	0.06	0.06	0.04	0.04
R	0.63	0.97	2.15	2.46	1.38	1.30	0.55	0.20

3 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.92	0.92	1.04	1.20	0.63	0.01	0.58	0.36
π	0.08	0.10	0.10	0.10	0.05	0.04	0.03	0.03
R	0.54	0.81	1.62	1.99	0.96	0.95	0.48	0.16
	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.91	0.92	0.97	1.13	0.57	0.56	0.54	0.35
π	0.10	0.10	0.11	0.11	0.05	0.04	0.04	0.03
R	0.45	0.55	1.15	1.50	0.67	0.67	0.48	0.16
	Without inflation expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.95	0.95	1.05	1.20	0.64	0.61	0.98	0.95
π	0.10	0.11	0.12	0.13	0.06	0.05	0.04	0.10
R	0.58	0.90	1.73	2.13	1.16	1.07	0.18	0.58

8 lags

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.43	0.52	0.51	0.53	0.31	0.27	0.23	0.21
π	0.04	0.05	0.05	0.06	0.03	0.03	0.02	0.02
R	0.26	0.50	1.12	1.21	0.44	0.44	0.20	0.11
	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.56	0.59	0.58	0.71	0.26	0.24	0.23	0.20
π	0.05	0.05	0.06	0.07	0.03	0.03	0.02	0.02
R	0.30	0.41	0.72	0.79	0.36	0.35	0.18	0.11
	Without inflation expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.63	0.67	0.75	0.85	0.36	0.32	0.27	0.25
π	0.07	0.08	0.08	0.08	0.04	0.04	0.03	0.03
R	0.36	0.68	1.30	1.41	0.58	0.54	0.24	0.16

Table A.3: F-tests, p-values, Using IPD inflation

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.65	0.35	0.75	0.82	0.80	0.94	0.93	0.47
π	0.55	0.15	0.15	0.19	0.13	0.04	0.20	0.22
R	0.22	0.28	0.26	0.32	0.00	0.00	0.06	0.00
	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.26	0.15	0.11	0.35	0.16	0.49	0.09	0.10
π	0.04	0.06	0.05	0.06	0.23	0.73	0.77	0.80
R	0.01	0.00	0.00	0.00	0.00	0.00	0.08	0.00

The table reports the P-value for the F-test that expected inflation coefficients in the equation are all equal to zero in a VAR with 4 variables and varying lags.

Table A.4: Variances of reduced form shocks, using IPD inflation

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.04	1.03	1.17	1.32	0.71	0.66	0.61	0.44
π	0.14	0.14	0.14	0.14	0.06	0.04	0.04	0.04
R	0.50	0.87	2.15	2.40	1.29	1.26	0.50	0.18
	With term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.01	1.00	1.12	1.29	0.69	0.65	0.58	0.43
π	0.13	0.14	0.14	0.14	0.06	0.04	0.04	0.04
R	0.46	0.65	1.66	1.83	1.10	1.10	0.51	0.18
	Without inflation expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	1.05	1.04	1.18	1.31	0.71	0.66	0.62	0.46
π	0.10	0.11	0.12	0.14	0.06	0.06	0.04	0.04
R	0.63	0.97	2.19	2.46	1.38	1.30	0.55	0.20

Table A.5: F-tests, p-values, Livingstone expectations

	1 lag							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.59	0.77	0.68	0.63	0.29	0.88	0.77	0.51
π	0.49	0.48	0.24	0.15	0.00	0.09	0.84	0.66
R	0.86	0.80	0.79	0.61	0.00	0.04	0.26	0.53
	2 lags							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.63	0.83	0.78	0.82	0.37	0.21	0.18	0.18
π	0.67	0.51	0.42	0.43	0.01	0.20	0.09	0.31
R	0.60	0.83	0.90	0.91	0.20	0.06	0.08	0.30

The table reports the P-value for the F-test that expected inflation coefficients in the equation are all equal to zero in a VAR with 4 variables and varying lags.

Table A.6: Variances of reduced form shocks, Livingstone expectations

	1 lags							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	1.21	1.42	1.47	1.47	0.83	0.81	0.81	0.72
π	0.27	0.27	0.31	0.33	0.11	0.10	0.09	0.09
R	1.43	2.04	2.21	2.28	1.03	0.62	0.62	0.50
	2 lags							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.80	1.13	1.18	1.19	0.48	0.36	0.37	0.37
π	0.21	0.20	0.19	0.19	0.08	0.08	0.07	0.07
R	1.12	1.75	1.86	2.03	0.81	0.47	0.46	0.40
	Without inflation expectations, 1 lags							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	1.26	1.44	1.51	1.50	0.88	0.81	0.82	0.72
π	0.28	0.28	0.33	0.33	0.16	0.11	0.09	0.09
R	1.44	2.07	2.24	2.34	1.15	0.72	0.66	0.52
	Without inflation expectations, 2 lags							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.83	1.17	1.22	1.23	0.53	0.39	0.40	0.40
π	0.22	0.22	0.20	0.20	0.09	0.09	0.08	0.08
R	1.15	1.79	1.90	2.08	0.84	0.49	0.49	0.43

Table A.7: F-tests, p-values, Greenbook expectations

sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.54	0.25	0.01	0.00	0.82	0.10	0.21	0.10
π	0.14	0.14	0.13	0.00	0.00	0.00	0.11	0.39
R	0.71	0.04	0.38	0.33	0.36	0.60	0.12	0.19

The table reports the P-value for the F-test that expected inflation coefficients in the equation are all equal to zero in a VAR with 4 variables and two lags.

Table A.8: Variances of reduced form shocks, Greenbook expectations

	With inflation expectations							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.87	0.84	0.96	1.11	0.79	0.68	0.66	0.47
π	0.09	0.12	0.13	0.13	0.04	0.04	0.03	0.03
R	0.77	1.10	2.73	3.08	1.37	1.33	0.57	0.19
	Without inflation expectations							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	1.00	1.00	1.21	1.38	0.79	0.73	0.69	0.51
π	0.12	0.12	0.14	0.16	0.06	0.05	0.04	0.03
R	0.78	1.21	2.77	3.12	1.41	1.35	0.60	0.20

Table A.9: F-tests, p-values, Using output growth expectations

	Greenbook forecasts, output and inflation expectations							
	Lags of inflation expectations							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.57	0.26	0.02	0.00	0.28	0.05	0.21	0.04
π	0.00	0.14	0.16	0.02	0.00	0.00	0.06	0.30
R	0.32	0.06	0.33	0.24	0.59	0.98	0.15	0.09
	Lags of output growth expectations							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.58	0.71	0.28	0.06	0.02	0.18	0.24	0.13
π	0.95	0.94	0.94	0.49	0.30	0.58	0.32	0.72
R	0.58	0.82	0.17	0.03	0.04	0.03	0.69	0.16
	Greenbook forecasts, output expectations only							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.55	0.72	0.29	0.11	0.06	0.33	0.24	0.29
π	0.96	0.91	0.93	0.20	0.47	0.58	0.54	0.95
R	0.57	0.84	0.18	0.04	0.02	0.01	0.57	0.35
	Professional forecasts, output and inflation expectations							
	Lags of inflation expectations							
sample	68:1-79:1	68:1-80:1	68:1-81:1	68:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.48	0.49	0.09	0.04	0.00	0.00	0.30	0.11
π	0.01	0.05	0.29	0.04	0.00	0.00	0.05	0.40
R	0.40	0.64	0.53	0.49	0.00	0.00	0.00	0.00
	Lags of output growth expectations							
sample	68:1-79:1	68:1-80:1	68:1-81:1	68:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.00	0.03	0.03	0.00	0.02	0.00	0.05	0.22
π	0.13	0.06	0.54	0.33	0.22	0.63	0.80	0.81
R	0.77	0.19	0.60	0.34	0.02	0.03	0.06	0.71
	Professional forecasts, output expectations only							
sample	68:1-79:1	68:1-80:1	68:1-81:1	68:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.00	0.01	0.04	0.01	0.10	0.03	0.17	0.33
π	0.20	0.10	0.48	0.15	0.02	0.31	0.76	0.65
R	0.46	0.19	0.62	0.36	0.07	0.67	0.10	0.18

The table reports the P-value for the F-test that expected output coefficients in the equation are all equal to zero in a VAR with 4 variables and two lags.

Table A.10: Variances of reduced form shocks, systems with output growth expectations

	Greenbook forecasts, output and inflation expectations							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.85	0.83	0.92	1.00	0.71	0.65	0.64	0.45
π	0.09	0.12	0.13	0.13	0.04	0.04	0.03	0.03
R	0.75	1.09	2.55	2.72	1.27	1.22	0.56	0.18
	Greenbook forecasts, output expectations only							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.87	1.21	1.07	1.22	0.74	0.71	0.67	0.49
π	0.12	0.14	0.14	0.15	0.06	0.05	0.04	0.03
R	1.21	1.24	2.66	2.87	1.29	1.22	0.59	0.19
	Without expectations							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	1.00	1.00	1.21	1.38	0.79	0.73	0.69	0.51
π	0.12	0.12	0.14	0.16	0.06	0.05	0.04	0.03
R	0.78	1.21	2.77	3.12	1.41	1.35	0.60	0.20
	Professional forecasts, output and inflation expectations							
sample	68:1-79:1	68:1-80:1	68:1-81:1	68:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.60	0.78	0.82	1.07	0.62	0.56	0.55	0.44
π	0.09	0.09	0.13	0.14	0.05	0.05	0.04	0.04
R	0.84	1.01	3.14	3.17	1.15	1.12	0.46	0.27
	Professional forecasts, output expectations only							
sample	68:1-79:1	68:1-80:1	68:1-81:1	68:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.63	0.81	0.93	1.24	0.74	0.66	0.65	0.46
π	0.12	0.11	0.13	0.16	0.06	0.05	0.04	0.04
R	0.89	1.04	3.25	3.27	1.33	1.31	0.53	0.30
	Without expectations							
sample	68:1-79:1	68:1-80:1	68:1-81:1	68:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.94	0.97	1.13	1.43	0.78	0.71	0.67	0.48
π	0.13	0.12	0.14	0.17	0.06	0.06	0.04	0.04
R	0.90	1.09	3.23	3.33	1.40	1.38	0.56	0.31

The table reports the P-value for the F-test that expected output coefficients in the equation are all equal to zero in a VAR with 4 variables and two lags.

Table A.11: F-tests, p-values, First principal component of expectations

sample	74:1-79:1	74:1-80:1	74:1-81:1	74:1-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.09	0.33	0.43	0.45	0.12	0.01	0.00	0.02
π	0.66	0.05	0.40	0.71	0.02	0.00	0.77	0.78
R	0.53	0.08	0.02	0.08	0.00	0.02	0.03	0.08

The table reports the P-value for the F-test that the first principal component of expected inflation coefficients in the equation are all equal to zero in a VAR with 4 variables and two lags.

Table A.12: Variances of reduced form shocks, First pricinpal component of expectations

	With expectations							
sample	74:1-79:1	74:1-80:1	74:1-81:1	74:1-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	0.83	0.95	1.29	1.59	0.75	0.65	0.60	0.45
π	0.03	0.05	0.09	0.11	0.05	0.05	0.04	0.03
R	0.93	1.36	3.39	4.32	1.23	1.22	0.55	0.18
	Without expectations							
sample	65:4-79:1	65:4-80:1	65:4-81:1	65:4-82:1	79:2-01:4	80:2-01:4	81:2-01:4	81:2-01.4
Δ GDP	1.27	1.11	1.41	1.70	0.79	0.73	0.69	0.51
π	0.04	0.08	0.10	0.12	0.06	0.05	0.04	0.03
R	1.04	1.89	5.03	5.34	1.41	1.35	0.60	0.20

Table A.13: F-tests, p-values, FAVAR system

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.00	0.00	0.00	0.00	0.19	0.22	0.05	0.05
π	0.15	0.74	0.49	0.29	0.00	0.00	0.02	0.03
R	0.31	0.00	0.00	0.06	0.00	0.02	0.04	0.00
PC	0.04	0.18	0.15	0.09	0.04	0.21	0.44	0.49
	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.13	0.09	0.18	0.24	0.06	0.07	0.10	0.12
π	0.41	0.34	0.03	0.02	0.00	0.00	0.46	0.05
R	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06
PC	0.09	0.95	0.51	0.35	0.64	0.44	0.17	0.42

The table reports the P-value for the F-test that expected inflation coefficients in the equation are all equal to zero in a VAR with 8 variables and two lags.

Table A.14: Variances of reduced form shocks, FAVAR system

	With Michigan expectations							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.65	0.64	0.67	0.78	0.53	0.51	0.49	0.33
π	0.05	0.07	0.07	0.08	0.04	0.03	0.02	0.02
R	0.57	0.81	1.62	1.98	1.13	1.11	0.51	0.17
PC	5.49	5.72	6.35	6.27	3.14	2.81	2.80	2.17
	With Term structure expectations							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.72	0.71	0.77	0.90	0.52	0.49	0.48	0.34
π	0.05	0.06	0.07	0.07	0.04	0.03	0.03	0.02
R	0.49	0.61	1.54	1.81	1.06	1.08	0.52	0.18
PC	5.38	6.00	6.56	6.50	3.33	2.85	2.74	2.70
	Without inflation expectations							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.77	0.76	0.81	0.93	0.55	0.52	0.50	0.36
π	0.06	0.07	0.08	0.08	0.05	0.04	0.03	0.02
R	0.59	0.93	1.78	2.13	1.27	1.20	0.55	0.19
PC	5.79	6.01	6.68	6.68	3.36	2.90	2.85	2.75

Table A.15: F-tests, p-values, Large VAR

	With Michigan expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.60	0.15	0.58	0.01	0.41	0.57	0.95	0.90
π	0.94	0.90	0.96	0.71	0.95	0.90	0.97	0.96
Δ C	0.43	0.31	0.50	0.93	0.42	0.30	0.16	0.24
Δ I	0.18	0.14	0.26	0.11	0.14	0.16	0.06	0.04
Hours	0.91	0.88	0.75	0.78	0.29	0.22	0.35	0.30
Δ M	0.24	0.33	0.06	0.10	0.59	0.65	0.72	0.89
R	0.21	0.39	0.05	0.08	0.44	0.31	0.48	0.01

	With Term structure expectations							
sample	60:1-79:2	60:1-80:2	60:1-81:2	60:1-82:2	79:3-05:4	80:3-05:4	81:3-05:4	82:3-05.4
Δ GDP	0.60	0.35	0.73	0.39	0.60	0.68	0.83	0.87
π	0.74	0.84	0.43	0.84	0.96	0.68	0.38	0.50
Δ C	0.20	0.58	0.61	0.37	0.07	0.69	0.59	0.53
Δ I	0.33	0.41	0.25	0.73	0.38	0.03	0.19	0.16
Hours	0.92	0.57	0.97	0.99	0.60	0.52	0.59	0.64
Δ M	0.11	0.47	0.85	0.55	0.84	0.51	0.70	0.73
R	0.50	0.33	0.38	0.06	0.19	0.10	0.22	0.19

The table reports the P-value for the F-test that expected inflation coefficients in the equation are all equal to zero in a VAR with 8 variables and two lags.

Table A.16: Variances of reduced form shocks, Large VAR

	With Michigan expectations							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	1.06	1.14	1.20	1.32	0.60	0.58	0.44	0.45
π	0.30	0.30	0.30	0.32	0.31	0.30	0.31	0.29
Δ C	0.48	0.59	0.61	0.62	0.32	0.21	0.21	0.21
Δ I	9.09	10.2	11.0	10.6	5.04	4.07	2.95	2.91
Hours	0.40	0.45	0.43	0.42	0.59	0.55	0.55	0.56
Δ M	362.3	371.8	371.7	370.8	142.6	135.1	118.9	112.2
R	0.16	0.18	0.19	0.22	0.24	0.20	0.18	0.18
	With Term structure expectations							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	0.33	0.46	0.99	1.14	0.63	0.61	0.47	0.47
π	0.30	0.30	0.30	0.31	0.31	0.30	0.31	0.29
Δ C	0.59	0.38	0.44	0.60	0.39	0.21	0.21	0.21
Δ I	2.09	6.02	6.78	7.80	5.26	3.91	2.99	2.92
Hours	0.22	0.31	0.44	0.42	0.59	0.55	0.54	0.56
Δ M	128.9	210.9	315.4	306.2	158.9	146.2	127.9	117.6
R	0.10	0.18	0.25	0.25	0.23	0.18	0.17	0.16
	Without inflation expectations							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	1.08	1.21	1.22	1.49	0.61	0.59	0.45	0.45
π	0.30	0.30	0.30	0.32	0.31	0.30	0.31	0.30
Δ C	0.50	0.62	0.62	0.62	0.40	0.22	0.22	0.21
Δ I	9.63	10.8	11.5	11.3	5.26	4.25	3.16	3.16
Hours	0.40	0.45	0.44	0.42	0.61	0.57	0.56	0.57
Δ M	380.3	385.3	403.7	395.8	144.3	136.5	119.8	112.5
R	0.17	0.19	0.21	0.23	0.24	0.20	0.19	0.18

Table A.17: F-tests, p-values, Simulated data with measurement error

	Continuity Solution, iid errors							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	0.00	0.00	0.05	0.07	0.16	0.10	0.92	0.70
π	0.14	0.17	0.23	0.94	0.16	0.20	0.26	0.32
R	0.05	0.05	0.10	0.17	0.10	0.10	0.25	0.26
	Orthogonality Solution, iid errors							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	0.05	0.05	0.10	0.34	0.74	0.30	0.92	0.70
π	0.36	0.28	0.60	0.05	0.23	0.25	0.26	0.32
R	0.61	0.63	0.82	0.68	0.10	0.15	0.25	0.26
	Continuity Solution, AR errors							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	0.00	0.00	0.04	0.07	0.16	0.10	0.92	0.70
π	0.12	0.14	0.21	0.90	0.16	0.20	0.26	0.32
R	0.04	0.05	0.09	0.15	0.10	0.10	0.25	0.26

The table reports the P-value for the F-test that expected inflation coefficients in the equation are all equal to zero in a VAR with 4 variables and two lags. Data from 1960:1 to 1979:4 are generated from the indeterminate solution, data from 1980:1 to 1999:4 are generated from the determinate solution. When measurement error is serially correlated, the persistence coefficent is set to 0.9.

Table A.18: Variances of reduced form shocks, Simulated data with measurement error

	Continuity solution, iid errors							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	3.47	3.42	3.41	3.31	0.18	0.07	0.05	0.05
π	1.67	1.66	1.72	1.70	1.65	1.64	1.62	1.70
R	1.41	1.41	1.40	1.36	0.18	0.12	0.11	0.12
	Orthogonality Solution, iid errors							
sample	60:1-78:4	60:1-79:4	60:1-80:4	60:1-81:4	79:1-99:4	80:1-99:4	81:1-99:4	82:1-99.4
Δ GDP	1.38	1.40	1.72	1.69	0.50	0.13	0.05	0.05
π	0.19	0.19	0.29	0.30	1.57	1.64	1.62	1.70
R	0.52	0.52	0.56	0.53	0.15	0.12	0.11	0.12
	Without inflation expectations, Continuity solution, iid errors							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	3.82	3.74	3.58	3.44	0.19	0.08	0.05	0.05
π	1.72	1.71	1.76	1.70	1.69	1.68	1.65	1.73
R	1.49	1.48	1.45	1.39	0.18	0.13	0.12	0.12
	Without inflation expectations, Orthogonality solution, iid errors							
sample	55:1-79:1	55:1-80:1	55:1-81:1	55:1-82:1	79:2-06:1	80:2-06:1	81:2-06:1	81:2-06.1
Δ GDP	1.35	1.37	1.66	1.61	0.47	0.12	0.05	0.05
π	0.18	0.18	0.29	0.27	1.57	1.64	1.61	1.67
R	0.53	0.52	0.56	0.54	0.15	0.11	0.11	0.11