Asymmetry in the Business Cycle: New Support for Friedman's Plucking Model

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Abstract

This paper presents an asymmetric correlated unobserved components model of US GDP. The asymmetry is captured using a version of Friedman's plucking model that suggests that output may be occasionally "plucked" away from a ceiling of maximum feasible output by temporary asymmetric shocks. The estimates suggest that US GDP can be usefully 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 found to be significantly negatively correlated, but the occasional asymmetric transitory shock appears to be uncorrelated with the permanent and symmetric transitory innovations. These results are robust to including a structural break to capture the productivity slowdown of 1973 and to changes in the time frame under analysis. The results suggest that both permanent movements and occasional exogenous asymmetric transitory shocks are important for explaining post-war recessions in the US.

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Section 1 Introduction

Campbell and Mankiw summarize the conventional view of the business cycle as "fluctuations in output represent[ing] temporary deviations from trend" (1987, abstract). Recent research, including Campbell and Mankiw's work, suggests, however, that this conventional view of the business cycle may be inappropriate. Decomposition of output into permanent and transitory movements by using the correlated unobserved components approach of Morley, Nelson, and Zivot (2003, hereafter MNZ), suggests that output experiences considerable permanent movements at business cycle frequencies.

The correlated unobserved components model of MNZ assumes, however, that the transitory movements are symmetric. If recessions, or at least some recessions, are fundamentally different from expansions, as suggested by Mitchell (1927, 1951), Burns and Mitchell (1946), Keynes (1936), Friedman (1969), and many others, then these symmetric models may not properly capture recessions. In particular, recessions may be characterized by more transitory movements than found when estimating models assuming symmetry. It is also possible that not all recessions are alike, as suggested by Kim and Murray (2002). Some recessions may be characterized by temporary deviations, whereas others may arise due to permanent movements.

Empirical research has recently focused on asymmetries in output. Sichel (1993), Beaudry and Koop (1993), Hamilton (1989), and Kim and Nelson (1999, 2001), have shown that asymmetric models appear to better characterize real US GDP than symmetric models. Mills and Wang (2002) have also found considerable support for the asymmetric model of Kim and Nelson (1999) for the G-7 countries.

There are also persuasive economic reasons to consider a model which allows asymmetric transitory shocks. Many economists are more comfortable with positive permanent shocks than 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 (see discussion in Hamilton, 2005, and 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 (see, for example, Mankiw, 1989). It is important, therefore, to explore the possibility that recessions, or at least some recessions, are driven by temporary asymmetric shocks, whereas expansions are driven by permanent movements. If this is the case, then symmetric estimates of real GDP may over-emphasize permanent movements due to the dominance of expansions in the data.

In 1964, Milton Friedman first suggested his "plucking model" (reprinted in 1969; revisited in 1993) as an asymmetric alternative to the self-generating, symmetric cyclical process often used to explain contractions and subsequent revivals. Friedman describes the plucking model of output as a string attached to a tilted, irregular board. When the string follows along the board it is at the ceiling of maximum feasible output, but the string is occasionally plucked down by a cyclical contraction.[2]

Kim and Nelson (1999) empirically estimate a version of Friedman's plucking model in an unobserved components framework. They find that this asymmetric model

[2] It is particularly noteworthy that Friedman specifically allowed for a stochastic trend, i.e. a tilted, *irregular* board representing maximum feasible output.

fits US real GDP better than the traditional symmetric unobserved components model. In particular, all NBER-dated US recessions within their sample appear to be characterized by "plucks," i.e. transitory asymmetric shocks.

The unobserved components model employed by Kim and Nelson, however, assumes zero-correlation between the permanent and transitory components.[3] MNZ show that for a symmetric model, the US data reject zero correlation between the components for output, and Mitra and Sinclair (2005) show that data for all G-7 countries also reject zero correlation between the unobserved components of GDP. Knowing that the data reject the symmetric zero-correlation model, it is important to extend Kim and Nelson's work to the correlated unobserved components (UC-UR) model of MNZ.

Once we think about the components being correlated, then we might also think about the implications of Friedman's plucking model in this form. Friedman's model implicitly suggests that plucks leading to cyclical contractions are due to a different process than the movements of the string along the tilted, irregular board. These asymmetric shocks would thus be expected to be uncorrelated with other innovations driving variation in the maximum feasible output. Testing for exogeneity of these asymmetric shocks then becomes a test of one of the implications of Friedman's plucking model.

The purpose of this paper is to relax the symmetry assumption of the UC-UR model of MNZ, combining it with Kim and Nelson's (1999) version of Friedman's

[3] They also implicitly assume zero-correlation between the asymmetric shock and the other shocks.

plucking model.[4] The key features of this model are that it allows for asymmetry in the transitory component via a Markov-switching process, 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 this model also allows for endogenous regime switching (based on Kim, Piger, and Startz, 2004).

An endogenous regime-switching model addresses the possibility that previous research may have been biased towards too much variability in the permanent component by allowing correlation between the components but not allowing for asymmetry (for example MNZ). At the same time, it also addresses the possibility that previous research may have been biased towards too little variability in the permanent component by not allowing for correlation between the components, whether or not asymmetry was included (Clark, 1987; Clark, 1989; Kim and Nelson, 1999).

To preview the results, the estimates of the asymmetric UC-UR model suggest that allowing for an asymmetric shock based on Friedman's plucking model yields considerably different estimates from the symmetric UC-UR model. Further, the transitory asymmetric plucks appear to be exogenous, suggesting that they are indeed due to a different process than the "normal times" movements in the economy. Allowing for this asymmetry, however, does not reverse the results of MNZ. There remain significant

[4] 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.

permanent movements in the series, and the permanent innovations are negatively correlated with the symmetric transitory innovations.

Finally, this paper also addresses recent research that questions the robustness of econometric analysis of the US business cycle. Perron and Wada (2005) recently showed that including a structural break in the drift term in the MNZ model results in US GDP appearing trend-stationary rather than having a significant stochastic trend. Others have also questioned whether there was a structural change in 1984 or elsewhere in the sample such that the time frame of analysis matters significantly for estimates. I address this by including structural breaks and also by examining sub-samples of the data. I find that the results are remarkably robust.

This paper proceeds as follows. Section 2 presents the asymmetric UC-UR model and the test for exogeneity of the state variable. Section 3 presents the results of estimating this model with US real GDP and compares the results to Kim and Nelson (1999). Section 4 provides conclusions and suggestions for possible extensions.

Section 2 The Model

The model can be viewed as an extension of the MNZ methodology to the Friedman plucking model, or as an extension of Kim and Nelson (1999) to allow for correlation between the components.

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. I also allow for a deterministic drift (μ) in the trend which captures the "tilted" nature of the trend described by Friedman. The permanent component is written as:

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

Following MNZ and Kim and Nelson (1999), I model each transitory component as an autoregressive process of order two (AR(2)). The innovation in this paper, as compared to MNZ, is to include a discrete, asymmetric shock, γS_t, in the transitory component so that the innovations to the transitory component are a mixture of a symmetric shock ε_t and the asymmetric discrete shock. 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.

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 normalization of the state variable, it is necessary to restrict the sign of the discrete, asymmetric shock, 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 mean. Thus we have occasional negative asymmetric shocks from a zero mean. The alternative would be long periods of positive mean with occasional zero-mean periods. This restriction is also useful because when "normal times" have a zero-mean transitory component we can interpret the permanent component as the steady state, as discussed in Morley and Piger (2004).

The model of MNZ is nested as a special case of this model with $\gamma = 0$. With the extended model, we can test the degree of asymmetry in the transitory component by considering the size of γ. In addition, we will be able to test the robustness of the results of the MNZ model in the face of asymmetry.

One concern with this approach is that the state variable may be correlated with the other components. If it is correlated with the other components, then it is an endogenous regressor, which results in biased and inconsistent estimates. Kim, Piger, and Startz (2004), however, develop a model of regime-switching models with endogenous switching.[5] In their model, the state (S_t) may be correlated with the regression residual. If the state is Markov-switching (i.e. the state is serially dependent), then we can use the lagged state variable as the instrument for the current state, assuming the lagged state variable is exogenous from the contemporaneous error term.

[5] Chib and Dueker (2004) present a non-Markovian regime switching model with endogenous states in the Bayesian framework which they apply to GDP growth as in the Hamilton (1989) model. Pesaran and Potter also provide another alternative model using a threshold autoregression (TAR) model. I follow Kim, Piger, and Startz because the application to the Kim and Nelson (1999) Markov switching model is more straightforward.

In order to allow for endogeneity of the state variable, I extend Kim, Piger, and Startz's model to state-space form and the more general case where the innovation to the latent state variable may be correlated with multiple innovations. In particular, I allow the innovation to the latent state variable to be jointly normally distributed with the innovations to both the permanent and transitory components. This allows for an exogeneity test and correction for potential endogeneity of the state variable as discussed below.

Section 2.1 Exogeneity Test and Bias Correction

Following Kim, Piger, and Startz (2004), I assume that the realization of the state process may be represented using a Probit specification as follows:

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

Further I assume that the joint distribution of w_t, η_t, and ε_t, is multivariate Normal:[6]

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

If the state variable is exogenous, then w_t is uncorrelated with η_t, and ε_t, and we have:

[6] This is an extension to the Kim, Piger, and Startz model because their application is only for a scalar variance, whereas here I correct the entire variance-covariance matrix in state-space form.

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

In this case the expectation of $\begin{bmatrix} \eta_t \\ \varepsilon_t \end{bmatrix}$, conditional upon S_t, S_{t-1}, and I_{t-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. Thus we have:

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

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, $\sigma_{\eta w}$and/or $\sigma_{\varepsilon w}$ does not equal zero. Thus the conditional mean and variance-covariance matrix become:

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

and

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

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

where

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

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

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

From here we can see that 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. [7]

Section 3 The Results

The data are the natural log of U.S. real GDP multiplied by 100 (y), quarterly, from 1947:1 – 2004:4.[8] To estimate the model presented in the previous section I cast it into state-space form. I then apply Kim's (1994) method of combining Hamilton's algorithm and a nonlinear discrete version of the Kalman filter for maximum likelihood

[7] I will use likelihood ratio test statistics for hypothesis testing throughout this paper for robust inference in the face of potential weak identification following the suggestion of Nelson and Startz (2004).
[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.

estimation (or quasi-maximum likelihood estimation in the case of endogeneity of the state variable) of the parameters and the components.[9]

First I determine whether the Markov-switching is exogenous or endogenous. Table 1 presents the results of estimating both an exogenous Markov-switching UC-UR model and an endogenous Markov-switching UC-UR model for US real GDP. The likelihood ratio test statistic is 3.1866. With two restrictions, the p-value is 0.203, which suggests there is no evidence of endogenous switching. In addition, the estimates are qualitatively similar whether we allow for endogenous switching or restrict the model to exogenous switching.[10] This lends support to the idea behind the Friedman plucking model that these discrete, asymmetric shocks are due to a different process than the other shocks affecting output. Therefore, for the rest of the discussion I will focus on the exogenous switching results.

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.[11] These estimates appear to be a hybrid of the zero-correlation plucking model

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[9] The state-space form is available in the appendix. In an update to their Federal Reserve Bank of St. Louis Working Paper, Kim, Piger, and Startz show that the method I use here is quasi-maximum likelihood instead of exact maximum likelihood in the case where there is endogenous Markov switching. They examine the case when there is only one innovation correlated with the state variable. For this case, they show that when there is endogenous switching, the regime-dependent conditional density function is no longer Gaussian, but rather belongs to the "skew-normal" family of density functions. It is not clear, however, how to derive the exact density function once we have two unobserved components within a non-stationary variable and the skew-normal density is not appropriate (or necessarily desirable – Azzalini and Capitanio (1998) discuss significant problems estimating skew-normal models with MLE). Assuming the density function is Gaussian results in quasi-maximum likelihood, which Campbell (2002) has shown to be inconsistent in cases where the specification error is correlated with the data.

[10] Finding that the results are qualitatively similar gives support to the use of quasi-MLE since under the null of no endogeneity the likelihood function is Gaussian.

[11] The filtered estimates are used instead of the smoothed estimates because including Markov switching results in smoothed estimates requiring successive approximations. See the discussion in Kim and Nelson (1999).

and the symmetric correlated model (see Figures 2 and 3 for comparison). 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 found by MNZ.

The results of estimating the model suggest that both asymmetry and correlated components are important for US data. First of all, including Markov-switching does appear to represent an improvement over the symmetric UC-UR model, as shown in Table 2. Testing the restriction of a symmetric model, i.e. that $\gamma = 0$, the likelihood ratio test statistic is 23.5, with three restrictions the standard p-value is less than 0.001. This is highly suggestive that the symmetry restriction is inappropriate for GDP, despite the fact that the test is nonstandard (see discussion in Kim and Nelson, 2001).

Including switching, however, does not reverse the results of MNZ that allowing correlation between the components is important. From Table 3 we can see that the restriction of zero correlation between the components for the asymmetric model (the asymmetric UC-0 model) is rejected with a p-value for the likelihood ratio test statistic of 0.011.

Perron and Wada (2005) have recently criticized the MNZ result by showing that in the symmetric univariate case, including a structural break in the drift term in 1973 reduces the permanent component of GDP to a deterministic trend. Table 4 presents estimates including a structural break in the drift term in 1973, and shows that the results are robust to this break. In fact, 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, so we cannot reject

the restriction of no break in 1973.[12] This further supports the claim of this paper that both correlation between the components and asymmetry are important.

We can also see in Figure 2 that the transitory component changes dramatically by allowing for asymmetry. Including asymmetry in the transitory components results in movements which look much more like the Friedman plucking model than the transitory components of the symmetric UC-UR model.

The asymmetric shocks only occur occasionally, so they do not explain a large amount of the variance in the series.[13] The estimated variances of the permanent and transitory components from the asymmetric model do not appear significantly different from the symmetric model (the no switching estimate in Table 2). The asymmetric shocks are large and significant, however, and they do appear important for a few episodes. We can see these episodes represented in Panel 3 of Figure 1. This panel presents the probabilities of plucks to the transitory component of real GDP. Similar to Kim and Murray (2002), the estimates of the asymmetric UC-UR model suggest that each recession differs in terms of the contribution of permanent and transitory movements. We can see that there is some positive probability of a pluck for all of the NBER dated recessions, but that of the ten NBER-dated recessions in the sample, six of the recessions have probability greater than 0.5 of being characterized by a pluck.

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[12] I also tried a break in γ (along with a break in the drift term) in 1973. This was also found to be insignificant with no qualitative difference in the results.

[13] Using an innovation regime-switching model, Kuan et al. (2005) also find that transitory movements only explain a small, but important, portion of the variance of US real GDP. They conclude that unit-root nonstationarity dominates in almost 85% of the sample periods, with 33 stationary periods which closely match NBER dating of recessions.

The four recessions which do not appear to be characterized by pluck are 1969:4 – 1970:4, 1973:4 – 1975:1, 1990:3 – 1991:1, and 2001:1 – 2001:4. For these recessions which do not appear to be characterized by a regime switch, 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 plucks, however, there is a noticeable peak-to-trough movement in the transitory component, but it is smaller in general than in the recessions which experienced plucks. Interestingly, forecasters had particular difficulty predicting two of the no-pluck recessions, 1969 – 1970 and 1990 – 1991, 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) 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.[14] Finally, there is still some discussion about the causes of the 2001 recession. Perhaps because it was particularly mild or because it is at the end of the sample, other econometric models also show that this recession looks different than other recessions (e.g. Kim, Morley, and Piger 2005).

For the recessions characterized by plucks, we can see from Figure 1 that for each one, with the exception of 1960-1961, the series drops below the permanent component.

[14] Interestingly, the other "oil-shock" recession in 1979-1980 does appear to be characterized by a pluck. This may be explained by the discussion on page 326 of Abel and Bernanke (2005) which suggests that people expected the oil shock of 1973 – 1975 to have permanent effects, but 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 plucks.

Here we see that these recessions do have the appearance of a pluck as described by Friedman such that the permanent component appears to be a ceiling for these recessions.

Kim, Morley, and Piger (2005) extend Hamilton's (1989) model to include a "bounce-back" effect and find that this greatly reduces the permanent effect of recessions. In their model they also find that the probability of a contractionary state does not exceed 0.5 for the 1970 and 2001 recessions, but that allowing for a structural break in the variance of output in 1984 improves their estimates. Allowing for a structural break in the asymmetric UC-UR model is problematic since it would require a break in the entire variance-covariance matrix, leaving few observations for identification of the model post-1984. Instead, Table 5 presents the pre-1984 sub-sample that looks surprisingly similar to the full sample estimates.[15] This similarity suggests that including data from 1984 to 2004 did not change the structure of the model significantly, but without sufficient data past 1984, we cannot test it. Excluding data post 1983 does not, however, increase significantly the probability of a pluck for the 1969:4 – 1970:4 recession, but it does increase the probability of a pluck in 1973:4 – 1975:1 to over 0.6. It is also worth noting that the persistence was lower for both recessions (by a little) and expansions (by a lot) in the pre-1984 sub-sample.

The estimates suggest that the data can be decomposed into three important movements: the permanent movements captured by the random walk with drift component, the symmetric transitory movements captured by the stationary AR(2)

[15] I also tried a trend and size of pluck break in 1984 similar to the specification for the 1973 breaks. Since there are no significant plucks after 1984, the size of the pluck goes to zero for the post-1984 period, but the trend break is not significant.

process with innovations that are significantly negatively correlated with the permanent innovations, and the occasional exogenous negative transitory shock which characterizes six of the ten NBER-dated recessions in the sample.

One movement which appears in the in the symmetric transitory component (and also in the permanent component due to the negative correlation) deserves some attention. From 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 look like a pluck, but from Panel 3, we can see that there less than 0.1 probability of a pluck for this time period. We can further see from close inspection of Panel 1 that this is the one point in the sample where it looks like the permanent component is jumping up away from the series. Interestingly, this is the same time period when forecasters at the time predicted a recession, but none occurred. Forecasters predicted that due to the oil shock in 1978, there should be a recession analogous to the recession following the 1973 oil shock. Goldfarb, Stekler, and David (2005) suggest that consumers reacted differently in 1978, which might explain the brief permanent movement above the series. If consumers changed their behavior, it is possible that this would show up as a permanent movement. Once they changed their behavior again when the recession did not materialize, we would expect another adjustment of the permanent component, as is seen in 1979. 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.

Section 3.1 Comparing the Results with Kim and Nelson (1999)

Kim and Nelson (1999) showed that the timing of the asymmetric shocks fit the NBER recession dates well using a zero-correlation unobserved components model (UC-0) version of Friedman's plucking model. But, as shown by Clark (1987), a simple symmetric transitory component also fits the NBER recession dates well when zero correlation between the components is imposed. MNZ show, however, that the US data reject zero correlation between the components for output. Once we allow for correlation between the components in a symmetric unobserved components model, the transitory component no longer looks anything like the conventional business cycle. In the asymmetric case, we also find that not allowing correlation overstates the importance of the transitory movements, as can be seen in Figure 3 where plucks only miss 2001 (which was not in Kim and Nelson's sample). This may make the restriction appealing, but the data clearly reject this restriction.

Kim and Nelson (1999) find evidence that for GDP there is no symmetric shock to the transitory component once they allow for the discrete, asymmetric shock. Here, however, I find that the symmetric shock remains important and retains its interpretation from MNZ as adjustment to permanent shocks. This allows for more permanent movements (note the higher standard deviations for the permanent innovations in the correlated case in Table 3) than if we impose a zero-correlation restriction between the permanent and transitory movements as in Kim and Nelson's model. [16]

[16] I also checked the time-frame that Kim and Nelson used (1951:1 to 1995:3). Estimating the Kim and Nelson sub-sample did not change the qualitative results, however I did not use their data series, but rather the sub-sample of the updated data, so data revisions may affect the results.

Kim and Nelson also find that the persistence of the transitory component of US real GDP decreases once they account for asymmetry. The estimates presented in Tables 2 and 3 show that a symmetric correlated UC model has the lowest persistence (0.59), but that the asymmetric correlated UC model exhibits a less persistent transitory component (0.70) than the asymmetric uncorrelated UC model (0.85).

4 Conclusions

This paper has provided new evidence for Friedman's plucking model. The results suggest there exists a ceiling of maximum feasible output which is well-approximated by a random walk, but that occasionally (for at least six of the last ten US recessions), output is "plucked" away from this ceiling by an exogenous transitory shock.

To summarize the results, the estimates of the asymmetric UC-UR model suggest that allowing for an asymmetric shock based on Friedman's plucking model yields considerably different results from the symmetric correlated unobserved components model. Further, the transitory asymmetric plucks 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 including a structural break in 1973 and also to various sub-samples.

The results presented here suggest that transitory shocks may be important for most recessions, but that US real GDP experiences more permanent movements than what we would expect from conventional business cycle models. These results suggest

that there may be different types of recessions with different underlying causes. Understanding these different causes will be a very important research agenda to pursue with important policy implications.[17]

[17] One possible direction 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 plucks are monetary, as suggested by Friedman (1993).

Appendix: State Space Form

In state-space form we can represent the series as follows

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

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, i.e. where

$$\begin{bmatrix} w_t \\ \eta_t \\ \varepsilon_t \end{bmatrix} \sim N(0, \Sigma_0), \Sigma_0 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sigma_\eta^2 & \sigma_{\eta\varepsilon} \\ 0 & \sigma_{\eta\varepsilon} & \sigma_\varepsilon^2 \end{bmatrix},$$

where w_t is the error term from equation (6) above, we have:

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

In the case of correlation between the state variable and the other innovations, i.e. where

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

the variance-covariance matrix becomes:

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

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

where

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

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

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

References

Azzalini, A. and A. Capitanio (1999). "Statistical Applications of the Multivariate Skew-Normal Distribution." Journal of the Royal Statistical Society **B 61**(3): 579-602.

Abel, A. B. and B. S. Bernanke (2005). Macroeconomics Pearson Addison Wesley.

Beaudry, P. and G. Koop (1993). "Do Recessions Permanently Affect Output?" Journal of Monetary Economics **31**(2): 149-163.

Burns, A. F. and W. C. Mitchell (1946). Measuring Business Cycles. New York, National Bureau of Economic Research.

Campbell, J. and G. Mankiw (1987). "Are Output Fluctuations Transitory." Quarterly Journal of Economics **102**(4): 857-880.

Campbell, S. D. (2002). "Specification Testing and Semiparametric Estimation of Regime Switching Models: An Examination of the US Short Term Interest Rate." Brown University Working Paper No. 2002-26.

Caner, M. and B. E. Hansen (2001). "Threshold Autroregression with a Unit Root." Econometrica **69**(6): 1555-1596.

Chauvet, M., C. Juhn, et al. (2002). "Markov Switching in Disaggregate Unemployment Rates." Empirical Economics **27**(2): 205-232.

Chib, S. and M. Dueker (2004). "Non-Markovian Regime Switching with Endogenous States and Time-Varying State Strengths." Federal Reserve Bank of St. Louis Working Paper No. 2004-030A.

Clark, P. K. (1987). "The Cyclical Component of U.S. Economic Activity." The Quarterly Journal of Economics **102**(4): 797-814.

Clark, P. K. (1989). "Trend Reversion in Real Output and Unemployment." Journal of Econometrics **40**(1): 15-32.

Enzler, J. J. and H. O. Stekler (1971). "An Analysis of the 1968-69 Economic Forecasts." The Journal of Business **44**(3): 271-281.

Fintzen, D. and H. O. Stekler (1999). "Why Did Forecasters Fail to Predict the 1990 Recession?" International Journal of Forecasting **15**(3): 309-323.

Fisher, I. (1932). Booms and Depressions: Some First Principles. New York, Adelphi Company.

Friedman, M. (1969). Monetary Studies of the National Bureau. The Optimum Quantity of Money and Other Essays. M. Friedman. Chicago, Aldine**:** 261-284.

Friedman, M. (1993). "The 'Plucking Model' of Business Fluctuations Revisited." Economic Inquiry **31**(2): 171-177.

Goldfarb, R. S., H. O. Stekler, et al. (2005). "Methodological Issues in Forecasting: Insights from the Egregious Business Forecast Errors of Late 1930." Journal of Economic Methodology: Forthcoming.

Hamilton, J. D. (1989). "A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle." Econometrica **57**(2): 357-384.

Hamilton, J. D. (2005). "What's Real About the Business Cycle." NBER Working Paper No. 11161.

Keynes, J. M. (1936). The General Theory of Employment, Interest and Money. London, Macmillan.

Kim, C.-J. (1994). "Dynamic Linear Models with Markov-Switching." Journal of Econometrics **60**: 1-22.

Kim, C.-J., J. C. Morley, et al. (2005). "Nonlinearity and the Permanent Effects of Recessions." Journal of Applied Econometrics **20**(2): 291-309.

Kim, C.-J. and C. J. Murray (2002). "Permanent and Transitory Components of Recessions." Empirical Economics **27**(2): 163-183.

Kim, C.-J. and C. R. Nelson (1999). "Friedman's Plucking Model of Business Fluctuations: Tests and Estimates of Permanent and Transitory Components." Journal of Money, Credit, and Banking **31**(3): 317-334.

Kim, C.-J. and C. R. Nelson (1999). State-Space Models with Regime Switching: Classical and Gibbs-Sampling Approaches with Applications. Cambridge, MA, MIT Press.

Nelson, C. R. and C.-J. Kim (2001). "A Bayesian Approach to Testing for Markov Switching in Univariate and Dynamic Factor Models." International Economic Review **42**(4): 989-1013.

Kim, C.-J. and J. Piger (2002). "Common Stochastic Trends, Common Cycles, and Asymmetry in Economic Fluctuations." Journal of Monetary Economics **49**(6): 1189-1211.

Kim, C.-J., J. Piger, et al. (2003). "The Dynamic Relationship Between Permanent and Transitory Components of U.S. Business Cycles." Federal Reserve Bank of St. Louis Working Paper No. 2001-017C.

Kim, C.-J., J. Piger, et al. (2004). "Estimation of Markov Regime-Switching Regression Models with Endogenous Switching." Federal Reserve Bank of St. Louis Working Paper Series **2003-15B**.

Kuan, C.-M., Y.-L. Huang, et al. (2005). "An Unobserved-Component Model with Switching Permanent and Transitory Innovation." Journal of Business and Economic Statistics **23**(4): 443-454.

Mankiw, G. (1989). "Real Business Cycles: A New Keynesian Perspective." Journal of Economic Perspectives **3**(3): 79-90.

Mills, T. C. and P. Wang (2002). "Plucking Models of Business Cycle Fluctuations: Evidence from the G-7 Countries." Empirical Economics **27**(2): 255-277.

Mitchell, W. C. (1927). Business Cycles: The Problem and its Setting. New York, National Bureau of Economic Research.

Mitchell, W. C. (1951). What Happens During Business Cycles. New York, National Bureau of Economic Research.

Mitra, S. and T. M. Sinclair (2005). International Business Cycles: An Unobserved Components Approach. Working Paper.

Morley, J. C., C. R. Nelson, et al. (2003). "Why Are the Beveridge-Nelson and Unobserved-Components Decompositions of GDP So Different?" The Review of Economics and Statistics **85**(2): 235-243.

Morley, J. C. and J. Piger (2004). "A Steady-State Approach to Trend/Cycle Decomposition." Federal Reserve Bank of St. Louis Working Paper No. 2004-006C.

Neftci, S. N. (1984). "Are Economic Time Series Asymmetric over the Business Cycle?" The Journal of Political Economy **92**(2): 307-328.

Nelson, C. R. and C.-J. Kim (2001). "A Bayesian Approach to Testing for Markov-Switching in Univariate and Dynamic Factor Models." International Economic Review **42**(4): 989-1013.

Nelson, C. R. and R. Startz (2004). “Zero-Information-Limit Models and Spurious Inference: The Case of ARMA with Near Cancellation.” University of Washington Working Paper.

Pesaran, M. H. and S. M. Potter (1997). "A Floor and Ceiling Model of US Output." Journal of Economic Dynamics and Control **21**(4-5): 661-695.

Sichel, D. E. (1993). "Business Cycle Asymmetry: A Deeper Look." Economic Inquiry **31**(2): 224-236.

Sinclair, T. M. (2005). Essays on Macroeconomics and the Labor Market. Dissertation, Department of Economics, Washington University in St. Louis.

Table 1: Asymmetric UC-UR Results for Quarterly US Real GDP, 1947-2004

Exogenous Switching Compared to Endogenous Switching

Description	**Parameter**	**Exogenous Switching Estimate (Standard Error)**	**Endogenous Switching Estimate (Standard Error)**
Log Likelihood		-305.2058	-303.6125
S.D. of Permanent Innovation	σ_η	1.0793 (0.1402)	1.1366 (0.1638)
S.D. of Temporary Innovation	σ_ε	0.5899 (0.2096)	0.6398 (0.2156)
Correlation between Permanent and Transitory Innovations	$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	-0.8105 (0.0944)
Drift	μ	0.8409 (0.0725)	0.8486 (0.0812)
1st AR parameter	ϕ_1	1.1143 (0.1055)	1.0445 (0.0915)
2nd AR parameter	ϕ_2	-0.4104 (0.0990)	-0.3339 (0.1090)
Persistence	$\phi_1 + \phi_2$	0.7039	0.7106
Size of the Pluck	γ	-1.8209 (0.2567)	-2.5829 (0.3859)
$Pr[S_t = 1 \mid S_{t-1} = 1]$	p	0.7121 (0.1156)	0.6163[18]
$Pr[S_t = 0 \mid S_{t-1} = 0]$	q	0.9666 (0.0141)	0.9618[19]
Expected Duration of State 1	$\frac{1}{1-p}$	3.4734 quarters	2.6062 quarters
Expected Duration of State 0	$\frac{1}{1-q}$	29.9401 quarters	26.1780 quarters
Correlation between the permanent innovation and the latent state variable innovation	$\rho_{\eta w}$	Restricted to be 0	0.3082 (0.1984)
Correlation between the transitory innovation and the latent state variable innovation	$\rho_{\varepsilon w}$	Restricted to be 0	0.3075 (0.2452)

[18] $p = 1 - \Phi(-(a_0+a_1))$, where $a_0 = -1.7719$ (SE: 0.2046), $a_1 = 2.0677$ (SE: 0.3708).

[19] $q = \Phi(-a_0)$, where $a_0 = -1.7719$ (SE: 0.2046).

Table 2:

Asymmetric UC-UR Compared to Symmetric UC-UR and MNZ

Parameter	**Asymmetric UC-UR Estimate (Standard Error)**	**Symmetric UC-UR Estimate (Standard Error)**	**MNZ Estimate 1947-1998 (Standard Error)**
Log Likelihood	-305.2058	-316.9769	-284.6507
σ_η	1.0793 (0.1402)	1.1275 (0.1299)	1.2368 (0.1518)
σ_ε	0.5899 (0.2096)	0.5372 (0.2419)	0.7485 (0.1614)
$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	-0.9611 (0.1252)	-0.9063 (0.0728)
μ	0.8409 (0.0725)	0.8358 (0.0745)	0.8156 (0.0865)
ϕ_1	1.1143 (0.1055)	1.3759 (0.1074)	1.3419 (0.1456)
ϕ_2	-0.4104 (0.0990)	-0.7874 (0.1193)	-0.7060 (0.0822)
$\phi_1 + \phi_2$ (persistence)	0.7039	0.5885	0.6359
γ	-1.8209 (0.2567)	Restricted to be 0	Restricted to be 0
p	0.7121 (0.1156)	N/A	N/A
q	0.9666 (0.0141)	N/A	N/A

Table 3:

Asymmetric UC-UR Compared to Asymmetric UC-0 and Kim and Nelson 1999

Parameter	**Asymmetric UC-UR Estimate (Standard Error)**	**Asymmetric UC-0 Estimate (llv: -308.4435) (Standard Error)**	**Kim and Nelson[20] Estimate (Standard Error)**
$\sigma_{\eta 0}$	1.0793 (0.1402)	0.6490 (0.1458)	0.57 (0.10)
$\sigma_{\eta 1}$			0.98 (0.18)
$\sigma_{\varepsilon 0}$	0.5899 (0.2096)	0.3727 (0.2417)	0.24 (0.20)
$\sigma_{\varepsilon 1}$			0.00 ---[21]
$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	Restricted to be zero	Restricted to be zero
μ	0.8409 (0.0725)	0.8096 (0.0459)	N/A[22]
ϕ_1	1.1143 (0.1055)	1.1576 (0.1149)	1.2565 (0.1260)
ϕ_2	-0.4104 (0.0990)	-0.3099 (0.1076)	-0.4595 (0.1182)
$\phi_1 + \phi_2$ (persistence)	0.7039	0.8477	0.7970
γ	-1.8209 (0.2567)	-1.7166 (0.2371)	-1.11 (0.31)
p	0.7121 (0.1156)	0.6900 (0.1063)	0.7116 (0.1157)
q	0.9666 (0.0141)	0.9583 (0.01748)	0.9326 (0.0336)

[20] Using estimates from Model 1. Kim and Nelson consider lnGDP; however I have multiplied the results by 100 in order to compare them to my results. Their sample is from 1951:1 – 1995:3 (see Table 5 for comparable sample with the asymmetric UC-UR model). Kim and Nelson also allow for variance changes for the different state, such that σ_0 is the variance when in State 0 and σ_1 is the variance when in State 1. In order to allow correlation between the components I follow instead the model presented in their textbook (1999) which does not include the state-dependent variances.

[21] Kim and Nelson note that the estimate of $\sigma_{\varepsilon y1}$ fell on the boundary and thus they treated it as a known parameter at $\sigma_{\varepsilon y1} = 0$ in order to calculate standard errors.

[22] Kim and Nelson allow for a random walk in the drift parameter with an estimated variance of 0.07 (SE: 0.05).

Table 4:

Asymmetric UC-UR Compared to Including 1973 Break

Parameter	**Asymmetric UC-UR Estimate (Standard Error)**	**With 1973 Break Estimate (Standard Error)**
Log Likelihood	-305.2058	-303.9961
σ_η	1.0793 (0.1402)	1.0194 (0.1386)
σ_ε	0.5899 (0.2096)	0.5190 (0.2084)
$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	-0.7899 (0.1154)
μ	0.8409 (0.0725)	0.9668 (0.1045)
$\mu 2$	Same as μ by assumption	0.7459 (0.0902)
ϕ_1	1.1143 (0.1055)	1.1073 (0.1014)
ϕ_2	-0.4104 (0.0990)	-0.4071 (0.0989)
$\phi_1 + \phi_2$ (persistence)	0.7039	0.7002
γ	-1.8209 (0.2567)	-1.8160 (0.2505)
p	0.7121 (0.1156)	0.7194 (0.0897)
q	0.9666 (0.0141)	0.9655 (0.0146)

Table 5

Asymmetric UC-UR and Sub-samples

Parameter	**Asymmetric UC-UR Estimate (Standard Error)**	**1947-1983 Sub-sample Estimate (Standard Error)**	**1951:1-1995:3 Sub-sample Estimate (Standard Error)**
Log Likelihood	-305.2058	-227.1005	-244.6483
σ_η	1.0793 (0.1402)	1.1590 (0.2506)	1.1504 (0.1570)
σ_ε	0.5899 (0.2096)	0.6570 (0.3911)	0.4511 (0.2358)
$\rho_{\eta\varepsilon}$	-0.8230 (0.0882)	-0.7142 (0.2316)	-0.9586 (0.1305)
μ	0.8409 (0.0725)	0.8653 (0.0994)	0.7981 (0.0869)
ϕ_1	1.1143 (0.1055)	1.1264 (0.1735)	1.0084 (0.1747)
ϕ_2	-0.4104 (0.0990)	-0.4051 (0.1812)	-0.4921 (0.0984)
$\phi_1 + \phi_2$ (persistence)	0.7039	0.7213	0.5163
γ	-1.8209 (0.2567)	-1.6492 (0.3402)	-1.6155 (0.2574)
p	0.7121 (0.1156)	0.6667 (0.1488)	0.7952 (0.1220)
q	0.9666 (0.0141)	0.9385 (0.0347)	0.9633 (0.0192)
Expected Duration of State 1	3.4734 quarters	3.000 quarters	4.8828
Expected Duration of State 0	29.9401 quarters	16.2602 quarters	27.2480

Figure 1

Asymmetric UC-UR with Exogenous Switching

Panel 1: GDP and the Estimate of the Permanent Component

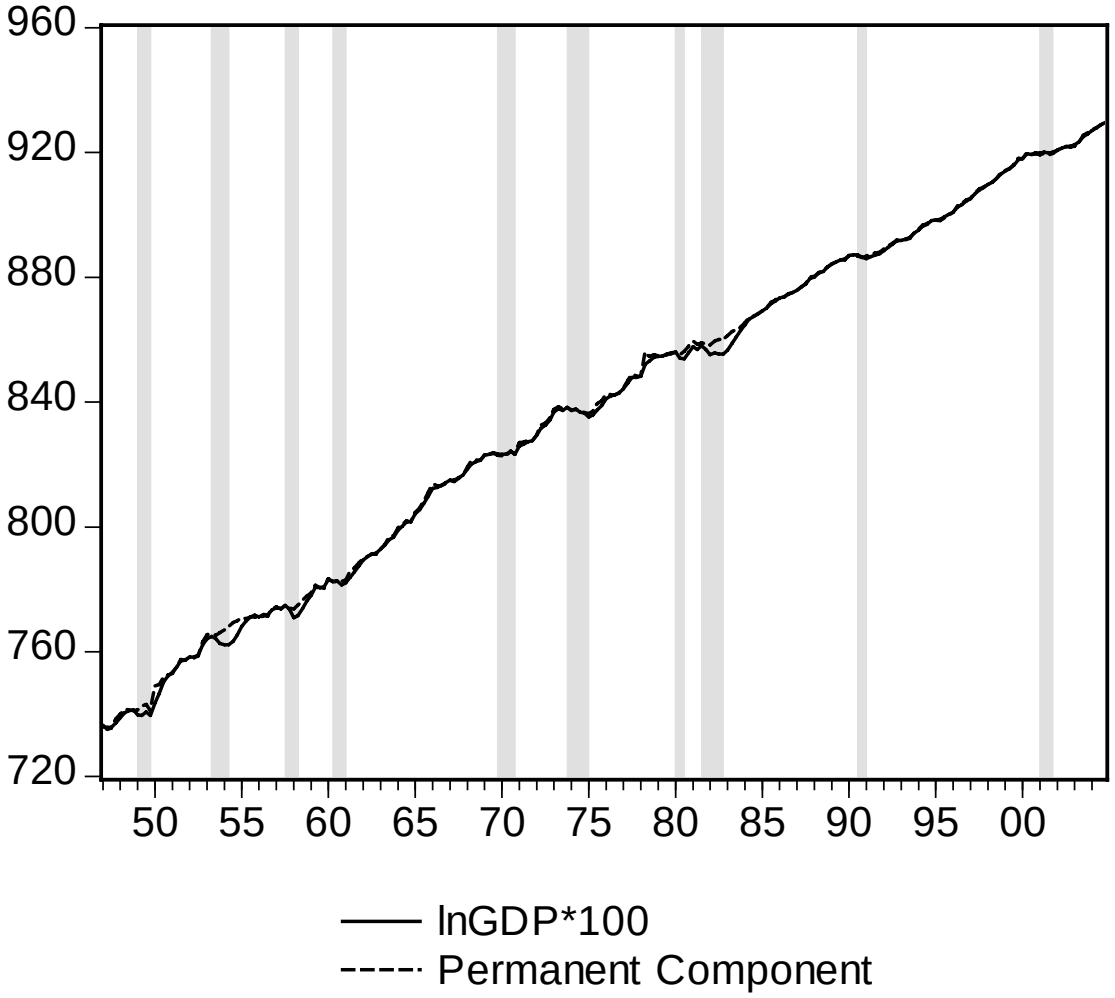


Figure 1

Asymmetric UC-UR with Exogenous Switching

Panel 2: Transitory Component of Real GDP

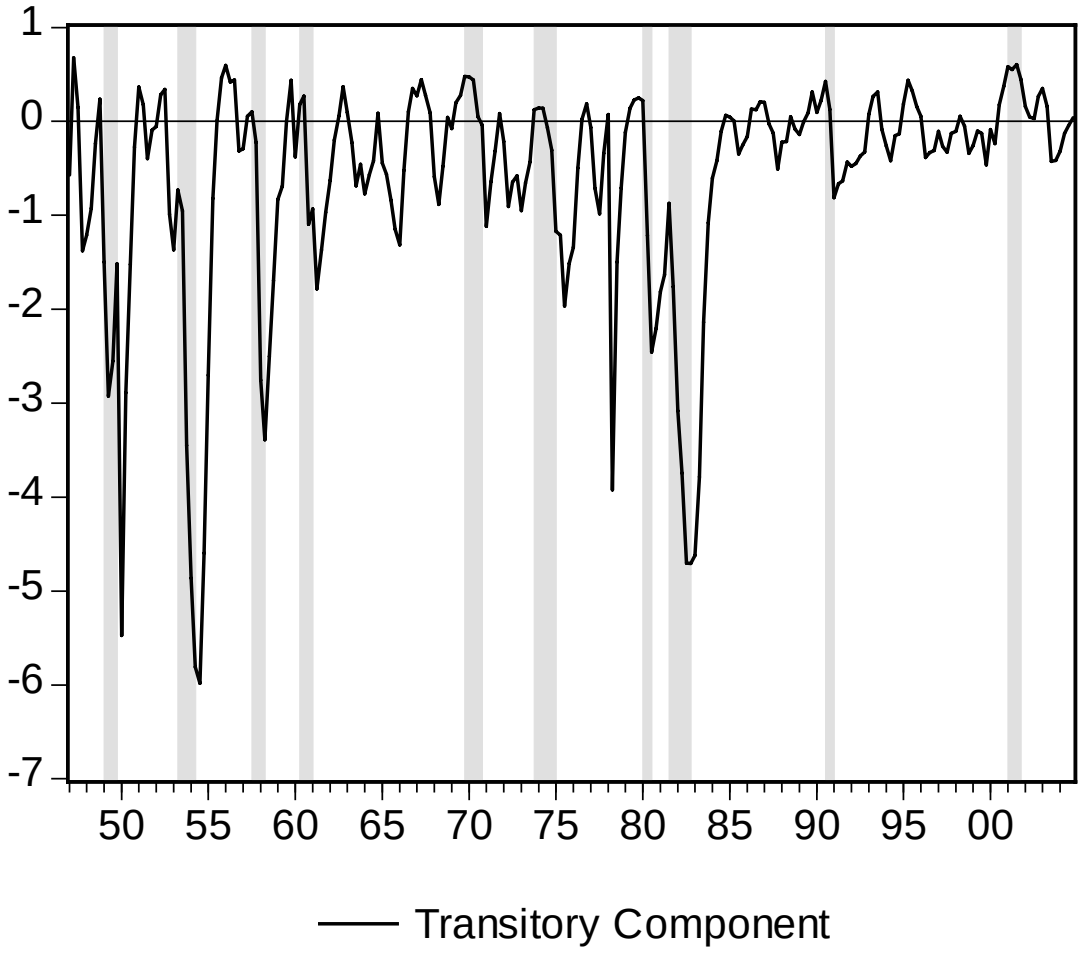


Figure 1

Asymmetric UC-UR with Exogenous Switching

Panel 3: Probabilities of Plucks (Exogenous Asymmetric Shocks)

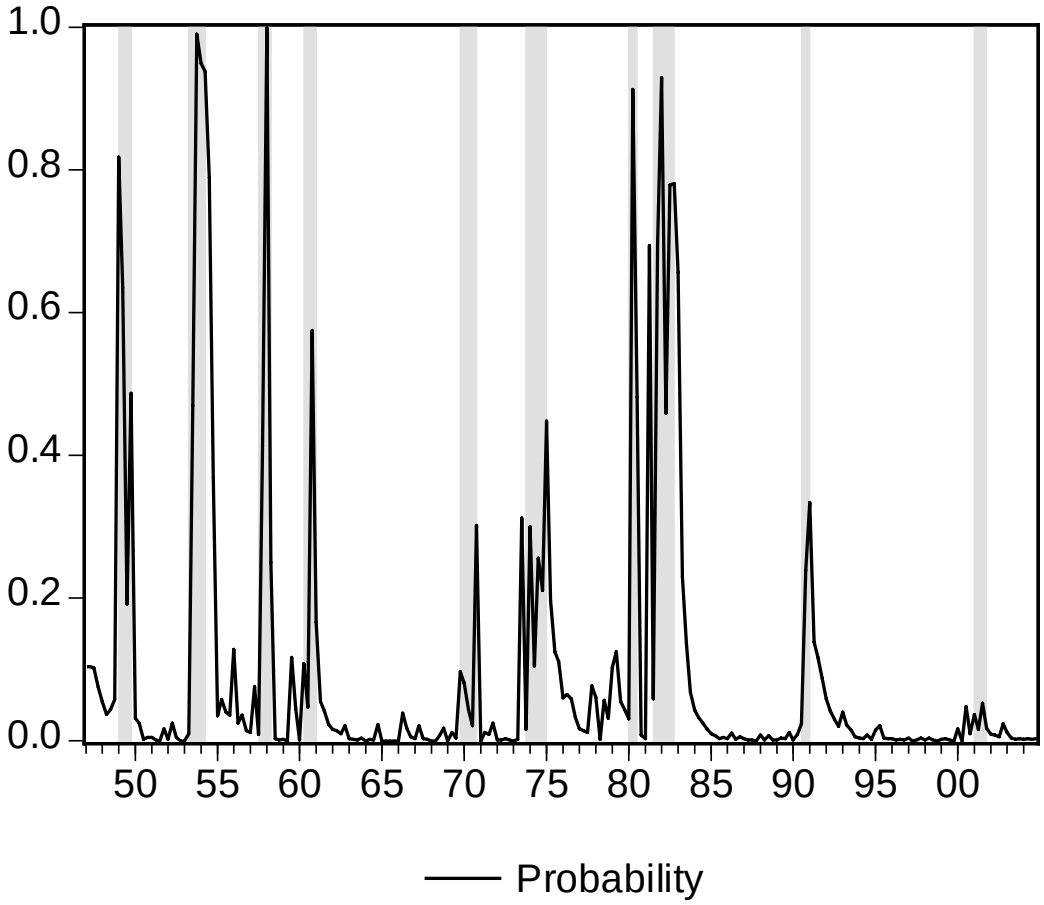


Figure 2

Asymmetric UC-UR Compared to Symmetric (i.e. Without Switching) UC-UR

Panel 1: Permanent Components

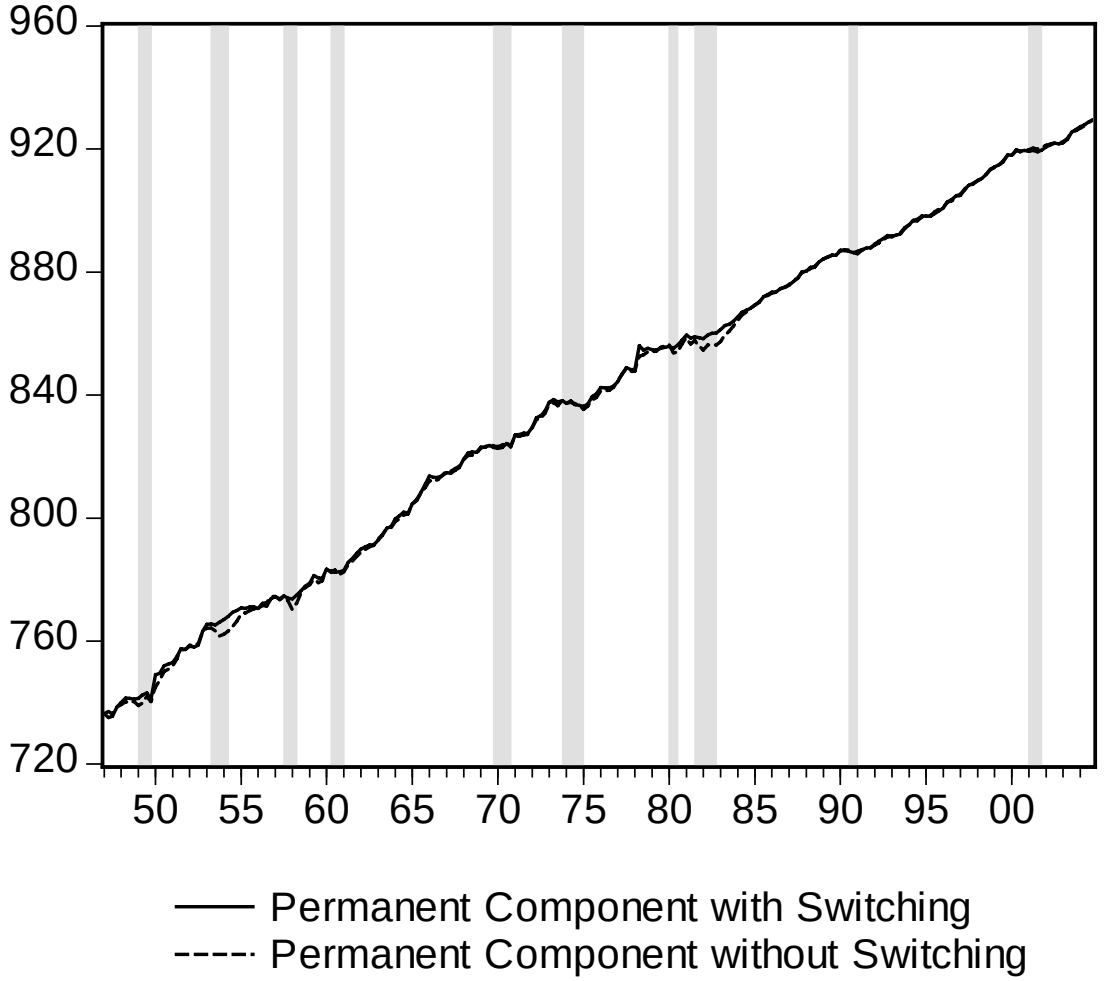


Figure 2

Asymmetric UC-UR Compared to Symmetric (i.e. Without Switching) UC-UR

Panel 2: Transitory Components

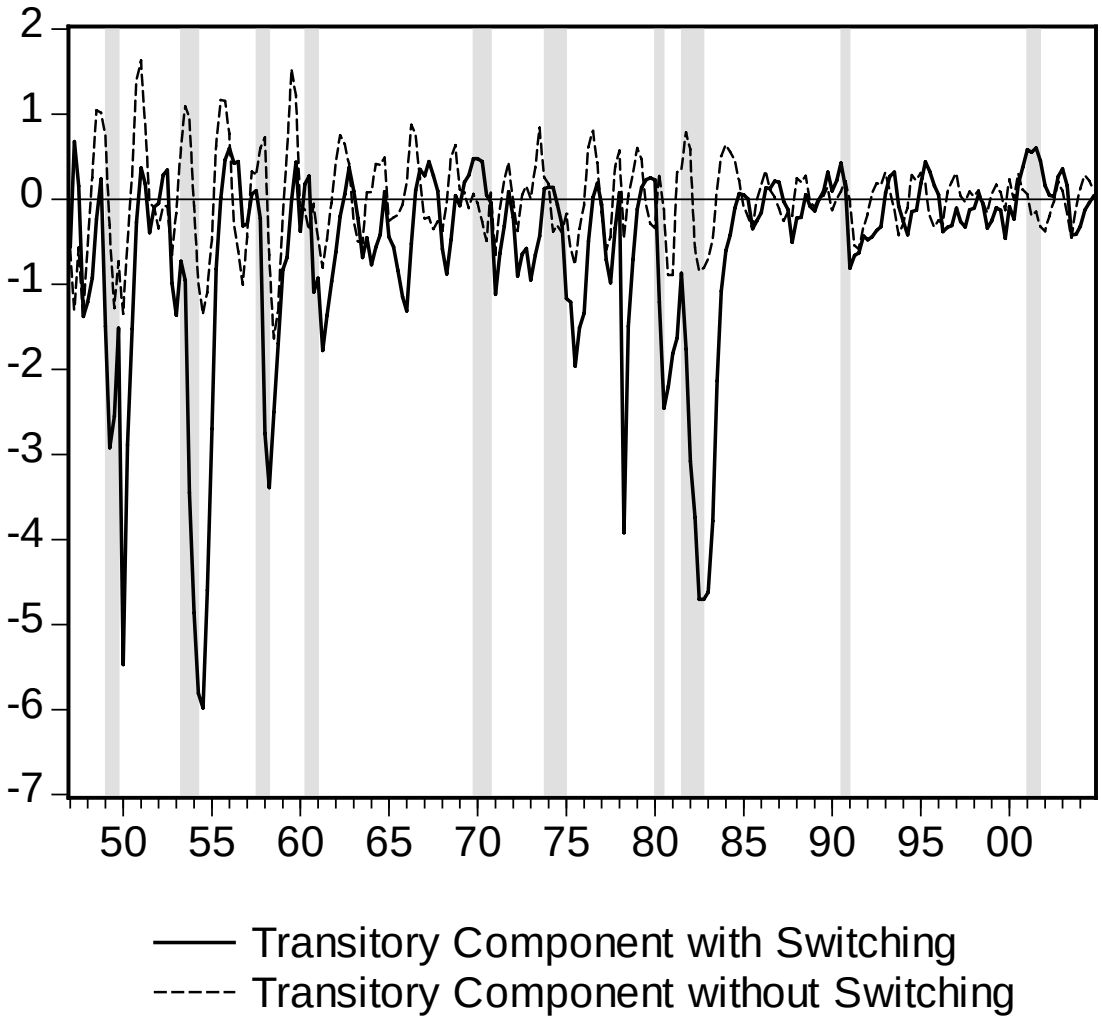


Figure 3

Asymmetric UC-UR Compared to Asymmetric UC-0

Panel 1: Permanent Components

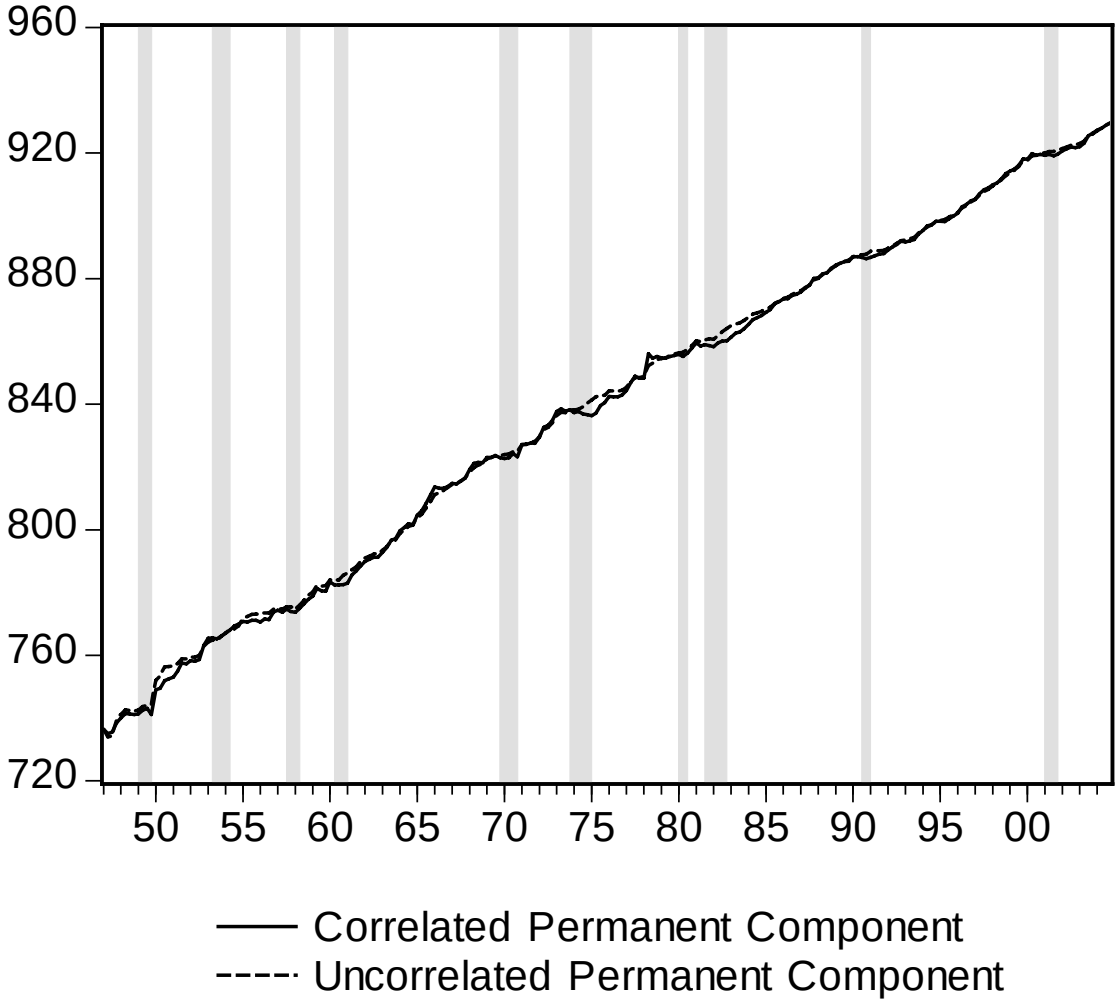


Figure 3

Asymmetric UC-UR Compared to Asymmetric UC-0

Panel 2: Transitory Components

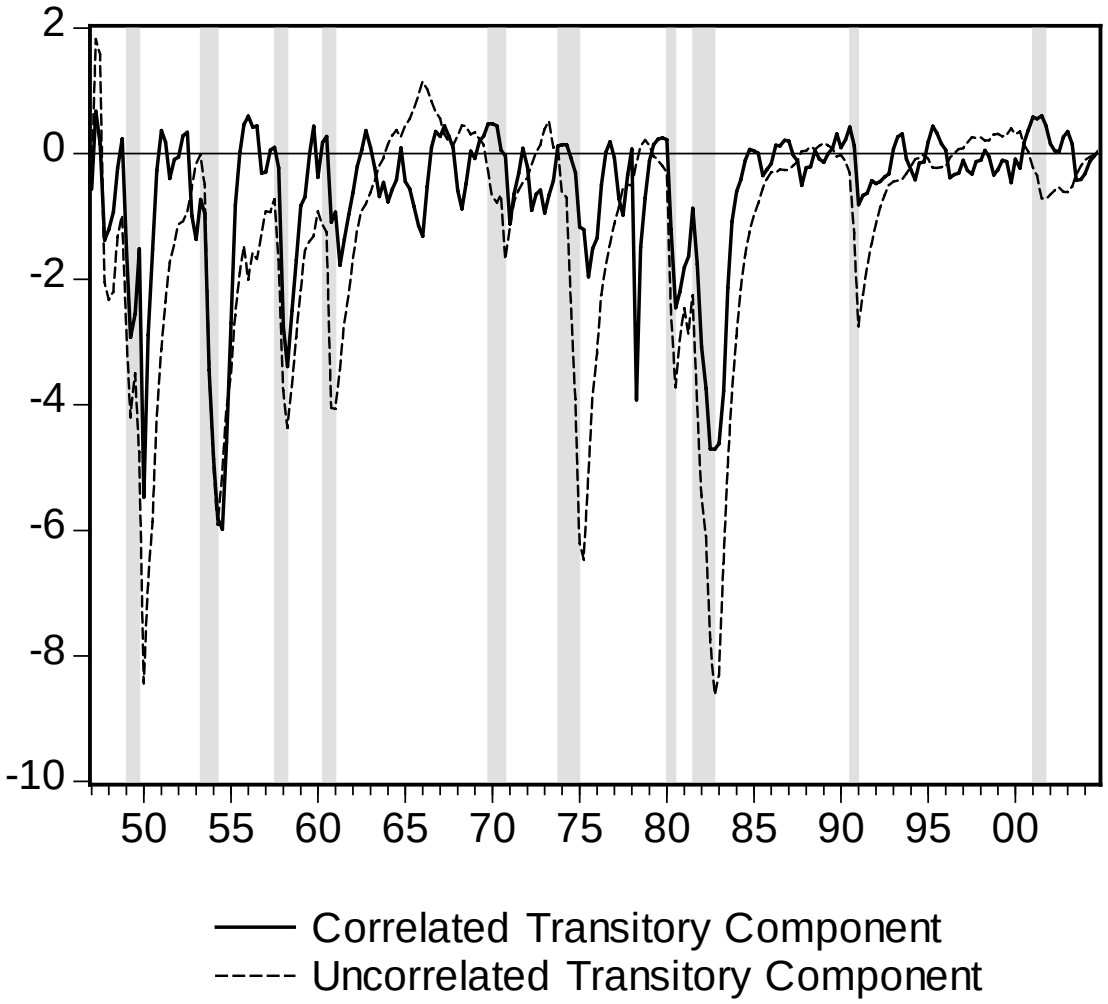
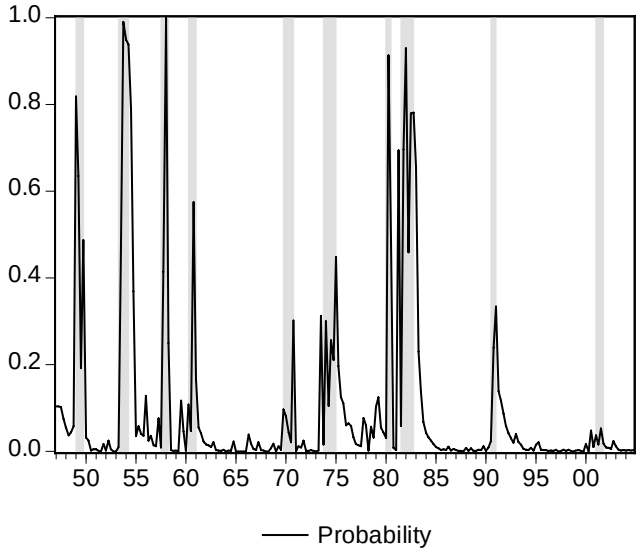


Figure 3

Asymmetric UC-UR Compared to Asymmetric UC-0

Panel 3: Probabilities of Plucks

Asymmetric UC-UR



Asymmetric UC-0