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Tara Sinclair
George Washington University

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Institute for International Economic Policy
1957 E St. NW, Suite 501
Voice: (202) 994-5320
Fax: (202) 994-5477
Email: **iiep@gwu.edu**
Web: **www.gwu.edu/~iiep**

Asymmetry in the Business Cycle: Revisiting the Friedman Plucking Model

Tara M. Sinclair[1]

Department of Economics
The George Washington University
Washington, DC 20052
tsinc@gwu.edu

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Abstract

Recent research suggests that unobserved components models can, under certain conditions, be estimated without imposing the common zero-correlation restriction between the permanent and transitory innovations. The impact of this restriction, however, has not previously been examined in an unobserved components model with asymmetric movements. This paper produces and estimates an unobserved components model that allows for both correlation between the innovations and asymmetric transitory movements. The asymmetry is modeled using Markov-switching in the transitory component, in the spirit of the Kim and Nelson (1999) version of the Friedman plucking model. The results reveal that U.S. real GDP can be decomposed into a permanent component, a symmetric transitory component, and an additional occasional asymmetric transitory shock. The innovations to the permanent component and the symmetric transitory component are significantly negatively correlated, but the asymmetric transitory shock is exogenous. The findings suggest that both permanent movements and asymmetric transitory shocks are important for explaining post-war output fluctuations in the U.S.

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Section 1 Introduction

This paper produces and estimates an unobserved components model for U.S. real GDP that allows for both asymmetry and correlation between the innovations to the components. This model is a generalization of recent advances that have allowed for correlation between the innovations to the components (Morley, Nelson, and Zivot, 2003, hereafter MNZ) and asymmetry (Kim and Nelson, 1999, hereafter KN). The asymmetry is modeled using Markov-switching in the transitory component in the spirit of KN's version of the Friedman (1993) plucking model.[2] Importantly, the model allows for correlation not just between the innovations to the permanent and transitory components, but also with the innovation that determines the realization of the Markov-switching state variable.

Traditionally, unobserved components models have been estimated assuming that the innovations to the components are uncorrelated. These models, when applied to U.S. output, generally imply smooth permanent components. For example, Clark (1987) estimates a symmetric, zero-correlation unobserved components model of U.S. output and finds that the fluctuations are driven primarily by transitory movements. Using a similar model but relaxing the assumption of symmetry, KN also find a relatively smooth permanent component for U.S. real GDP. The results of their model suggest, however, that U.S. recessions are characterized by *asymmetric* transitory shocks.

[2] Alternative zero-correlation asymmetric unobserved components models include Crespo Cuaresma (2003) and Koopman and Lee (2005). Both of these papers use stochastic trigonometric cycles for the transitory component. Luginbuhl and de Vos (1999) estimate an unobserved components model with Markov-switching in the drift term.

In contrast to the results of Clark and KN, MNZ find that output experiences considerable *permanent* movements at business cycle frequencies. MNZ allow for correlation between the innovations to the components and are able to reject the zero-correlation restriction of Clark's model. MNZ's model, however, is symmetric. If recessions, or at least some recessions, are fundamentally different from expansions, then a symmetric model may not properly capture recessions. The idea of asymmetric business cycles has been around since the beginning of business cycle research (e.g. Mitchell, 1927 and 1951, Burns and Mitchell, 1946, Keynes, 1936, and Friedman, 1969). In particular, recessions may be characterized by more transitory movements than found when assuming symmetry. MNZ's model may thus overstate the variability of the permanent component. It is also possible that not all recessions are alike, as suggested by Kim and Murray (2002) and French (2005). Some recessions may be characterized by temporary deviations, whereas others may arise due to permanent movements.

There are persuasive economic reasons to generalize MNZ's model to allow for asymmetric shocks. Many economists are more comfortable with positive permanent shocks than with negative permanent shocks. Permanent shocks are often thought of as arising from improvements in productivity. These shocks may not occur at a constant rate over time (Hamilton, 2005; Friedman, 1993), but economists struggle to explain the "technological regress" needed to justify negative permanent shocks (Fisher, 1932). The difficulty in defending negative permanent shocks has become a popular criticism of the real business cycle literature (Mankiw, 1989). Empirical evidence also suggests that the business cycle experiences asymmetric movements, particularly in downturns (see

Morley, forthcoming, for a discussion of this evidence). It is important, therefore, to explore the possibility that at least some recessions are driven by temporary asymmetric shocks. If this is the case, then the symmetric estimates of MNZ may over-emphasize permanent movements due to the dominance of expansions in the data.

To preview the results, the estimates of the asymmetric correlated unobserved components (asymmetric UC-UR) model suggest that allowing for both asymmetry in the transitory component and correlation between the innovations yields considerably different estimates from previous models. The transitory asymmetric shocks, although infrequent, are found to be necessary to account for most recessions. Further, the transitory asymmetric shocks appear to be exogenous, suggesting that they arise from a different process than the "normal times" movements in the economy. The permanent component is variable and captures the majority of output fluctuations. There also remains a symmetric transitory component which is negatively correlated with the permanent innovations and can be interpreted primarily as adjustment to permanent shocks. These results are remarkably robust to structural breaks, including the mean growth slowdown of the early 1970s and the reduction in variance in U.S. real GDP growth around 1984.

This paper proceeds as follows. Section 2 presents the asymmetric UC-UR model and the test for exogeneity of the Markov-switching state variable. Section 3 presents and discusses the results of estimating this model for U.S. real GDP. Section 4 provides conclusions and implications.

Section 2 The Model

The model extends the UC-UR model of MNZ to allow for asymmetry in the spirit of Kim and Nelson's (1999) version of the Friedman plucking model. The key features of this model are that it allows for asymmetry in the transitory component via a Markov-switching process,[3] and at the same time it allows for correlation between all of the innovations within the model. Allowing for correlation introduces the possibility of endogeneity if the Markov-switching state variable is also correlated with the other innovations. Thus, as discussed below, this model also allows for endogenous regime switching, building upon the approach of Kim, Piger, and Startz (forthcoming).

Similar to MNZ, output (y_t) can be decomposed into two unobserved components:

$$y_t = \tau_t + c_t \tag{1}$$

where τ represents the permanent (or trend) component and c represents the transitory component.

A random walk for the trend component, as suggested by Friedman (1993), allows for permanent movements in the series. The model also allows for a deterministic drift (μ) in the trend that captures the "tilted" nature of the trend described by Friedman.[4] The permanent component is written as:

$$\tau_t = \mu + \tau_{t-1} + \eta_t \tag{2}$$

[3] Other models, most notably Hamilton (1989), explore asymmetry in the permanent component. Kim and Piger (2002) show that applying Hamilton's model to data with "plucking"-type recessions results in a potential bias towards too much permanent movement.

[4] The unobserved components model of Clark (1987) allowed the drift term to evolve as a random walk. As discussed in Oh and Zivot (2006), the correlations are not all identified if we want to also allow the innovations to the drift term to be correlated with the other innovations. Oh and Zivot (2006) find that the results of MNZ are robust to allowing a random walk drift term in a univariate model. For simplicity, a single known structural break is considered in Section 3.7 to address potentially changing drift.

Following MNZ and KN, each transitory component is modeled as an AR(2) process. The novelty of this model, as compared to MNZ, is to include a discrete, asymmetric innovation, γS_t, in the transitory component. The innovation to the transitory component is now a mixture of the symmetric innovation, ε_t, and the asymmetric discrete innovation. This asymmetric innovation captures the "plucks" of Friedman's plucking model, following KN.[5] The transitory component is written as:

$$c_t = \phi_1 c_{t-1} + \phi_2 c_{t-2} + \gamma S_t + \varepsilon_t \tag{3}$$

The innovations (η_t and ε_t) are assumed to be jointly normally distributed random variables with mean zero and a general covariance matrix, Σ, which allows for correlation between η_t and ε_t.[6] The model of MNZ is nested as a special case of this model with γ = 0. With the extended model presented here, the size of γ can therefore be used to test the degree of asymmetry in the transitory component.

The state of the economy (whether S_t = 0 or 1) is determined endogenously in the model. The unobserved state variable, S_t, is assumed to evolve according to a first-order Markov-switching process:

$$Pr[S_t = 1 \mid S_{t-1} = 1] = p \tag{4}$$

$$Pr[S_t = 0 \mid S_{t-1} = 0] = q \tag{5}$$

For identification of the state variable, it is sufficient to restrict the sign of the discrete, asymmetric innovation (γ). In the case of output, γ is restricted to be negative. This restriction forces the more persistent state, that of "normal times," to have a zero

[5] This model is based on the version of the plucking model presented in Kim and Nelson (1999b).
[6] Identification of the model is confirmed in a similar fashion to that of MNZ. The basic model is the same as MNZ and is therefore identified. Including Markov-switching adds as many parameters to the reduced form as to the "structural" model, so the model remains identified.

mean. The alternative, i.e. restricting γ to be positive, would result in long periods of positive mean with occasional zero-mean periods. When "normal times" have a zero-mean transitory component, the permanent component can be usefully interpreted as the steady state, as discussed in Morley and Piger (2007).

To take account of the possible correlation between the state variable and the other innovations, the model includes an extended version of Kim, Piger, and Startz's (forthcoming) endogenous regime-switching model.[7] Since the state is serially dependent, the lagged state variable can be used as the instrument for the current state, assuming the lagged state variable is exogenous from the contemporaneous error term. The model presented here extends Kim, Piger, and Startz's model to allow the innovation to the latent state variable to be correlated with multiple innovations. The model then allows for an exogeneity test of the state variable as discussed below.

Section 2.1 Exogeneity Test and Bias Correction

Following Kim, Piger, and Startz (forthcoming), the realization of the state process is assumed to be represented using a Probit specification as follows:

$$S_t = \begin{cases} 0 \text{ if } S_t^* < 0 \\ 1 \text{ if } S_t^* \geq 0 \end{cases} \qquad (6)$$
$$S_t^* = a_0 + a_1 S_{t-1} + w_t$$

Furthermore, the joint distribution of w_t, η_t, and ε_t, is assumed to be multivariate Normal:

[7] Chib and Dueker (2004) present a non-Markovian regime-switching model with endogenous states in the Bayesian framework that they apply to real GDP growth as in the Hamilton (1989) model. As discussed in Pesaran and Potter (1997), another alternative model would be a threshold autoregression (TAR) model. The application to the plucking model is most straightforward building on the model of Kim, Piger, and Startz, so their method is used here.

$$\begin{bmatrix} w_t \\ \eta_t \\ \varepsilon_t \end{bmatrix} \sim N(0,\Sigma), \quad \Sigma = \begin{bmatrix} 1 & \sigma_{\eta w} & \sigma_{\varepsilon w} \\ \sigma_{\eta w} & \sigma_{\eta}^2 & \sigma_{\eta\varepsilon} \\ \sigma_{\varepsilon w} & \sigma_{\eta\varepsilon} & \sigma_{\varepsilon}^2 \end{bmatrix}$$

However, in the special case where the state variable is exogenous, w_t is uncorrelated with η_t, and ε_t:

$$\begin{bmatrix} w_t \\ \eta_t \\ \varepsilon_t \end{bmatrix} \sim N(0,\Sigma_1), \Sigma_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sigma_{\eta}^2 & \sigma_{\eta\varepsilon} \\ 0 & \sigma_{\eta\varepsilon} & \sigma_{\varepsilon}^2 \end{bmatrix}.$$

In this case the expectation of $\begin{bmatrix} \eta_t \\ \varepsilon_t \end{bmatrix}$, conditional upon S_t, $S_{t\text{-}1}$, and $I_{t\text{-}1}$ (the information available at time t-1) is zero. Similarly, the conditional variance for $\begin{bmatrix} \eta_t \\ \varepsilon_t \end{bmatrix}$ is equal to the unconditional variance:

$$E\left(\begin{bmatrix} \eta_t \\ \varepsilon_t \end{bmatrix} | S_t = i, S_{t-1} = j, I_{t-1}\right) = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

and

$$\text{var}\left(\begin{bmatrix} \eta_t \\ \varepsilon_t \end{bmatrix} | S_t = i, S_{t-1} = j, I_{t-1}\right) = \begin{bmatrix} \sigma_{\eta}^2 & \sigma_{\eta\varepsilon} \\ \sigma_{\eta\varepsilon} & \sigma_{\varepsilon}^2 \end{bmatrix}.$$

In the case of endogenous switching, however, either $\sigma_{\eta w}$ and/or $\sigma_{\varepsilon w}$ does not equal zero. Thus the conditional mean and variance-covariance matrix become:

$$E\left(\begin{bmatrix}\eta_t\\ \varepsilon_t\end{bmatrix} \mid S_t = i, S_{t-1} = j, I_{t-1}\right) = \begin{bmatrix}\sigma_{\eta w} M_{ij}\\ \sigma_{\varepsilon w} M_{ij}\end{bmatrix}$$

and

$$\mathrm{var}\left(\begin{bmatrix}\eta_t\\ \varepsilon_t\end{bmatrix} \mid S_t = i, S_{t-1} = j, I_{t-1}\right) =$$

$$\begin{bmatrix}\sigma_\eta^2 - \sigma_{\eta w}^2 M_{ij}(M_{ij} + a_0 + a_1 S_{t-1}) & \sigma_{\eta\varepsilon} - \sigma_{\eta w}\sigma_{\varepsilon w} M_{ij}(M_{ij} + a_0 + a_1 S_{t-1})\\ \sigma_{\eta\varepsilon} - \sigma_{\eta w}\sigma_{\varepsilon w} M_{ij}(M_{ij} + a_0 + a_1 S_{t-1}) & \sigma_\varepsilon^2 - \sigma_{\varepsilon w}^2 M_{ij}(M_{ij} + a_0 + a_1 S_{t-1})\end{bmatrix},$$

where

$$M_{00} = \frac{-\phi(-a_0)}{\Phi(-a_0)} \qquad M_{01} = \frac{-\phi(-a_0 - a_1)}{\Phi(-a_0 - a_1)}$$

$$M_{10} = \frac{\phi(-a_0)}{1 - \Phi(-a_0)} \qquad M_{11} = \frac{\phi(-a_0 - a_1)}{1 - \Phi(-a_0 - a_1)} \ .$$

ϕ is the standard normal probability density function and Φ is the standard normal cumulative distribution function. a_0 and a_1 come from the equation for S* in (6) above.

The exogenous switching model is nested within the endogenous switching model with the restriction that $\sigma_{\eta w} = \sigma_{\varepsilon w} = 0$. This nesting allows for a simple test of exogeneity with a likelihood ratio test comparing the endogenous model with the restricted exogenous model. The results of this test are discussed in Section 3.1.

Section 3 The Results

The data (y) are the natural log of U.S. real GDP multiplied by 100, quarterly, from 1947:1 – 2004:4.[8] To estimate the model presented in the previous section, it is cast into state-space form, available in the appendix. Kim's (1994) method of combining Hamilton's algorithm and a nonlinear discrete version of the Kalman filter is then used for an approximation to maximum likelihood estimation of the parameters and the components.[9] If the state variable is endogenous, the regime-dependent conditional density function is no longer Gaussian (see discussion in Kim, Piger, and Startz, forthcoming). Assuming the density function is Gaussian results in quasi-maximum likelihood estimation.

Section 3.1 Testing for Exogenous Markov-Switching

First we must determine whether the Markov-switching is exogenous or endogenous. Estimating the endogenous Markov-switching UC-UR model for U.S. real GDP results in a log likelihood value of -303.6, whereas the restricted model of exogenous switching has a log likelihood value of -305.2. Thus, the likelihood ratio test statistic is 3.2 and the null hypothesis of exogenous switching cannot be rejected at conventional significance levels with a p-value of 0.2.[10] In addition, the estimates are qualitatively similar whether we allow for endogenous switching or restrict the model to exogenous switching. This result suggests that the discrete, asymmetric shocks are due to

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[8] The data come from the FRED database at the Federal Reserve Bank of St. Louis. They are in billions of chained 2000 dollars, seasonally adjusted annual rate, from the September 29, 2005 release of the U.S. Department of Commerce: Bureau of Economic Analysis.

[9] To ensure that the estimates represent the global maximum, estimates of all models were repeated using different starting values approximating a course grid search.

[10] Likelihood ratio test statistics will be used for hypothesis testing throughout this paper for robust inference in the face of potential weak identification following Nelson and Startz (2007).

a different process than the other shocks that affect output. In addition, this result provides support for previous research which assumed that the Markov-switching was exogenous (e.g. research building on the model of Hamilton, 1989). Based on this result, the rest of the discussion will focus on the estimates using exogenous Markov-switching, which are presented in the first column of Table 1.

Section 3.2: Testing for Asymmetry

Including the asymmetric transitory shock appears to represent an improvement over the symmetric UC-UR model, as shown in Table 1, comparing columns (1) and (2). Testing the restriction of a symmetric model, i.e. that $\gamma = 0$, the likelihood ratio test statistic is 23.5. This test statistic, however, is nonstandard. In order to establish the statistical significance of this result, a bootstrap test was performed.[11] Data was simulated under the null of no asymmetry, i.e. using the parameter estimates of the symmetric UC-UR model from column 2 of Table 1. The bootstrapped p-value, based on 999 bootstrap samples, is 0.037. This suggests that asymmetry is indeed important for explaining the movements in U.S. real GDP.

[11] See MacKinnon (2002, 2006) for summaries of bootstrap methods.

Section 3.3: Testing for Correlation

Including the asymmetric transitory component does not eliminate the correlation between the innovations to the permanent component and the symmetric transitory component. Comparing columns (1) and (3) of Table 1 shows that the restriction of zero correlation between the permanent and symmetric transitory innovations for the asymmetric model (the asymmetric UC-0 model) is rejected, with a p-value for the likelihood ratio test statistic of 0.011. Allowing for correlation between the permanent and symmetric transitory innovations results in more permanent movements than if a zero-correlation restriction were imposed as in KN's model (note the higher standard deviation of the permanent innovation in the correlated case in column (1) of Table 1 as compared to column (3)).

KN further find evidence that for U.S. real GDP there is no symmetric shock to the transitory component once they allow for the discrete, asymmetric shock. Here, however, the symmetric innovation remains important and retains its interpretation from MNZ as an adjustment to permanent shocks. Restricting the variance of the symmetric transitory innovation as well as the correlation between this innovation and the permanent innovation to both be zero results in a log likelihood value of -308.65. We can therefore reject the restrictions with a p-value of 0.037. Note that this log likelihood value is only slightly smaller than the log likelihood for the asymmetric UC-0 case, thus confirming KN's result. If the correlation between the innovations is restricted to zero, then the symmetric transitory shock is not statistically significant.

Section 3.4: The Estimated Components of U.S. Real GDP

Panels 1 and 2 of Figure 1 present the filtered estimates of the unobserved components of output based on the exogenous Markov-switching asymmetric UC-UR model. The filtered estimates are used instead of the smoothed estimates because including Markov switching results in smoothed estimates requiring successive approximations, as discussed in KN. These estimates appear to be a hybrid of the symmetric correlated model and the zero-correlation plucking model, as can be seen in Figure 2. The permanent component is more variable than in the zero-correlation case (with the standard deviation of the permanent innovation being almost twice as large), but there is also more transitory movement, particularly near NBER recession dates, than was found by MNZ.

The difference in the transitory components is not due to the symmetric innovation or to the AR parameters, which are similar in the two models. The difference arises due to the inclusion of the asymmetric shock, resulting in movements in the transitory component for the asymmetric UC-UR model between –5.98 to 0.68, whereas the symmetric UC-UR transitory component ranges in value from –1.63 to 1.63.

Including asymmetry in the transitory component results in movements which look much more like the Friedman plucking model than the transitory component of the symmetric UC-UR model. In particular, the transitory component appears to move in general with the business cycle, as indicated by the shaded NBER recession dates. These results are similar to the findings of Morley and Piger (2007) who use a generalization of the Beveridge-Nelson (1981) decomposition for processes in which both trend and cycle can be regime switching. This similarity should not be surprising since MNZ show that in the symmetric case, a correlated unobserved components model produces the same estimated components as the Beveridge-Nelson (1981) decomposition for the same forecasting model. Morley and Piger's approach, combined with the 'bounce-back' model of Kim, Morley, and Piger (2005) allows regime switches into recessions to have permanent and/or transitory effects, but they find that regime switches have largely transitory effects, as is assumed here.[12]

The asymmetric shocks only occur occasionally, so they do not explain a large amount of the variance of the series, but they are large and significant. The estimated variances of the innovations to the permanent and transitory components from the asymmetric model are not significantly different from those of the symmetric model (the no switching estimate in Table 1 column (2)). Based on the estimates of p and q presented in column (1) of Table 1, the expected duration of State 1 (i.e. when the mean of the transitory component is negative) is approximately 3.5 quarters, whereas the expected duration of State 0 is almost 30 quarters. Other research has also found that transitory movements may only explain a small, but important, portion of the variance of U.S. real GDP. Using an innovation regime-switching model, Kuan, Huang, and Tsay (2005) conclude that unit-root nonstationarity dominates in almost 85% of the sample periods, with 33 stationary periods that closely match the NBER dating of recessions.

One movement which appears in the symmetric transitory component (and also in the permanent component due to the negative correlation) deserves some attention. From

[12] Kim, Morley, and Piger (2005) find that allowing for an asymmetric 'bounce-back' effect results in a much smaller permanent effect of recessions as compared to Hamilton's (1989) model.

1978:2 to 1979:1, we observe the largest symmetric transitory movement in the sample. At first glance, this movement, as seen in Panel 2 of Figure 1, may appear to be due to an asymmetric transitory shock, but Panel 3 shows that there is less than 0.1 probability of such a shock for this time period. Panel 1 also shows that at this point in the sample the permanent component appears to spike away from the series. Forecasters predicted that due to the oil shock in 1978, there should follow a recession analogous to the recession following the 1973 oil shock. The brief permanent movement above the series may perhaps be explained by changes in consumer behavior in response to the oil shock (Goldfarb, Stekler, and David, 2005). The movement in the transitory component shows simply that the series did not adjust immediately to the permanent movement, resulting in the transitory gap between the permanent component and the series.

The estimates of the asymmetric UC-UR model suggest that each recession differs in terms of the contribution of permanent and transitory movements. These results are similar to the results from Kim and Murray's (2002) multivariate model of monthly indicators. They specifically allow for there to be differences in the role of permanent versus transitory movements for different recessions and find that each recession indeed differs.

Section 3.5: The "Pluck" Recessions

Although rare, the asymmetric shocks appear important in a few key episodes. These episodes are represented in Panel 3 of Figure 1. This panel presents the probabilities of asymmetric shocks to the transitory component of real GDP. There is some positive probability of a transitory asymmetric shock for all of the NBER-dated recessions, with six of the ten recessions in the sample having probability greater than 0.5. Figure 1 shows that for the recessions characterized by asymmetric shocks, with the exception of 1960-1961, the series drops below the permanent component. These recessions have the appearance of a pluck as described by Friedman such that the permanent component appears to be a ceiling. As discussed by Friedman (1993) and KN, models that emphasize monetary or other demand-oriented shocks may be more appropriate for explaining these recessions.

Section 3.6: The "No-Pluck" Recessions

The no-pluck recessions appear to represent a different type of recession from those characterized by asymmetric shocks. The four recessions where the probability of an asymmetric transitory shock remains below 0.5 are 1969:4 – 1970:4, 1973:4 – 1975:1, 1990:3 – 1991:1, and 2001:1 – 2001:4. For these recessions, the movement is in general largely permanent, as can be seen in Figure 1. In fact, for the 2001 recession, the transitory component remains positive for the entire recession. In the other three recessions without asymmetric shocks, however, there is a noticeable peak-to-trough movement in the transitory component, but it is smaller in general than in the recessions that experienced asymmetric shocks.

The recession which occurred in 1973:4 – 1975:1 appears quite close to the cutoff with a probability of 0.45. The remaining three no-pluck recessions were classified by Koenders and Rogerson (2005) as the three recessions characterized by jobless recoveries. These recessions therefore appear to have different features than the "pluck" recessions. In addition, for the 1969 – 1970 and 1990 – 1991 recessions, forecasters had particular difficulty predicting them, as discussed in Enzler and Stekler (1971) and Fintzen and Stekler (1999). Since the permanent component captures the unpredictable movements of the series, it is not surprising that these two recessions appear to be largely captured by the permanent component. Kim and Murray (2002) and French (2005) also find that the 1990-91 recession does not appear as a transitory movement. The 1973 – 1975 recession is often characterized as caused by a permanent shock due to the behavior of OPEC at the time.[13] Finally, for the 2001 recession, other econometric models also find that this recession looks different than other recessions (e.g. Kim, Morley, and Piger, 2005, and French, 2005), perhaps because it was particularly mild or because it is near the end of the sample.

Section 3.7: Robustness Checks

Two possible structural changes in U.S. real GDP need to be examined more carefully before accepting the results of this model. First, there may have been a structural break in the drift term of the permanent component in the early 1970s. Second, GDP growth experienced a significant volatility reduction in 1984, otherwise known as the Great Moderation. This section presents evidence that the results of this model are robust to controlling for these changes in U.S. real GDP.

Including a structural break in the drift term in 1973, Perron and Wada (2006), show that the results for MNZ's symmetric model change significantly. In particular, the estimated permanent component of U.S. real GDP reduces to a deterministic trend with a

[13] The other "oil-shock" recession in 1979-1980 does appear to be characterized by an asymmetric transitory shock. Abel and Bernanke (2005, page 326**)** argue that people expected the oil shock of 1973 – 1975 to have permanent effects, but expected the shock of 1979 – 1980 to only have temporary effects. They note as evidence that the real interest rate rose in 1979 – 1980 whereas in 1973 – 1974 it did not. Friedman (1993) suggests that oil shocks may also be asymmetric shocks.

single structural break. Table 2 presents estimates including a structural break in the drift term in 1973, and shows that the results of the asymmetric UC-UR model are robust to this break. In fact, in the asymmetric model the restriction of no structural break in the drift term of the permanent component is not rejected. The likelihood ratio test statistic for the restriction of no break in 1973 is only 2.4. With one restriction, the p-value is 0.12. A break in γ (along with a break in the drift term) in 1973 was also found to be insignificant with no qualitative difference in the results. Furthermore, testing for a structural break at an unknown date between 1965 and 1975 found no significant break dates based on the test given in Andrews (1993). Finally, searching for a joint break in the drift term and γ at the same time did not change these results.

Table 3 presents the estimates allowing for a structural break in the covariance matrix in the first quarter of 1984 to capture the Great Moderation. This break is statistically significant, but it does not change any of the main results presented in the previous sections, nor does it significantly affect parameters other than those in the covariance matrix. The variance reduction appears for both the permanent and transitory innovations. The post-1983 variance of the permanent component is less than 60% of the pre-1984 variance. The post-1983 variance of the transitory component is slightly more than 75% of the pre-1984 variance. The correlation parameter, however, increased in absolute value after 1983. This change in the correlation may be interpreted either as an increase in the importance of adjustments to permanent movements in driving the transitory innovations after 1983, or equivalently as a decrease in the importance of other transitory shocks. Estimating a model allowing for a break in the size of the shock in

1984 (with or without also allowing for a change in the covariance matrix) results in an asymmetric model before 1984, but reduces to the symmetric MNZ model post-1983. These results are thus similar to the full sample estimates which also find no asymmetric shocks after 1983, based on a cutoff probability of 0.5. Estimating the full model with only the 1947:1 – 1983:4 sample also resulted in estimates that are remarkably similar to the full sample results.

4 Conclusions

This paper has presented and estimated an unobserved components model that allows for correlation between the innovations to the components as well as for asymmetry in the transitory component. This model is a generalization of Morley, Nelson, and Zivot's (2003, MNZ) correlated unobserved components model, allowing for asymmetry in the transitory component. The asymmetry is modeled using Markov-switching in the transitory component in the spirit of Kim and Nelson's (1999, KN) version of Friedman's (1993) plucking model. The results suggest there exists a ceiling of maximum feasible output that is well-approximated by a random walk, but that occasionally (for at least six of the last ten U.S. recessions), output is "plucked" away from this ceiling by an exogenous transitory shock.

The estimates of the asymmetric UC-UR model suggest that allowing for both correlation and asymmetry yields considerably different results from both the symmetric correlated unobserved components model of MNZ and the asymmetric uncorrelated unobserved components model of KN. The permanent component is more variable than in the zero-correlation case, but there is also more transitory movement, particularly near

NBER recession dates, than was found by MNZ. Further, the transitory asymmetric shocks appear to be exogenous, suggesting that they are due to a different process than the "normal times" movements in the economy. There remain, however, significant permanent movements in the series, and the permanent innovations are negatively correlated with the symmetric transitory innovations. These results are robust to allowing for structural breaks to control for the mean growth slowdown of the early 1970s as well as for the variance reduction in 1984.

The results presented here suggest that exogenous transitory shocks may be important for most recessions, but that U.S. real GDP experiences more permanent movements than what might be expected based on conventional business cycle models. These results suggest that there may be different types of recessions with different underlying causes. These different causes may have important policy implications.[14] In particular, this paper adds to the growing research arguing that policy should take into consideration the importance of asymmetric shocks. As discussed by De Long and Summers (1988), the presence of asymmetric shocks suggests that policy addressed at reducing these shocks may be able to lessen the impact of recessions without reducing peaks. Policy could thus increase the mean of output, rather than just reduce its volatility.

[14] One possible research agenda to follow would be to consider the suggestion of Hamilton (2005) that the volatility of interest rates may play an important role in causing asymmetric shocks. He finds that many, but not all, economic downturns are accompanied by a change in the dynamic behavior of short-term interest rates. Another reasonable direction to follow is to try to determine if the asymmetric shocks are monetary, as suggested by Friedman (1993).

Appendix: State Space Form

In state-space form the series can be represented as follows:

Observation Equation: $[y_t] \equiv [1 \quad 1 \quad 0]\begin{bmatrix}\tau_t \\ c_t \\ c_{t-1}\end{bmatrix}.$

State Equation: $\begin{bmatrix}\tau_t \\ c_t \\ c_{t-1}\end{bmatrix} = \begin{bmatrix}\mu \\ \gamma S_t \\ 0\end{bmatrix} + \begin{bmatrix}1 & 0 & 0 \\ 0 & \phi_1 & \phi_2 \\ 0 & 1 & 0\end{bmatrix}\begin{bmatrix}\tau_{t-1} \\ c_{t-1} \\ c_{t-2}\end{bmatrix} + \begin{bmatrix}1 & 0 \\ 0 & 1 \\ 0 & 0\end{bmatrix}\begin{bmatrix}\eta_t \\ \varepsilon_t\end{bmatrix}.$

Variance-Covariance Matrix:

In the case of exogenous switching:

$$E\left(\begin{bmatrix}\eta_t \\ \varepsilon_t\end{bmatrix}[\eta_t \quad \varepsilon_t]\right) = \begin{bmatrix}\sigma_\eta^2 & \sigma_{\eta\varepsilon} \\ \sigma_{\eta\varepsilon} & \sigma_\varepsilon^2\end{bmatrix}.$$

In the case of correlation between the state variable and the other innovations the variance-covariance matrix becomes:

$$\operatorname{var}\left(\begin{bmatrix}\eta_t \\ \varepsilon_t\end{bmatrix} \mid S_t = i, S_{t-1} = j, I_{t-1}\right) =$$

$$\begin{bmatrix}\sigma_\eta^2 - \sigma_{\eta w}^2 M_{ij}(M_{ij} + a_0 + a_1 S_{t-1}) & \sigma_{\eta\varepsilon} - \sigma_{\eta w}\sigma_{\varepsilon w} M_{ij}(M_{ij} + a_0 + a_1 S_{t-1}) \\ \sigma_{\eta\varepsilon} - \sigma_{\eta w}\sigma_{\varepsilon w} M_{ij}(M_{ij} + a_0 + a_1 S_{t-1}) & \sigma_\varepsilon^2 - \sigma_{\varepsilon w}^2 M_{ij}(M_{ij} + a_0 + a_1 S_{t-1})\end{bmatrix}$$

where a_0 and a_1 come from the equation for S* in equation (6) from Section 2.1 and the M_{ij} are also defined as in Section 2.1.

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Table 1: Maximum Likelihood Estimation of the Three Primary Models

Parameters		**(1) Asymmetric UC-UR Estimate (Standard Error)**	**(2) Symmetric UC-UR Estimate (Standard Error)**	**(3) Asymmetric UC-0 Estimate (Standard Error)**
Log Likelihood		-305.2058	-316.9769	-308.4435
Standard deviation of the permanent innovation	σ_η	1.0793 (0.1402)	1.1275 (0.1299)	0.6490 (0.1458)
Standard deviation of the transitory innovation	σ_ε	0.5899 (0.2096)	0.5372 (0.2419)	0.3727 (0.2417)
Correlation between the innovations	$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	-0.9611 (0.1252)	Restricted to be zero
Drift term	μ	0.8409 (0.0725)	0.8358 (0.0745)	0.8096 (0.0459)
AR(1) parameter	ϕ_1	1.1143 (0.1055)	1.3759 (0.1074)	1.1576 (0.1149)
AR(2) parameter	ϕ_2	-0.4104 (0.0990)	-0.7874 (0.1193)	-0.3099 (0.1076)
Asymmetric shock parameter	γ	-1.8209 (0.2567)	Restricted to be 0	-1.7166 (0.2371)
$\Pr[S_t = 1 \mid S_{t-1} = 1]$	p	0.7121 (0.1156)	N/A	0.6900 (0.1063)
$\Pr[S_t = 0 \mid S_{t-1} = 0]$	q	0.9666 (0.0141)	N/A	0.9583 (0.01748)

Table 2: Testing the Effects of a Break in the Drift Term in 1973:1

Parameters		**Asymmetric UC-UR Estimate (Standard Error)**	**With 1973 Drift Break Estimate (Standard Error)**
Log Likelihood		-305.2058	-303.9961
Standard deviation of the permanent innovation	σ_η	1.0793 (0.1402)	1.0194 (0.1386)
Standard deviation of the transitory innovation	σ_ε	0.5899 (0.2096)	0.5190 (0.2084)
Correlation between the innovations	$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	-0.7899 (0.1154)
Drift term through 1972	μ	0.8409 (0.0725)	0.9668 (0.1045)
Drift term from 1973 on	$\mu 2$		0.7459 (0.0902)
AR(1) parameter	ϕ_1	1.1143 (0.1055)	1.1073 (0.1014)
AR(2) parameter	ϕ_2	-0.4104 (0.0990)	-0.4071 (0.0989)
Asymmetric shock parameter	γ	-1.8209 (0.2567)	-1.8160 (0.2505)
$\Pr[S_t = 1 \mid S_{t-1} = 1]$	p	0.7121 (0.1156)	0.7194 (0.0897)
$\Pr[S_t = 0 \mid S_{t-1} = 0]$	q	0.9666 (0.0141)	0.9655 (0.0146)

Note: This table focuses on the estimate allowing a structural break in the drift term in 1973:1 to address the Perron and Wada (2006) critique of the MNZ model. Based on the Andrews (1993) test for a single unknown structural break in the drift term, there were no significant breaks in the drift term between 1965 and 1975.

Table 3: Testing the Effects of a Break in the Covariance Matrix in 1984:1

Parameters		Asymmetric UC-UR Estimate (Standard Error)	With 1984 Break in Variance Estimate (Standard Error)[15]
Log Likelihood		-305.2058	-285.0573
Standard deviation of the permanent innovation through 1983	σ_η	1.0793 (0.1402)	1.1642 (0.2736)
Standard deviation of the permanent innovation through from 1984 on	$\sigma_{\eta 2}$		0.8975 (0.2191)
Standard deviation of the transitory innovation through 1982	σ_ε	0.5899 (0.2096)	0.8167 (0.4122)
Standard deviation of the transitory innovation through from 1984 on	$\sigma_{\varepsilon 2}$		0.7138 (0.2416)
Correlation between the innovations through 1983	$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	-0.6830 (0.2161)
Correlation between the innovations from 1984 on	$\rho_{\eta\varepsilon 2}$		-0.9373 (0.0617)
Drift term	μ	0.8409 (0.0725)	0.8199 (0.0711)
AR(1) parameter	ϕ_1	1.1143 (0.1055)	1.1131 (0.1871)
AR(2) parameter	ϕ_2	-0.4104 (0.0990)	-0.3714 (0.1697)
Asymmetric shock parameter	γ	-1.8209 (0.2567)	-1.8668 (0.4788)
$\Pr[S_t = 1 \mid S_{t-1} = 1]$	p	0.7121 (0.1156)	0.6981 (0.1377)
$\Pr[S_t = 0 \mid S_{t-1} = 0]$	q	0.9666 (0.0141)	0.9762 (0.0179)

[15] A model including a break in the mean in 1973:1 and a break in gamma in 1984:1 along with the covariance break was also estimated, but it was not significantly different from the model presented here with a single structural break in the covariance matrix in 1984:1.

Figure 1: Asymmetric UC-UR with Exogenous Switching

Panel 1: Real GDP and the Estimate of the Permanent Component

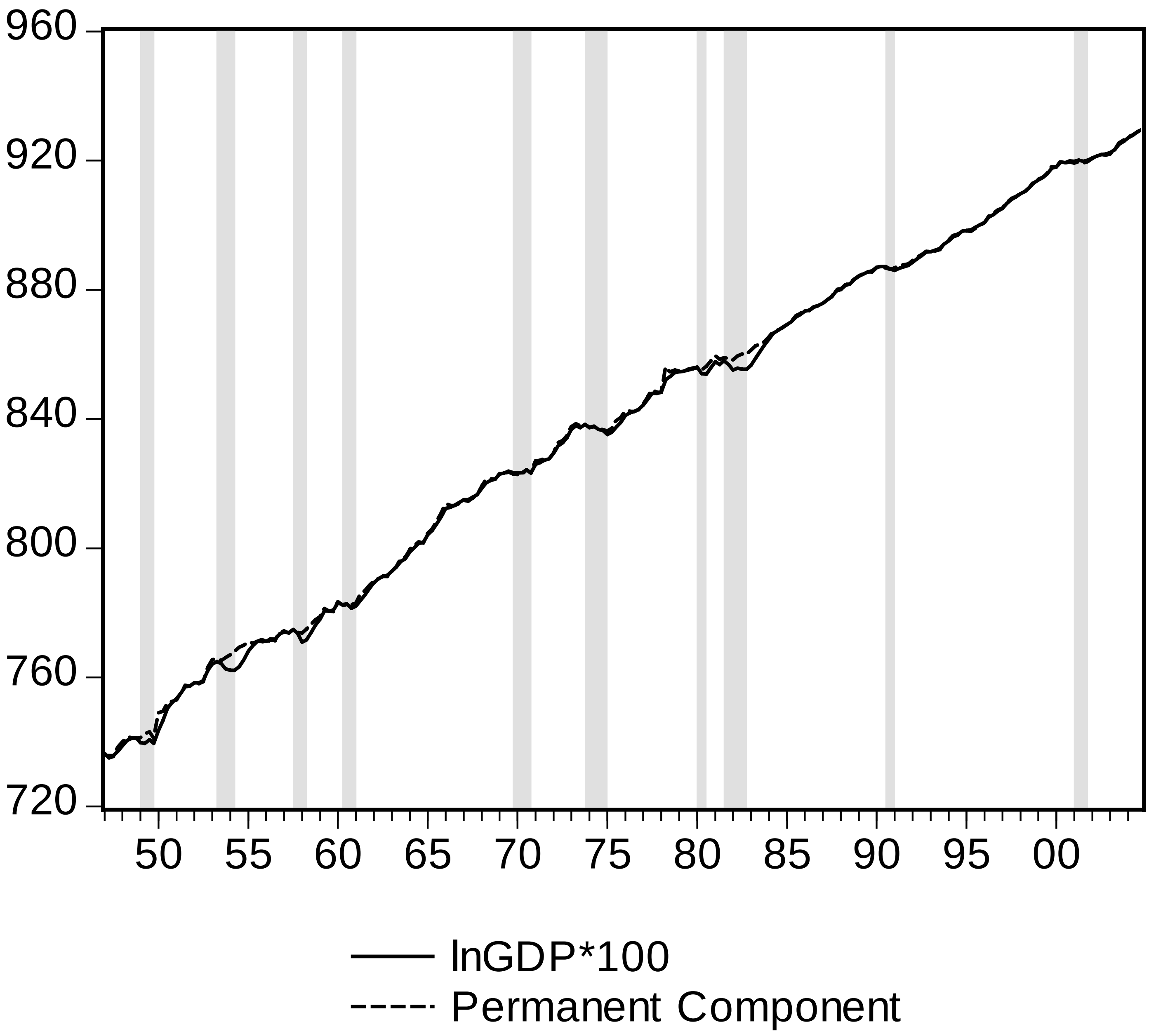
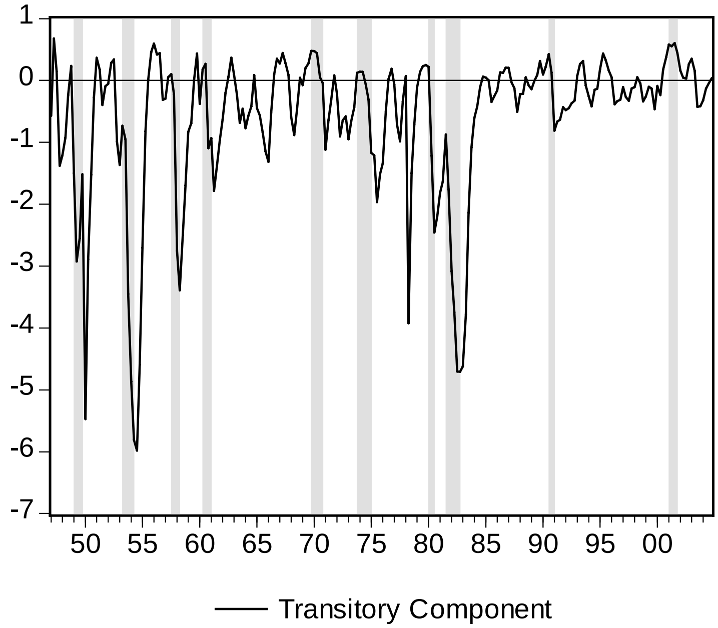


Figure 1: Asymmetric UC-UR with Exogenous Switching

Panel 2: Transitory Component of Real GDP



Panel 3: Probabilities of Exogenous Asymmetric Shocks

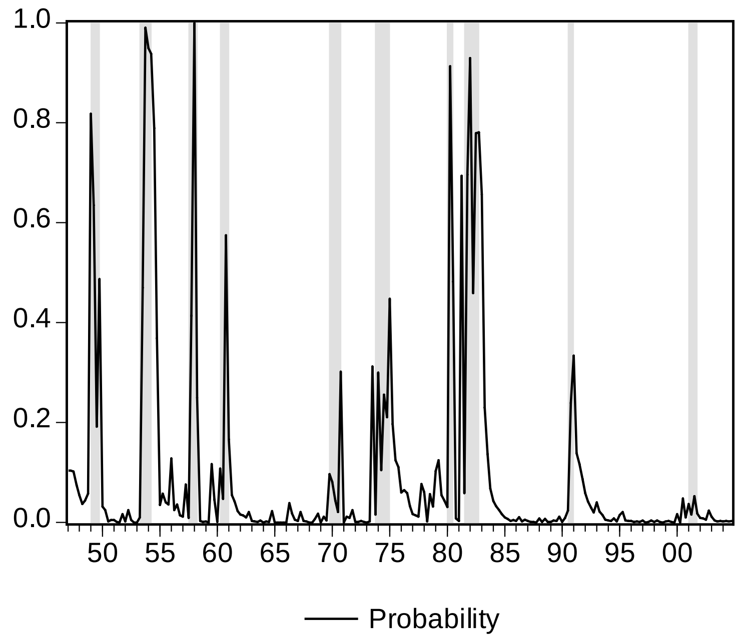


Figure 2: Comparison of the Estimated Transitory Components for the Different Models