The Dynamic Relationship Between Permanent and Transitory Components of U.S. Business Cycles

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Abstract

This paper investigates the dynamic relationship between permanent and transitory components of post-war U.S. business cycles. We specify a time-series model for real GNP and consumption in which the two share a common stochastic trend and transitory component, and Markov-regime switching is used to model business cycle phases in these components. The timing of switches between business cycle phases is allowed to differ across the permanent and transitory components. The parameter estimates suggest a specific pattern of recessions: switches in the permanent component lead switches in the transitory component both when entering and leaving recessions.

Key words: Asymmetry, Business Cycle, Markov-Switching, Fluctuations

J.E.L classification: C32, E32

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We estimate a multivariate unobserved-components (UC) model of U.S. real GNP and consumption which, following Kim and Murray (2002), incorporates regime-switching in both the permanent and transitory components. We begin first with our results, and then back up to discuss the underlying model. We uncover a surprising, and very strong, temporal pattern to recessions: the permanent component leads the transitory component both when entering and leaving recessions.

Suppose that the trend of output is a random walk with drift μ_1 when the permanent component is in the recession state (S^P=1) and drift μ_0 when the permanent component is in the expansion state (S^P=0). Suppose analogously that the cyclical component of output switches between recession states (S^T=1) and expansion states (S^T=0). Our most important results are summarized in Table 1, which presents estimates of the transition probabilities for moving from one state to another and can be used to trace out the pattern of S^P and S^T over the business cycle. The first column of Table 1 shows how recessions begin. When the economy is in an expansion ($S^P = 0$ and $S^T = 0$) it tends to stay there (probability = 0.93), but when it finally enters a recession it does so because of a shock to the permanent component. We see in the third column that this situation is most likely to persist for another quarter, but with probability equal to 0.24 a transitory shock will pile on top of the permanent shock. When this happens, the most likely outcome in the next quarter (from the fourth column) is the permanent component switches back to expansion while the transitory component persists in recession.

This summary oversimplifies our results, which we describe with greater care below. But this does give the central, and we think surprising, lesson of the paper: permanent shocks temporally lead transitory shocks in the business cycle.

The decomposition of aggregate measures of output into permanent and transitory components, with the components often used as measurements of "trend" and "cycle", is a primary tool for modern analysis of the business cycle. The UC approach of Harvey (1985) and Clark (1987) is a popular methodology for performing trend/cycle decomposition. The literature applying UC models to measures of economic activity has typically adopted two assumptions. First, linear time-series models such as ARMA processes are used to describe the unobserved components. Second, the permanent and transitory components are assumed to be independent.

Recently, Kim and Murray (2002), using a multivariate framework of monthly economic indicators, extended the UC model to allow for nonlinear dynamics in both the permanent and transitory components.[1] Using Markov-switching techniques, these authors allow for two distinct business cycle phases, expansion and recession, over which the time-series dynamics of the permanent and transitory components differ.[2] However, the assumption of independent unobserved components is maintained. Morley, Nelson and Zivot (2003), working with a linear UC model of real GDP, relax the assumption of independent unobserved components, and document substantial contemporaneous correlation between the shocks to the permanent and transitory components.

The empirical UC model used in this paper incorporates both nonlinear dynamics and dependence between the observed components. Specifically, we specify real GNP and consumption as a cointegrated system with a common, random walk, stochastic trend. The deviation from the common stochastic trend is the transitory component of each series, which is modeled as arising partly from common shocks and partly from shocks idiosyncratic to each

[1] Building on work by Diebold and Rudebusch (1996), Chauvet (1998) and Kim and Yoo (1995) incorporate nonlinear dynamics into the common factor of a multivariate system. However, these authors do not decompose the time series in the system into permanent and transitory components.

series. To capture recession and expansion phases, we allow for regime shifts in the mean growth rate of the common stochastic trend as in Hamilton (1989), and in the mean of the transitory component as in Kim and Nelson (1999a), with separate regime indicator variables used for the two components. We then investigate what dependence might exist, both contemporaneously and at lags, between the regime shifts in the permanent component and regime shifts in the transitory component. We accomplish this by modeling the evolution of the two Markov-switching state variables as driven by a single, four-state Markov-switching process.

Recessions can be usefully characterized by a typical pattern: Recessions begin with a switch to the recession state in the permanent component, characterized by a reduction in the mean growth rate of the common stochastic trend. During most recessions, following the reduction in trend growth rate a corresponding switch to the recession state in the transitory component occurs, characterized by large negative reductions to its level. The effects of the regime shift in the transitory component contribute a bit more to movements in real GNP during recessions than the slowdown in the growth rate of the common stochastic trend. In the majority of recessions, the permanent component then switches back to its expansionary state, in most cases at least one quarter before the transitory component exits the recession state. The recession then ends and the economy gradually asymptotes to its new growth path.

In this paper we are primarily interested in documenting stylized facts regarding the dynamic relationship between permanent and transitory components of the business cycle. However, the result that recessions begin with a switch in the permanent component, rather than a switch in the transitory component, may suggest sources underlying the recessions. In

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[2] The Kim and Murray (2002) model is extended to a cointegrated system in Kim and Piger (2002), which is the framework used in this paper.

particular, permanent and transitory components of business cycles are often interpreted as "trend" and "cycle". To the extent that variation in trend and cycle are due to different sources, such as technology vs. demand shocks, our empirical results may suggest a prominence of one of these sources in triggering recessions.

In the following section we formally present the empirical model. Section 3 reports and interprets the estimation results. Section 4 concludes.

2. Model Specification

2.1 A Time-Series Model of the Business Cycle

Consider the following unobserved-components model of business cycle fluctuations:

$$\begin{bmatrix} y_t \\ c_t \end{bmatrix} = \begin{bmatrix} 0 \\ \alpha \end{bmatrix} + \begin{bmatrix} 1 \\ \gamma_x \end{bmatrix} x_t + \begin{bmatrix} 1 \\ \gamma_z \end{bmatrix} z_t + \begin{bmatrix} e_{y,t} \\ e_{c,t} \end{bmatrix} \tag{1}$$

Here, the log of real GNP (y_t) and the log of real consumption of non-durable goods and services (c_t) are divided into a common stochastic trend x_t, a common transitory component, z_t, and idiosyncratic transitory components $e_{y,t}$ and $e_{c,t}$. This specification is based on simple neoclassical growth models such as that in King, Plosser and Rebelo (1988) suggesting that output and consumption exhibit balanced stochastic growth, that is they are cointegrated with cointegrating vector (1, $-\gamma_x$), where γ_x is equal to one. Here we will estimate γ_x rather than impose this theoretical value. The transitory components, z_t, $e_{y,t}$ and $e_{c,t}$ capture transitory deviations from the shared common stochastic trend, which may arise from a variety of sources such as the propagation of supply-side shocks, as in Kydland and Prescott (1982), or more traditional demand shocks.

We model the common stochastic trend component as in Hamilton (1989):

$$x_t = \mu_1^* S_t^P + \mu_0^* \left(1 - S_t^P\right) + x_{t-1} + v_t \tag{2}$$

where $v_t \sim N(0, \sigma_v^{2*})$, and $S_t^P = \{0,1\}$ indicates the state of the economy for the trend component. Labeling $S_t^P = 1$ as the recession state, the average growth rate of x_t is given by μ_0^* during expansions and μ_1^* during recessions. Thus, the average growth rate of the trend is reduced by the discrete amount $\mu_0^* - \mu_1^*$ during each quarter that $S_t^P = 1$. This reduction in trend leaves output and consumption permanently lower than if the recession had never occurred.

Each series contains two sources of transitory variation. The first is the common transitory component, z_t, which evolves according to the following stationary autoregression:

$$\phi(L) z_t = \varepsilon_t \tag{3}$$

where $\phi(L)$ has all roots outside the unit circle and $\varepsilon_t \sim N(0, \sigma_\varepsilon^{2*})$ is uncorrelated with v_t. The second is the idiosyncratic transitory components, $e_{y,t}$ and $e_{c,t}$. These are assumed to evolve according to a regime-switching, stationary autoregression "plucking model" as in Kim and Nelson (1999a).

$$\begin{aligned} \psi_y(L) e_{y,t} &= \tau_y S_t^T + \omega_{y,t} \\ \psi_c(L) e_{c,t} &= \tau_c S_t^T + \omega_{c,t} \end{aligned} \tag{4}$$

where $\psi_y(L)$ and $\psi_c(L)$ have all roots outside the unit circle and $\omega_{y,t} \sim N(0, \sigma_{\omega_y}^2)$, $\omega_{c,t} \sim N(0, \sigma_{\omega_c}^2)$ are uncorrelated with each other and with ε_t and v_t.

$S_t^T = \{0,1\}$ indicates the state of the economy for the transitory component. Labeling $S_t^T = 1$ as the recession state, $e_{y,t}$ and $e_{c,t}$ are reduced by the discrete amounts, τ_y and τ_c, during each quarter that $S_t^T = 1$.[3] However, when the economy returns to normal times, that is $S_t^T = 0$, the effects of past τ_y and τ_c wear off in accordance with the transitory autoregressive dynamics and the economy reverts back to the stochastic trend. The farther the economy is plucked down, the faster the growth of the economy as it "bounces back" or "peak-reverts" to trend. Note that this sort of pattern is consistent with Friedman's (1964, 1993) "plucking" model of business cycles.[4]

The last 30 years of U.S. macroeconomic data are problematic for the estimation of UC models, as it contains two well documented sources of structural change in the model parameters. First, there is a large literature suggesting that the growth rate of productivity slowed at some point in the postwar sample, with the predominant view that this slowdown roughly coincides with the first OPEC oil shock. For example, Perron (1989) identifies 1973 as the date of a break in the trend growth of U.S. quarterly real GNP. Using multivariate techniques, Bai, Lumsdaine and Stock (1998) find evidence of a reduction in the growth rate of the common stochastic trend shared by real GNP and consumption, dating the break to the late 1960's. To account for this productivity slowdown we allow for a reduction in the average growth rate of trend beginning in 1973.[5] This is accomplished by defining:

$$\begin{aligned} \mu_0^* &= \mu_0 + \mu^k DU1_t \\ \mu_1^* &= \mu_1 + \mu^k DU1_t \end{aligned} \tag{5}$$

[3] Note that the two idiosyncratic components share the same Markov-switching state variable, introducing a source of common dynamics into these "idiosyncratic" components. The model could be modified so that the regime shifts enter the common transitory component instead. We make the former modeling choice to avoid having the loading factor on the common transitory component scale both the variance of shocks to the common transitory component and the size of the effect of the regime shifts.

[4] See also Beaudry and Koop (1993) and Sichel (1994).

[5] Preliminary estimation suggested that if a productivity slowdown is not incorporated the autoregressive dynamics of z_t^y are very persistent. This is consistent with Perron's (1989) finding that unit root tests are biased towards non-rejection if a break in mean growth has occurred and is not allowed. Our results are robust to dating the structural break to the late 1960's, as suggested by Bai, Lumsdaine and Stock (1998).

where $DU1_t$ is 0 before the first quarter of 1973 and 1 thereafter. The second structural change we consider is in the volatility of U.S. real GNP, which has seen a marked reduction in the last 20 years. Kim and Nelson (1999b) and McConnell and Perez-Quiros (2000) both date this break to 1984. To account for this volatility reduction we define:

$$\begin{aligned} \sigma_\varepsilon^* &= \sigma_\varepsilon(1 - DU2_t) + \sigma_\varepsilon^k DU2_t \\ \sigma_v^* &= \sigma_v(1 - DU2_t) + \sigma_v^k DU2_t \end{aligned} \quad (6)$$

where $DU2_t$ is 0 before the first quarter of 1984 and 1 thereafter.[6]

2.2 Modeling the Relationship between Regime Shifts in the Permanent and Transitory Components

In this subsection we discuss the methodology used to allow the timing of regime shifts in the permanent and transitory components to be correlated. Note that each of S_t^P and S_t^T can take on one of two values, 0 or 1, corresponding to expansion or recession. Therefore, S_t^P and S_t^T as a pair can take on one of four different combinations. It will be useful to think in terms of this four combination, or four-state model:

Value of S_t^P	**Value of S_t^T**	**Interpretation**
0	0	Expansion
0	1	Recession State for Transitory Component Only
1	0	Recession State for Permanent Component Only
1	1	Recession State for Both Components

[6] We could also include a structural break in the variances of the shocks to the idiosyncratic components. However, based on a likelihood ratio test, we can not reject the null hypothesis that these variances are stable at the 10% level. By contrast, the structural break in the variances of the shocks to the common trend and transitory components are highly statistically significant.

We assume that the four states above evolve according to a first-order Markov process with the following sixteen transition probabilities:

$$P\left(S_t^P = i, S_t^T = j \mid S_{t-1}^P = k, S_{t-1}^T = q\right),\ i, j, k, q = 0,1 \qquad (7)$$

For particular realizations of S_t^P and S_t^T these can be represented with the notation, $p_{S_t^P S_t^T | S_{t-1}^P S_{t-1}^T}$.

For example, $p_{10|01}$ would correspond to $P(S_t^P = 1, S_t^T = 0 \mid S_{t-1}^P = 0, S_{t-1}^T = 1)$. These transition probabilities are summarized in the following table in which the *m, n'th* element is the probability of moving to the value of S_t^P and S_t^T specified in row *m* given that the values of S_{t-1}^P and S_{t-1}^T were as in column *n*:

	$\left(S_{t-1}^P = 0, S_{t-1}^T = 0\right)$	$\left(S_{t-1}^P = 0, S_{t-1}^T = 1\right)$	$\left(S_{t-1}^P = 1, S_{t-1}^T = 0\right)$	$\left(S_{t-1}^P = 1, S_{t-1}^T = 1\right)$
$\left(S_t^P = 0, S_t^T = 0\right)$	$p_{00\|00}$	$p_{00\|01}$	$p_{00\|10}$	$p_{00\|11}$
$\left(S_t^P = 0, S_t^T = 1\right)$	$p_{01\|00}$	$p_{01\|01}$	$p_{01\|10}$	$p_{01\|11}$
$\left(S_t^P = 1, S_t^T = 0\right)$	$p_{10\|00}$	$p_{10\|01}$	$p_{10\|10}$	$p_{10\|11}$
$\left(S_t^P = 1, S_t^T = 1\right)$	$p_{11\|00} = 1 - p_{00\|00} - p_{01\|00} - p_{10\|00}$	$p_{11\|01} = 1 - p_{00\|01} - p_{01\|01} - p_{10\|01}$	$p_{11\|10} = 1 - p_{00\|10} - p_{01\|10} - p_{10\|10}$	$p_{11\|11} = 1 - p_{00\|11} - p_{01\|11} - p_{10\|11}$

These transition probabilities allow for two kinds of interdependence between S_t^P and S_t^T. The first is that the evolution of S_t^P and S_t^T depends on both S_{t-1}^P and S_{t-1}^T, so that lagged values of both states influence a state's current value. Second, S_t^P and S_t^T are allowed to be contemporaneously correlated conditional on lagged values of the states.

Finally, for comparison purposes we will be interested in a model in which S_t^P and S_t^T are independent, so that the stochastic process for S_t^P and S_t^T can be completely described based on their own lagged values. That is, we estimate transition probabilities of the form:

$$P(S_t^r = w \mid S_{t-1}^r = l),\ r = P,T\ ;\ w,l = 0,1 \qquad (8)$$

Here, there are eight transition probabilities, which can be used to recover the 16 transition probabilities in (7) as follows:

$$P\left(S_t^P = i, S_t^T = j \mid S_{t-1}^P = k, S_{t-1}^T = q\right) = P\left(S_t^P = i \mid S_{t-1}^P = k\right) * P\left(S_t^T = j \mid S_{t-1}^T = q\right) \qquad (9)$$

3. Empirical Results

3.1 Data

The data are quarterly observations on 100 times the logarithm of U.S. real GNP and U.S. real consumption of non-durables and services. The latter series was constructed from total consumption and consumption of durable goods using the Tornqvist approximation to the ideal Fisher index described in Whelan (2000). The data span from the first quarter of 1952 to the second quarter of 2003.

3.2 Evidence on Integration and Cointegration

The model in Section 2 imposes a common stochastic trend in the logarithms of output and consumption. Thus, we are interested in testing for a unit root in each of these series, and for cointegration between the series. Table 2 presents details of such tests. Based on the Augmented Dickey-Fuller (ADF) test developed by Dickey and Fuller (1979) and Said and Dickey (1984), we fail to reject the null hypotheses that the logarithm of real GNP and consumption are integrated at the 10% level. With regards to cointegration, the neoclassical growth theory that motivates the cointegration of the logarithms of real GNP and consumption gives a theoretical cointegrating vector of (1,-1), suggesting the difference between these series will be stationary. In this case, one approach to test for cointegration, advocated by Stock (1994), is simply to apply ADF tests to the difference between the logarithm of real GNP and real consumption of non-durable goods and services. Based on this test, we reject the null hypothesis of no cointegration at the 1% level. This is consistent with the results of other investigations of the cointegration properties of output and consumption, such as King, Plosser, Stock and Watson (1991), Bai, Lumsdaine, and Stock (1998) and Stock and Watson (1999).[7]

3.3 Maximum Likelihood Estimation

The model described in Section 2 is estimated via Kim's (1994) approximate maximum likelihood algorithm. It is well known that maximum likelihood estimation of regime-switching models is plagued by complicated likelihood functions with numerous local maxima. To provide some reassurance of the robustness of our results, we estimated the model with several different sets of starting values. We present results for the estimation in which the lag orders of $\phi(L)$, $\psi_y(L)$ and $\psi_c(L)$ are each set equal to two. This choice was based on likelihood ratio tests suggesting that higher order lags were statistically insignificant.

3.4 The Relationship between Regime Shifts in the Permanent and Transitory Components

In this subsection we describe the estimation results for the model described in Section 2. Throughout the discussion, we have referred to S_t^P and S_t^T as switching between expansion and recession phases. Thus, we are first interested in whether the estimated switches in these state variables match the timing of recessions for the U.S. economy established by the NBER. Figure

[7] Evans and Lewis (1993) show that cointegration tests can be biased in favor of the null hypothesis if a series in the cointegrating equation undergoes Markov regime switching. Since we reject the null hypothesis this does not seem to be a significant problem in this case.

1 shows the filtered probability that either S_t^P or S_t^T is one, given by $P\left(S_t^P = 1 \cup S_t^T = 1 \mid t\right) =$ $P\left(S_t^P = 1, S_t^T = 0 \mid t\right) + P\left(S_t^P = 0, S_t^T = 1 \mid t\right) + P\left(S_t^P = 1, S_t^T = 1 \mid t\right)$, along with shading indicating the NBER recession dates. From the figure, $P\left(S_t^P = 1 \cup S_t^T = 1 \mid t\right)$ spikes up above 50% during every NBER recession and is close to zero during most expansion quarters. Thus, the model is identifying regime shifts related to the NBER business cycle chronology.

How do the model's parameters change from expansion to recession? Table 3 presents the maximum likelihood parameter estimates. The estimates of τ_y and τ_c are -1.2 and -0.7, implying that, when $S_t^T = 1$, the transitory components of GNP and consumption are reduced by 1.2 and 0.7 percent respectively. In the permanent component, μ_1 is estimated to be less than μ_0 by 0.6, suggesting low and high growth phases for the trend component. In sum, these parameter estimates suggest that recessions are characterized by a large reduction in the level of real GNP from what would have obtained had the recession not occurred, and that this reduction has both a permanent and transitory component.

We turn now to an examination of the dynamic relationship between switches in the permanent and transitory component from expansion to recession, that is between S_t^P and S_t^T. Our first task is to evaluate the statistical significance of the correlation between these state variables. From Table 3, the log likelihood for the estimated model is 56.08. We then estimate a restricted version of the model in which S_t^P and S_t^T are independent. Operationally, this is done by enforcing the restrictions detailed in equations (8) and (9). The log likelihood for the restricted model is 46.53, yielding a likelihood ratio test statistic of the null hypothesis that S_t^P

and S_t^T are independent of 19.1. Given the 8 additional parameters in the unrestricted model, this test statistic has a p-value of 0.014.

Given this statistically significant dependence, what is the dynamic relationship between S_t^P and S_t^T that is captured by the model? To begin, Table 1 shows the estimated four-state transition probability matrix, which can be used to trace out a pattern for S_t^P and S_t^T over the business cycle. The first column of Table 1 shows how recessions begin. When the economy was in an expansion last period, that is $S_{t-1}^P = S_{t-1}^T = 0$, the economy tends to stay in the expansion: $S_t^P = S_t^T = 0$ with probability 0.93 ($p_{00|00} = 0.93$). The probability that a recession begins with both the transitory and permanent component switching at the same time ($p_{11|00}$), or just the transitory component switching ($p_{01|00}$), are both estimated to be zero to the third decimal place. Therefore, recessions begin with a switch of the permanent component to its recession state. In other words, recessions begin with a reduction in the average growth rate of the stochastic trend shared by output and consumption.

The third column of Table 1 indicates what happens once this slowdown has begun, that is, when $S_{t-1}^P = 1$ and $S_{t-1}^T = 0$. The transition probabilities indicate that this state has a 58% chance of persisting ($p_{10|10} = 0.58$), while there is 24% chance that the transitory component also switches to its recession state ($p_{11|10} = 0.24$). Finally, there is an 18% chance that the economy moves back into an expansion ($p_{00|10} = 0.18$).

The fourth column of Table 1 describes the chain of events when both the transitory and permanent components have entered the recession state. From the fourth column, this state has a 35% chance of persisting ($p_{11|11} = 0.35$), and has a 27% chance of returning to the state in which only the permanent component is in recession ($p_{10|11} = 0.27$). Finally, there is a 38% chance that the economy switches to the state in which only the transitory component is in the recession state ($p_{01|11} = 0.38$). When this final outcome occurs, column 2 demonstrates that it either persists ($p_{10|10} = 0.67$) or switches to the expansion state ($p_{00|10} = 0.33$).

What does this pattern of the business cycle suggest for the dynamic relationship between S_t^P and S_t^T ? Before characterizing this correlation, it is useful to distinguish between two different types of recessions identified by the transition probabilities in Table 1. In the first, the transitory component never switches into its recession state, and thus there is no relationship between the timing of switches in S_t^P and S_t^T . In the second type of recession, both the permanent and transitory component enters the recession state at some point during the recession. It is this second type of recession that is of interest for investigating the dynamic relationship between S_t^P and S_t^T .

The transition probabilities suggest that in recessions for which both the permanent and transitory components enter their recession state, S_t^P tends to lead S_t^T both when entering and leaving recessions. In the case of the beginning of recessions, this is clear from the transition probabilities in Table 1, which indicate that recessions begin with a shift, by itself, of the permanent component into its recession state. Indeed, there is no other way in which a recession can begin according to the transition probabilities in the first column. The tendency of S_t^P to lead when leaving recessions is less obvious from the transition probabilities in Table 1. To evaluate this, we simulated 1000 recession episodes from the four-state transition probability matrix in Table 1, keeping only those simulations for which both the permanent and transitory components switched to their recession states during the recession. Of 1000 such simulations, the permanent component exited its recession state prior to the transitory component 76% of the time.

3.5 Evidence on the Relative Importance of the Permanent and Transitory Components

The above discussion characterized the correlation between the two recession state variables, S_t^P and S_t^T. In this subsection we use the estimated model to obtain measures of the relative importance of the permanent and transitory components for explaining fluctuations in real GNP.

First, we investigate the relative importance of the regime shifts in the permanent and transitory components for explaining output losses in real GNP during recessions. To do so, we perform a simulation experiment in which 1000 recession episodes are generated from the transition probabilities in Table 1. In the simulation we focus only on those recessions for which both the permanent and transitory components enter their recession state. For each recession episode, three counterfactual GNP series are simulated. The first is based on the estimated parameters from Table 3, with the exception that $\mu_1 = \mu_0$ and $\tau_y = 0$, so that there are no effects of regime shifts in the permanent or transitory components. The second and third simulated GNP series are generated similarly, except that one of either the permanent or transitory component experiences effects from the regime shifts. We then compare the level of real GNP in the last quarter of a recession from the second and third series to that from the first series. This gives the amount of the output loss in the level of real GNP from what it would have been if the recession hadn't occurred that can be attributed to the permanent and transitory component. This simulation experiment suggests that the average output loss resulting from the permanent component during a recession episode is 3.3 percent. Similarly, the average output loss resulting from the transitory component is 3.8 percent, a bit larger than for the permanent component.

This calculation is an average across the historical record of recessions. To analyze the role that the regime shifts in the permanent and transitory components have had in specific recessions, we can view the graphs of the filtered probabilities $P\left(S_t^P = i, S_t^T = j \mid t\right)$ $i, j = 0,1$.

Figure 2 plots the probability that the transitory component has shifted into its recession state, $P(S_t^T = 1 \mid t) = P\left(S_t^P = 0, S_t^T = 1 \mid t\right) + P\left(S_t^P = 1, S_t^T = 1 \mid t\right)$ and the probability that the permanent component has shifted into its recession state, $P(S_t^P = 1 \mid t) = P\left(S_t^P = 1, S_t^T = 0 \mid t\right) +$ $P\left(S_t^P = 1, S_t^T = 1 \mid t\right)$.

Figure 2 demonstrates that both the permanent and transitory component have played a role in most post-war recession, with $P(S_t^P = 1 \mid t)$ and $P(S_t^T = 1 \mid t)$ each rising above 50% in most cases. The two primary exceptions are the 1970 recession, for which neither $P(S_t^P = 1 \mid t)$ nor $P(S_t^T = 1 \mid t)$ rises appreciably above 50%, and the recent 2001 recession, for which only the permanent component appears to enter its recession state.

What is the relative importance of the permanent and transitory components in explaining the variability in real GNP growth? To answer this question, we simulated 1000 real GNP series from the parameter estimates in Table 3 and the transition probabilities in Table 1. We find that the standard deviation of the growth rate of the permanent component, Δx_t, is 0.38, while the standard deviation of the growth rate of the sum of the common and idiosyncratic transitory component, $\Delta(z_t + e_{y,t})$ is 0.79. Thus the transitory component is quite important in explaining overall variability in real GNP.

In sum, the evidence from these various measures suggest that both the permanent and transitory component play a role in explaining fluctuations in real GNP both over the business cycle and during recessions, with the transitory component the more important of the two. Note that this stands in contrast to the evidence presented by Beveridge and Nelson (1981), Nelson and Plosser (1982) and Campbell and Mankiw (1987), who find, using linear time series models, that the majority of output fluctuations in the United States are due to permanent shocks. Instead, our results are consistent with recent studies using nonlinear models to investigate this question, such as Kim and Murray (2002) and Kim and Piger (2002).

3.6 Evidence on the Dynamics of Consumption

Cochrane (1994) and Fama (1992) have both argued that aggregate consumption of non-durable goods and services is close to a random walk process, consistent with the permanent income hypothesis. This, along with the cointegration of consumption and real GNP, suggests that consumption is close to the common stochastic trend shared with real GNP. Are the parameter estimates in Table 3 consistent with this finding? Consistent with the permanent income hypothesis, the loading coefficient on the common transitory component shared with real GNP, γ_z, is small. However, inconsistent with the permanent income hypothesis, τ_c is negative and large in absolute value, suggesting that consumption undergoes substantial transitory shocks during recessions. Also, the variance of idiosyncratic shocks to consumption, given by σ_{ω_c}, is non-zero. Overall, these results suggest that consumption contains an important transitory component, particularly during recessions.

4. Conclusion

In this paper we have investigated the relationship between permanent and transitory components of U.S. recessions in a model that explicitly incorporates business cycle asymmetry. In particular we specify a cointegrated model of real GNP and consumption which separates both series into permanent and transitory components, the dynamics of which are allowed to undergo regime shifts between expansion and recession states. The timing of switches from expansion to recession in the permanent component is allowed to be correlated with those in the transitory component. The parameter estimates suggest a specific pattern of recessions: Switches in the permanent component lead switches in the transitory component both when entering and leaving recessions.

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Table 1: Transition Probability Matrix

	$\left(S_{t-1}^P = 0, S_{t-1}^T = 0\right)$	$\left(S_{t-1}^P = 0, S_{t-1}^T = 1\right)$	$\left(S_{t-1}^P = 1, S_{t-1}^T = 0\right)$	$\left(S_{t-1}^P = 1, S_{t-1}^T = 1\right)$
$\left(S_t^P = 0, S_t^T = 0\right)$	0.93	0.33	0.18	0.00
$\left(S_t^P = 0, S_t^T = 1\right)$	0.00	0.67	0.00	0.38
$\left(S_t^P = 1, S_t^T = 0\right)$	0.07	0.00	0.58	0.27
$\left(S_t^P = 1, S_t^T = 1\right)$	0.00	0.00	0.24	0.35

Table 2: Summary Statistics and Unit Root Tests for Log Real GNP, y_t, and Log Real Consumption of Non-Durables and Services c_t (1952:Q1-2003:Q2)

	Summary Statistics	
	Mean	**Std. Deviation**
100 * Δy_t	0.81	0.97
100 * Δc_t	0.81	0.49

	Augmented Dickey Fuller Tests[8]	
	Dickey Fuller *t*-Statistic	**5% Critical Value**
y_t	-2.43	-3.43
c_t	-1.33	-3.43
$y_t - c_t$	-3.85	-2.88

[8] The Augmented Dickey Fuller equations were estimated with lag length chosen using the BIC, with a maximum of four lags considered. One lag was chosen for each series. Tests for log real GNP and log real consumption of non-durables and services included a time trend and constant in the test regression. Tests for the log GNP / consumption ratio included a constant in the test regression.

Table 3: Maximum Likelihood Estimates
(1952:Q1 – 2003:Q2, Standard Errors in Parentheses)

Parameter	**Estimate**			
$P\left(S_t^P=0,S_t^T=0\mid S_{t-1}^P=0,S_{t-1}^T=0\right)$	0.93 (0.03)			
$P\left(S_t^P=0,S_t^T=1\mid S_{t-1}^P=0,S_{t-1}^T=0\right)$	0.00 (0.00)			
$P\left(S_t^P=1,S_t^T=0\mid S_{t-1}^P=0,S_{t-1}^T=0\right)$	0.07 (0.03)			
$P\left(S_t^P=0,S_t^T=0\mid S_{t-1}^P=0,S_{t-1}^T=1\right)$	0.33 (0.08)			
$P\left(S_t^P=0,S_t^T=1\mid S_{t-1}^P=0,S_{t-1}^T=1\right)$	0.67 (0.09)			
$P\left(S_t^P=1,S_t^T=0\mid S_{t-1}^P=0,S_{t-1}^T=1\right)$	0.00 (0.01)			
$P\left(S_t^P=0,S_t^T=0\mid S_{t-1}^P=1,S_{t-1}^T=0\right)$	0.18 (0.10)			
$P\left(S_t^P=0,S_t^T=1\mid S_{t-1}^P=1,S_{t-1}^T=0\right)$	0.00 (0.02)			
$P\left(S_t^P=1,S_t^T=0\mid S_{t-1}^P=1,S_{t-1}^T=0\right)$	0.58 (0.13)			
$P\left(S_t^P=0,S_t^T=0\mid S_{t-1}^P=1,S_{t-1}^T=1\right)$	0.00 (0.00)			
$P\left(S_t^P=0,S_t^T=1\mid S_{t-1}^P=1,S_{t-1}^T=1\right)$	0.38 (0.21)			
$P\left(S_t^P=1,S_t^T=0\mid S_{t-1}^P=1,S_{t-1}^T=1\right)$	0.27 (0.19)			
$\phi_1,\ \phi_2$	0.78 (0.12)	0.09 (0.13)		
$\psi_{y1},\psi_{y2},\psi_{c1},\psi_{c2}$	1.14 (0.08)	-0.33 (0.04)	0.70 (0.10)	0.13 (0.10)
$\sigma_{\omega_y},\ \sigma_{\omega_c}$	0.22 (0.11)	0.20 (0.04)		
$\sigma_\varepsilon,\ \sigma_\varepsilon^k,\ \sigma_v,\ \sigma_v^k$	0.71 (0.04)	0.33 (0.08)	0.35 (0.09)	0.08 (0.08)
$\tau_y,\ \tau_c$	-1.20 (0.17)	-0.69 (0.10)		
μ_0,μ_1,μ^k	1.09 (0.09)	0.51 (0.09)	-0.25 (0.08)	
$\gamma_x,\ \gamma_z$	0.98 (0.03)	-0.08 (0.08)		
Log Likelihood	56.08			

Figure 1: Filtered Probability that $S_t^P = 1$ or $S_t^T = 1$, $P\left(S_t^P = 1 \cup S_t^T = 1 \mid t\right)$

(1952:Q1 – 2003:Q2, Shaded Areas Indicate NBER Recession Dates)

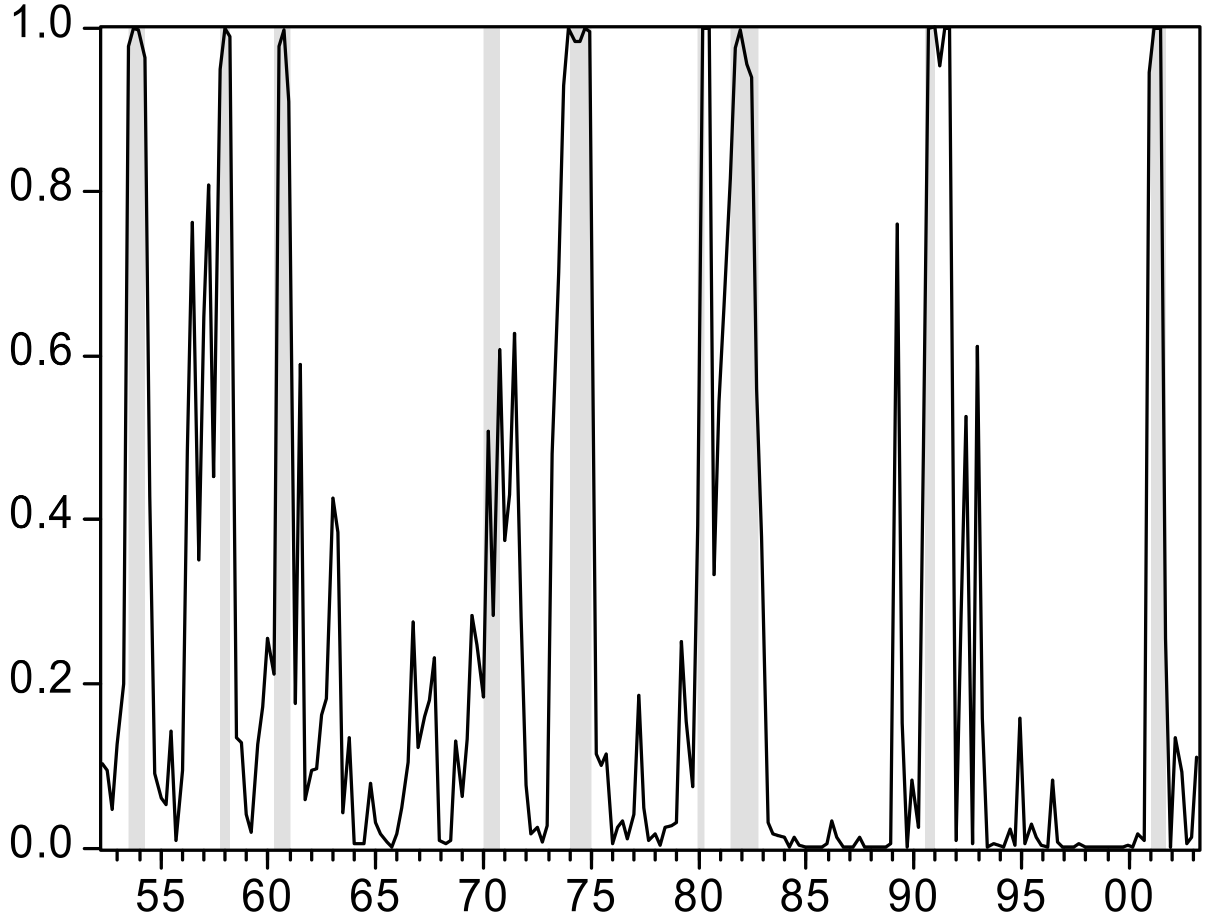
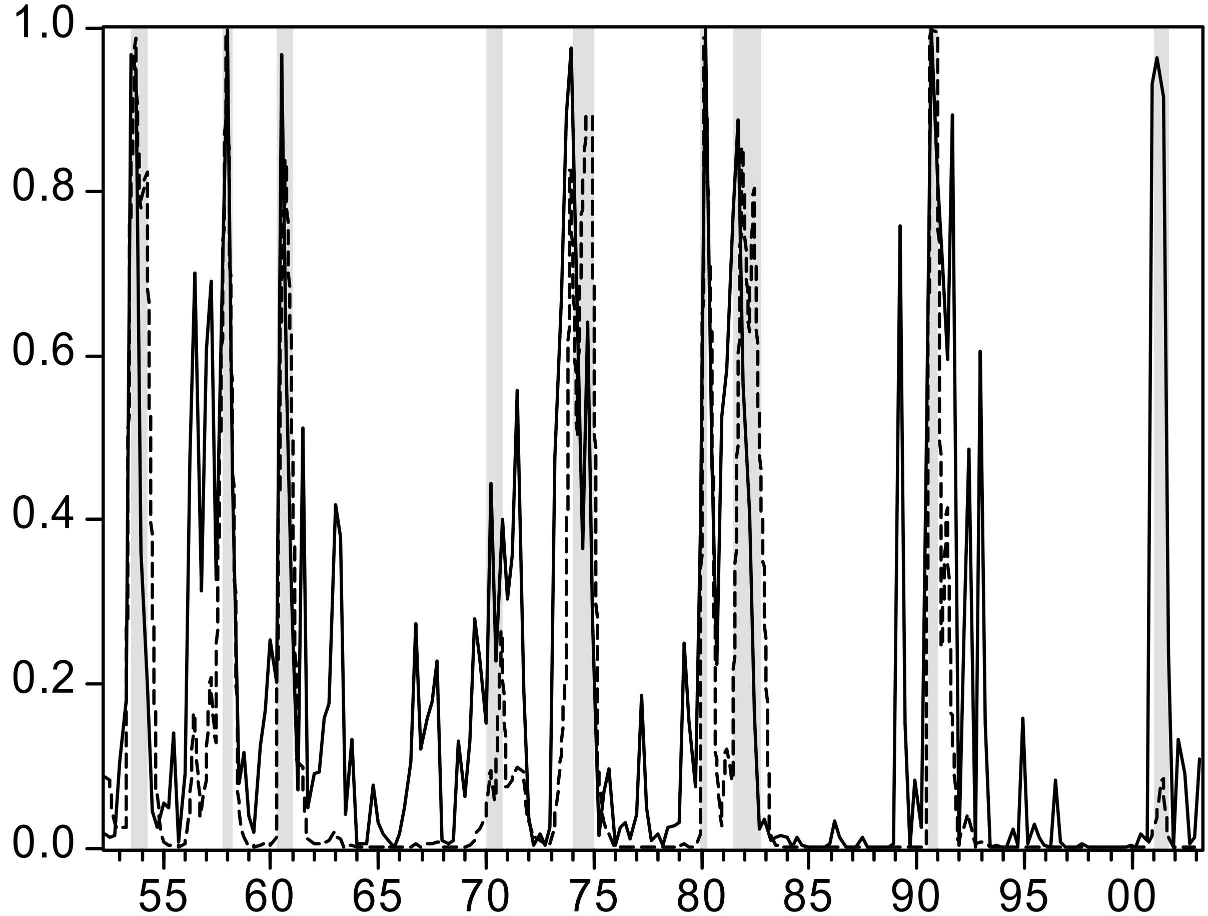


Figure 2: Filtered Probability of Trend Asymmetry $P(S_t^P = 1 | t)$ (solid line) and Transitory Asymmetry $P\left(S_t^T = 1 | t\right)$ (dashed line)

(1952:Q1 – 2003:Q2, Shaded Areas Indicate NBER Recession Dates)



Appendix: State Space Representation

In this appendix we present the state-space representation used for estimation of the model given in equations 1-6. The state-space representation is written for the case where all transitory dynamics are AR(2).

Observation Equation:

$$\begin{bmatrix} \Delta y_t \\ \Delta c_t \end{bmatrix} = \begin{bmatrix} \mu_1^* S_t^P + \mu_0^*(1-S_t^P) \\ \gamma_x(\mu_1^* S_t^P + \mu_0^*(1-S_t^P)) \end{bmatrix} + \begin{bmatrix} 1 & -1 & 1 & -1 & 0 & 0 \\ 1 & -1 & 0 & 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} z_t \\ z_{t-1} \\ e_{y,t} \\ e_{y,t-1} \\ e_{c,t} \\ e_{c,t-1} \end{bmatrix} + \begin{bmatrix} v_t \\ \gamma_x v_t \end{bmatrix}$$

Transition Equation:

$$\begin{bmatrix} z_t \\ z_{t-1} \\ e_{y,t} \\ e_{y,t-1} \\ e_{c,t} \\ e_{c,t-1} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \tau_y S_t^T \\ 0 \\ \tau_c S_t^T \\ 0 \end{bmatrix} + \begin{bmatrix} \phi_1 & \phi_1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \psi_{y,1} & \psi_{y,2} & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \psi_{y,1} & \psi_{y,2} \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} z_{t-1} \\ z_{t-2} \\ e_{y,t-1} \\ e_{y,t-2} \\ e_{c,t-1} \\ e_{c,t-2} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ 0 \\ \omega_{y,t} \\ 0 \\ \omega_{c,t} \\ 0 \end{bmatrix}$$

The covariance matrix of the disturbance vector in the observation equation is given by:

$$E\left(\begin{bmatrix} v_t \\ \gamma_x v_t \end{bmatrix} \begin{bmatrix} v_t & \gamma_x v_t \end{bmatrix} \right) = \begin{bmatrix} 1 & \gamma_x \\ \gamma_x & \gamma_x^2 \end{bmatrix} \sigma_v^{*2}$$

Finally, we have the covariance matrix of the disturbance vector in the transition equation:

$$E\left(\begin{bmatrix} \varepsilon_t \\ 0 \\ \omega_{y,t} \\ 0 \\ \omega_{c,t} \\ 0 \end{bmatrix} \begin{bmatrix} \varepsilon_t & 0 & \omega_{y,t} & 0 & \omega_{c,t} & 0 \end{bmatrix} \right) = \begin{bmatrix} \sigma_\varepsilon^{*2} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sigma_{\omega_y}^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sigma_{\omega_c}^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$