Common Stochastic Trends, Common Cycles, and Asymmetry in Economic Fluctuations

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Abstract

We investigate the nature of asymmetries in U.S. business cycle dynamics using a dynamic two-factor model of output, investment, and consumption that incorporates both the common stochastic trend implied by neoclassical growth theory and a common transitory component. This framework allows for identification of both types of asymmetry commonly identified in the literature: 1. Shifts in the growth rate of the trend component and 2. Transitory deviations below trend, or "plucking". The model also lends itself easily to tests of the marginal significance of each type of asymmetry when the other is allowed to be present. Such tests suggest that both types of asymmetries have played a significant role in post-war recessions, although the nature of shifts in the growth rate of trend is different than the received literature suggests. We also search for a one-time structural break in the long run growth rate of the common stochastic trend (a productivity slowdown) and in the magnitude of the asymmetry parameters. We find evidence of a productivity slowdown and an increase in the relative importance of shifts in the common stochastic trend vs. the "plucking" type of asymmetry. The evidence suggests a gradual structural break which begins in the mid 1960's and is complete by the end of 1973.

Key words: Asymmetry, Common Shocks, Economic Fluctuations, Productivity Slowdown

J.E.L classification: C32, E32

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The question of whether the dynamics of recessions are different from those of expansions has a long history. Early students of the business cycle, including Mitchell (1927), Keynes (1936), and Burns and Mitchell (1946) noted that declines in economic activity take hold quicker, are steeper, and last for a shorter amount of time than expansions. To these observers, recessions appeared to come from a different regime than booms. Recent interest in this type of asymmetry was sparked by Salih Neftci (1984), who presented evidence that increases in the unemployment rate were sharper and shorter than declines.

Since that time, two parametric time-series models of U.S. output were proposed that are capable of capturing steep, short recessions. However, they are fundamentally different in their implications for the effects of recessions on the long run level of output. In other words, the hypothesized persistence of shocks that lead to recessions is very different in the two models. The first model, due to Hamilton (1989), divides the business cycle into two phases, negative trend growth and positive trend growth, with the economy switching back and forth according to a latent state variable. This two phase business cycle implies that following the trough of a recession, output switches back to the normal growth phase, never regaining the ground lost during the downturn. Recessions will therefore have permanent effects. The second model, having its roots in work by Friedman (1964, 1993) and recently formalized in an econometric model by Kim and Nelson (1999b), suggests that recessions are periods where output is temporarily "plucked" downward from a stochastic trend. Following the trough, output enters a high growth recovery phase, returning to the trend. This "bounce-back effect" or "peak-reversion" is the critical phase of Friedman's model. Output then begins a third phase, growing at the slower, trend growth rate. Thus, Friedman's view is that recessions are entirely transitory deviations from trend, not movements in the trend itself.

Both forms of asymmetry have received substantial amounts of attention in the empirical literature, with conflicting conclusions. Using classical likelihood based tests, Hansen (1992) and Garcia (1998) both fail to reject a linear autoregressive model in favor of Hamilton's model for U.S. GNP. Kim and Nelson (1999c) reach a similar conclusion using a test based on Bayesian methods. On the other hand, both Chib (1995) and Koop and Potter (1999) find evidence in favor of Hamilton's model using Bayesian techniques. Support for the peak-reversion implication of Friedman's model is given by Wynne and Balke (1992), Sichel (1993, 19994), and Beaudry and Koop (1993). However, Elwood (1998) argues that the evidence in favor of peak-reversion has been overstated. Specifically, Elwood presents evidence that negative shocks are not significantly less persistent than positive ones. A shortcoming of this empirical literature is that most authors have analyzed the two forms of asymmetry separately form one another. That is, little attention has been paid to evaluating the relative importance of the two forms of asymmetry[1]. An additional shortcoming is the literature's domination by univariate analysis. As pointed out by Kim and Nelson (1999a), tests based on univariate models have low power in detecting a specific form of asymmetry in the business cycle as the data may be obscured by idiosyncratic variation.

In this paper, we present a dynamic two-factor model of real GNP, fixed investment, and consumption that incorporates the common stochastic trend suggested by neoclassical growth theory and a common transitory component. This allows us to capture both the Hamilton and Friedman types of asymmetry through regime switching in the permanent and transitory components respectively. By capturing both types of asymmetry across several indicators, our

[1] An exception is Kim and Murray (1999), who estimate an experimental coincident index of economic activity which incorporates both types of asymmetry discussed above. However, their investigation employs economic indicators that are not cointegrated.

model should provide a more powerful tool for identifying the precise nature of business cycle asymmetry. This method also allows us to test for the presence of one type of asymmetry while the other is allowed to be present. We also consider the possibility of a one-time structural break in the growth rate of the common stochastic trend (a productivity slowdown) and in the relative importance of the Hamilton and Friedman types of asymmetry. We search for the date of this break using a multivariate version of a technique suggested by Kim and Nelson (1999c).

Section 1 of the paper presents a review of the Hamilton and Friedman types of asymmetry in business cycle dynamics. Section 2 discusses the theory supporting a common stochastic trend and a common cyclical component in output, investment and consumption, presents the formal empirical model used in this paper, and discusses the technique used to search for a one-time structural break. Section 3 presents estimation results and statistical tests of the importance of the two types of asymmetry. The results suggest that both have played a statistically significant role in post-war recessions. The investigation of a one-time structural break is suggestive of a productivity slowdown and an increase in the relative importance of the Hamilton type of asymmetry. The dating of the structural break suggests a gradual break which begins in the mid 1960's and is complete by the end of 1973. This is consistent with recent work by Bai, Lumsdaine, and Stock (1998) that suggests the productivity slowdown began in the late 1960's. Section 5 summarizes and concludes.

1. A Review of the Hamilton and Friedman Models

1.1 Hamilton's (1989) Model

In an influential 1989 *Econometrica* paper, James Hamilton proposed a model in which the growth rate of the trend function of U.S. GNP switches between two different states

according to a first order Markov process. Hamilton's results suggest the two states correspond to business cycle dynamics, the first being normal growth and the second recession. Figure 1 contains a stylized graph of a business cycle characterized by Hamilton type asymmetry. Note that following the recession output does not rebound back to its level had the recession not occurred. Instead, because recessions are movements in the trend of the series, output is *permanently* lower. Specifically, Hamilton's results suggest that a typical economic recession is characterized by a 3% permanent drop in the level of GNP. Thus, while the Hamilton model is capable of explaining a business cycle in which recessions are quick, steep drops in economic activity, it also has a dire implication for the welfare effects of recessions.

Evaluation of Hamilton's model is complicated by the fact that standard distribution theory for hypothesis testing does not apply to Markov-switching models. Testing the Markov-switching model vs. linear alternatives is troubled by the familiar Davies problem, in which a nuisance parameter is not identified under the null hypothesis. Hamilton's original paper offers suggestive evidence that the two state Markov-switching model outperforms linear models in terms of forecasts, but no statistical tests. Hansen (1992) and Garcia (1998) use classical likelihood based test procedures designed to deal with the Davies' problem and find that linear autoregressive models cannot be rejected for real GNP. Kim and Nelson (1999a) confirm this result using Bayesian techniques. Also using Bayesian techniques, Chib (1995) and Koop and Potter (1999) find evidence that the Markov-switching model outperforms linear models. Thus, the empirical evidence regarding Hamilton's model is mixed and incomplete.

In a rare example of estimation preceding theory, Hamilton's model has been followed by a growing volume of theoretical work in which the economy undergoes endogenous switching between "good" and "bad" states. Specifically, Howit and McAfee (1992) employ a model of

switching consumer confidence which leads to multiple equilibria with statistical properties well characterized by Markov-switching. In Cooper (1994), agents choose between multiple equilibria and then remain in the chosen equilibrium until a large shock induces a switch. Acemoglu and Scott (1993) and Startz (1998) also employ models in which shocks generate endogenous switching between growth states.

1.2 Friedman's (1964, 1993) "Plucking" Model

Friedman (1964, 1993), argued for a type of business cycle asymmetry that, while yielding steep, sudden recessions, has very different implications for the long run effects of recessions than Hamilton's model[2]. Specifically, the business cycle is posited to have the following three phases: First, recessions are quick *transitory* drops in output away from a stochastic trend function. Next, output rebounds quickly back to the trend – commonly referred to as the high growth recovery phase. Finally, output begins to grow at a slower pace determined by the stochastic trend. Friedman called this the "plucking" model, likening the path of output to a string attached to a board (representing the stochastic trend) which is occasionally "plucked" downward. Figure 2 contains a stylized graph of a business cycle characterized by plucking. In addition to the three phases of the business cycle, notice the production ceiling for output given by the trend. Output is occasionally plucked downward from this trend, implying recessions will be "deeper" relative to trend than expansions are tall.

The literature contains many statistical tests of various implications of Friedman's model. Wynne and Balke (1992) show that the deeper the recession the stronger the ensuing recovery, a result consistent with the "bounce-back" effect in Friedman's hypothesis. Sichel (1993) presents evidence that de-trended industrial production and unemployment exhibit "deepness", while Sichel (1994) presents strong evidence of a three phase business cycle and Goodwin and

Sweeney (1993) find evidence of a production ceiling in international data. Finally, Kim and Nelson (1999b) estimate a formal econometric model of Friedman's hypothesis in which output is occasionally plucked downward by large negative transitory shocks driven by a latent Markov-switching variable. They find strong evidence of both a high growth recovery phase and a production ceiling for U.S. real GDP.

In Friedman's model, recessions have only transitory effects while expansions, being driven by the stochastic trend, are permanent. An implication of this is that negative shocks are less persistent than positive shocks. Beaudry and Koop (1993) showed that a variable measuring the depth of real GNP below its historic high was useful for predicting changes in output. This suggests that declines in GNP are transient, implying the shocks that lead to those declines are less persistent than shocks that lead to increases. Elwood (1998) took issue with Beaudry and Koop's techniques, arguing that by considering only shocks which reduce the level of GNP they ignore a large number of negative shocks that fail to reduce the level of the series. Elwood uses an unobserved components model capable of identifying all negative and positive shocks and finds that negative shocks are not statistically significantly less persistent than positive shocks. This controversy is suggestive of two kinds of negative shocks to the economy, large, asymmetric, recession causing shocks and smaller shocks which come from a symmetric process. Beaudry and Koop's analysis proxies for the large negative shocks by considering only shocks which actually reduce the level of GNP. On the other hand, Elwood's analysis smears the effects of large and small negative shocks together by assuming all negative shocks have the same variance. To effectively evaluate Friedman's model one must allow for both large negative shocks leading to recessions, what Friedman called plucks, and smaller negative shocks. This is the technique used in this paper.

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[2] The behavior described in this paragraph is also consistent with De Long and Summers' (1986) "output gaps".

Theoretical support for the Friedman type of asymmetry in output can be found in models of aggregate supply in which prices are upwardly flexible but downwardly rigid. In these models, positive monetary shocks have no real effects on GNP but are instead simply reflected in prices. However, negative monetary shocks have important real effects, albeit transitory, because prices are slow to adjust downward.[3] This type of asymmetry in price adjustment would also explain "plucking" in fixed investment as well. A negative monetary shock would temporarily raise the real interest rate, making certain irreversible investment less attractive. Firms will temporarily delay these projects, plucking investment down. However, after the economy returns to equilibrium and real interest rates return to normal, there will be a catch-up effect in investment leading to a high growth recover phase. Positive monetary shocks will not have symmetric effects on investment in the other direction as prices are upwardly flexible.

1.3 Do Both Types of Asymmetry Matter?

Empirical work has focused on either the Hamilton or Friedman type of asymmetry separately, a consequence of the prevalence of univariate techniques. However, since the two types of asymmetry both capture the steep, sharp nature of recessions, both might provide improvement over linear models if considered separately. The situation is not unlike that of a classical regression in which a dependent variable, *W*, is linearly determined by an independent variable, X_1, which is correlated with some other variable, X_2. A regression of *W* on X_2 might suggest that X_2 has marginal explanatory value for *W*. Only by considering both explanatory variables simultaneously does one get an accurate sense of the marginal contribution of X_2. The same is true in the context considered here – to determine if both the Hamilton and Friedman

[3] Cover (1992) presents empirical evidence that only negative monetary shocks have real effects on output. Increases in the money supply have only nominal effects.

types of asymmetry are important one must allow the data to exhibit both types of asymmetry in unison. A researcher might find that once the Hamilton type asymmetry is captured, the Friedman type of asymmetry is no longer useful in characterizing economic activity, as in Figure 1. The opposite might also be true, as would be the case in Figure 2. Finally, both types of asymmetry might be important, as in Figure 3. Here, output *partially* recovers what was lost during a recession, implying recession are composed of both drops in trend and transitory deviations from that trend. In the next section, we present a model capable of testing for the marginal significance of each type of asymmetry when the other is present.

2. Model Motivation and Specification

2.1 Common Permanent and Transitory Components - Theory

The concept of trend vs. cycle plays an important role in defining the Hamilton and Friedman types of asymmetry. One advantage of our multivariate model of output, investment and consumption is its natural interpretation of trend provided by neoclassical growth theory. To see this, consider a basic one-sector model of capital accumulation based on that in King, Plosser, and Rebelo (1988). Output is produced by two factors, capital and labor, and is subject to exogenous growth in labor augmenting technology, q_t:

$$Y_t = F(K_t, q_t L_t) \tag{1}$$

Each representative agent in the economy has identical preferences over the consumption of goods, C_t and leisure, R_t given by:

$$U = \sum_{t=0}^{\infty} b^t u(C_t, R_t) \tag{2}$$

where utility is increasing in both consumption and leisure. Finally, the capital accumulation process is:

$$K_{t+1} = (1-d)K_t + I_t \qquad (3)$$

where d is the rate of depreciation on capital and I_t is investment. The economy is also subject to constraints on the amount of time a worker has to allocate between work and leisure and the amount of consumption and investment possible for a given level of output. If a steady state exists in this model it will be one in which the logarithms of output, investment, and consumption grow at a rate determined by labor augmenting technological progress. In the case where there are permanent technology shocks, as is the case if the logarithm of q_t follows a random walk, these three quantities share a stochastic trend[4]. Each series is then individually integrated but can be combined with either of the other two in a linear combination that is stationary. In the terminology of Engle and Granger (1987), the logarithm of output, fixed investment and consumption are cointegrated with cointegrating vectors (1, -1, 0)' and (1, 0, -1)'.

That a common stochastic trend accounts for a large amount of the movement in output, investment, and consumption at growth horizons is perhaps not controversial. However, at business cycle horizons transitory deviations from this stochastic trend are also likely to be important. For example, many real business cycle models, such as Kydland and Prescott (1982), extend the model presented above in ways that allow technology shocks to induce transitory dynamics as the economy moves towards the new steady state. Transitory deviations from a long run stochastic trend might also come from more traditional demand-side nominal shocks. Regardless of whether transitory shocks stem from Walrasian or Keynesian sources however, it

[4] A steady state under random walk productivity growth, called a stochastic steady state, will obtain under restrictions on preferences and production technology, (Cobb-Douglas production is not required). The interested reader is referred to King, Plosser and Rebelo (1988) and King and Rebelo (1987) for details.

is likely that some portion of the shocks will come from sources that are common to output, investment, and consumption. For example, if shocks to the money supply have real, albeit transitory, effects, one would expect that these effects would be pervasive across macroeconomic time series. Likewise, if general productivity shocks induce transitory dynamics, these dynamics should be felt economy-wide. Thus, in addition to the common stochastic trend suggested by neoclassical growth theory, we would also expect common sources of transitory dynamics at business cycle horizons.

2.2 A Dynamic Two-Factor Regime Switching Model

The above discussion is suggestive of a general empirical model in which the logarithms of output, y_t, investment, i_t, and consumption, c_t are influenced by shocks to a common stochastic trend, a common transitory component, and idiosyncratic transitory shocks. The common stochastic trend and common transitory component are captured by two dynamic factors, labeled x_t and z_t[5]:

$$\begin{aligned} y_t &= a_y + g_y x_t + l_y z_t + e_{yt} \\ i_t &= a_i + g_i x_t + l_i z_t + e_{it} \\ c_t &= a_c + g_c x_t \end{aligned} \tag{4}$$

The $e_{jt}, j = y, i$ are stationary residuals that capture idiosyncratic transitory variation in y_t and i_t. g_j and l_j are factor loadings on the common stochastic trend and the common transitory component respectively. For identification, g_y and l_y are normalized to one. Notice that consumption does not share any of the transitory components of the model. The recent literature,

[5] This model is similar to the "common trends" representation suggested by King, Plosser, Stock and Watson (1991). There, the effects of the common and idiosyncratic transitory components above are combined into an I(0) disturbance which may be correlated across indicators. Their empirical analysis employs a VECM framework to investigate the relative importance of the common stochastic trend in real GNP, fixed investment, and consumption. While a VECM lends itself easily to impulse analysis, incorporation of asymmetry is difficult. Identification of asymmetry in a dynamic factor model is natural, motivating our choice of empirical model.

for example Fama (1992) and Cochrane (1994), suggest that while consumption does seem to contain a statistically significant transitory component, it is so small as to be economically insignificant. Based on this result, Fama (1992) chooses to define consumption as the common stochastic trend in output, investment, and consumption. Up to the scale factor g_c consumption will proxy for the common stochastic trend in our system as well.

We are now ready to discuss how the two types of asymmetry are incorporated in the model. We begin with the Hamilton type asymmetry, which we incorporate as in Hamilton (1989). Recall, the Hamilton type asymmetry involves shifts in the growth rate of the trend function between two different states. Thus, we allow the common stochastic trend, x_t, to follow a random walk with a switching drift term:

$$x_t = m_1^* S_t + m_0^* + x_{t-1} + v_t \tag{5}$$

where $v_t \sim N(0, s_{vt}^2)$, $s_{vt}^2 = s_{v1}^2 S_t + s_{v0}^2 (1 - S_t)$ and $S_t = \{0,1\}$ indicates the state of the economy. We assume that S_t is driven by a first order Markov process with transition probabilities given by:

$$\begin{aligned} P(S_t = 1 \mid S_{t-1} = 1) &= p_{11} \\ P(S_t = 0 \mid S_{t-1} = 0) &= p_{00} \end{aligned} \tag{6}$$

To incorporate the Friedman type asymmetry we allow the idiosyncratic transitory component of output and investment to undergo regime switching as in Kim and Nelson (1999b)[6]. Formally:

$$y_j(L) e_{jt} = e_{jt} + t_j^* S_t, \; j = y, i \tag{7}$$

[6] The "plucking" parameter is incorporated in the idiosyncratic transitory component of output and investment, instead of in the common transitory component, to allow for the possibility that the magnitude of the pluck might be different across economic series. However, in interpreting the model the plucks are better characterized as common shocks because they are driven by the same state variable. In other words, when output is plucked down, so is investment.

where $e_{jt} \sim N(0, s_{ej}^2)$, $y_j(L)$ has all roots outside the unit circle, and $t_j^* < 0$ is a term which "plucks" output and investment down when $S_t = 1$. When the economy returns to normal times 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" to trend.

To complete the model we must specify the dynamics of the common transitory component z_t:

$$f(L)z_t = w_t \tag{8}$$

where $w_t \sim N(0, s_{wt}^2)$, $s_{wt}^2 = s_{w1}^2 S_t + s_{w0}^2 (1 - S_t)$ and $f(L)$ is a lag polynomial with roots that lie outside the unit circle. For identification purposes we assume that v_t, w_t, e_{yt}, and e_{it} are uncorrelated at all leads and lags.

A comment regarding hypothesis testing in this model is in order. Notice that the regime switching in the Hamilton and Friedman types of asymmetry are driven by the same state variable, S_t. This is an important assumption, as it allows us to test the null hypothesis that one type of asymmetry is marginally statistically insignificant when the other is present. If the two types of asymmetry were driven by separate state variables, testing this null hypothesis would be complicated by the familiar Davies problem, or the fact that one set of Markov-switching parameters would be unidentified under the null hypothesis. The Davies problem is avoided by the assumption that a single state variable drives both forms of asymmetries.

2.3 Searching for a One Time Permanent Structural Break

There is a large literature suggesting that the growth rate of productivity has slowed at some point in the postwar sample, with the predominant view being 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[7]. In a recent paper, Bai, Lumsdaine and Stock (1998) find evidence in favor of a productivity slowdown beginning somewhere between 1966 and 1971. Their work is particularly relevant here because they employ a multivariate model of quarterly real GNP, fixed investment, and consumption to test for and date a break in the growth rate of the common stochastic trend. Here, we will also search for a break in the growth rate of the stochastic trend, m_0^*[8]. However, we do so in a model which allows for asymmetries in the business cycle. In addition, we search for a one time structural break in the relative importance of the Hamilton and Friedman types of asymmetry, that is changes in the magnitudes of m_1^*, t_y^*, and t_i^*.

We endogenously estimate the date of the structural break using a technique due to Kim and Nelson (1999c)[9]. This method consists of defining a separate state variable, D_t, which also undergoes regime switching according to a first order Markov process independent of that for S_t. However, we restrict the switching to occur only from $D_t = 0$ to $D_t = 1$ and not in the opposite direction. This is accomplished by a restriction on the transition probabilities of the Markov process:

$$\begin{aligned} &P(D_t = 1 \mid D_{t-1} = 1) = 1 \\ &P(D_t = 0 \mid D_{t-1} = 0) = q_{00} \end{aligned} \tag{9}$$

To investigate any change in the long run growth rate of the stochastic trend and the relative importance of the asymmetry parameters we then define $m_0^*, m_1^*, t_y^*, t_i^*$ as follows:

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[7] Preliminary estimation of our model suggested that if a productivity slowdown is not incorporated the autoregressive dynamics of e_{yt}, e_{it}, and z_t 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 is not accounted for.

[8] In preliminary estimation we also searched for a break in the variance of output as in Kim and Nelson (1999c). Allowing for such a break did not change the results regarding the nature of business cycle asymmetry substantively.

[9] Kim and Nelson (1999c) use Bayesian techniques to estimate the date of the break. Here we use classical likelihood based methods.

$$m_0^* = m_0 (1 - D_t) + m_0^k D_t \tag{10}$$

$$m_1^* = m_1 (1 - D_t) + m_1^k D_t \tag{11}$$

$$t_y^* = t_y (1 - D_t) + t_y^k D_t \tag{12}$$

$$t_i^* = t_i (1 - D_t) + t_i^k D_t \tag{13}$$

3. Estimation Results

3.1 A Look at the Data

The data used are quarterly observations on the logarithm of U.S. private GNP, or GNP less government expenditures, (GNPQ-GGEQ), U.S. gross private domestic business fixed investment, (GIF), and U.S. real consumption on non-durables and services, (GCNQ+GCSQ). All data was obtained from the DRI Basics Economic database and span from the first quarter of 1952 to the third quarter of 1998. DRI mnemonics appear in parentheses in the preceding.

The model presented in Section 3 imposes a common stochastic trend in the logarithms of output, investment and consumption. Thus, we are interested in the empirical evidence regarding the integration and cointegration properties of the data. First of all, using standard univariate unit root tests developed by Dickey and Fuller (1979), we fail to reject the null hypothesis that the logarithm of GNP, fixed investment, and consumption are integrated[10][11]. Table 2 contains results of Johansen (1991, 1995) cointegration tests performed with 6 lags in levels. The tests indicate that the null hypothesis of no cointegrating vectors is rejected at the 1% level, while the null

[10] The details and results of the ADF tests, which are familiar from the received literature, are omitted. The results of these tests are available from the authors.

[11] Given that our model assumes structural change in the data, it might seem reasonable to consider unit root tests that are robust to a specific number of structural breaks such as those suggested by Perron (1994). However, results presented by Nelson, Piger, and Zivot (1999) suggest that these tests do not provide substantial increases in power over the ADF test when data undergoes Markov regime switching.

hypothesis of at most 1 cointegrating vector is rejected at the 5% level. The null hypothesis of at most 2 cointegrating vectors is not rejected, suggesting there are 2 cointegrating relationships and therefore a single common stochastic trend in the system. This is consistent with the results of other investigations of the cointegration properties of output, investment, and consumption, such as King, Plosser, Stock and Watson (1991) and Bai, Lumsdaine, and Stock (1998).

3.2 Estimation Results and Hypothesis Tests

We estimate three versions of the model given above. Model 1 is our benchmark model with no further restrictions. Model 2 is a version that does not allow for the "plucking" type asymmetry, that is $t_y = t_y^k = t_i = t_i^k = 0$. Model 3 does not allow for switches in the growth rate of the stochastic trend, that is $m_1 = m_1^k = 0$. All models are estimated via Kim's (1993a, 1993b, 1994) approximate maximum likelihood algorithm. Table 1 contains the estimated parameters and standard errors for Models 1-3[12]. Our discussion will focus on model 1, the benchmark model. The other models will be of primary interest in performing hypothesis tests regarding the presence of asymmetry.

In the preceding discussion, asymmetry was defined as differences in the dynamics of a macroeconomic time series during recessions vs. expansions. In our model, the dynamics change when the state variable $S_t = 1$. Thus, we are interested in whether the estimated filtered and smoothed probabilities that $S_t = 1$, $P(S_t = 1)$, coincides with the timing of recessions for the U.S. economy. Figures 4 and 5 show these probabilities along with the NBER recession dating. During every recession $P(S_t = 1)$ spikes up above 50%, but is essentially zero during expansions. Thus, our model is identifying recessions as periods where output, investment, and consumption undergo changes in dynamics.

Next, we move to the topic of main interest in this paper, the relative importance of the Hamilton and Friedman types of asymmetries. We begin with the Hamilton type of asymmetry, shifts in the common stochastic trend. The estimation results suggest that the common stochastic trend appears to be well characterized by regime switching in its growth rate. The parameters m_1 and m_1^k are large in absolute value suggesting two distinct growth states in the common stochastic trend. By comparing Models 1 and 3 we are able to perform a likelihood ratio test of the null hypothesis that $m_1 = m_i^k = 0$. In other words, we test the null hypothesis that the Hamilton type asymmetry is unimportant once the Friedman type asymmetry is accounted for. This null hypothesis is rejected at any reasonable significance level with a p-value of .001.

While the Hamilton type asymmetry does seem to play a significant role in the data, the parameter estimates for m_0, m_0^k, m_1, m_1^k are suggestive of a different type of switching than that found by Hamilton (1989). In Hamilton's original paper, as well as in much subsequent work, the growth rate of the stochastic trend is positive during booms and negative during recessions. Here, once the Friedman type asymmetry is accounted for, the growth rate of the stochastic trend simply slows during recessions. For example, the growth rate during booms when $D_t = 0$ is 1.10 while it is 0.88 when $D_t = 1$. The growth rates during recessions are 1.10 - .36 = 0.74 when $D_t = 0$ and 0.88 - 0.51 = 0.37 when $D_t = 1$. In the framework of the growth model presented in section 2 recessions are periods of slowdown in the rate of growth of total factor productivity. Thus, our model is not indicative of an economy with negative permanent shocks large enough to lower the *level* of the common stochastic trend.

[12] After various diagnostic checks, we settled on an AR(2) representation for all transitory dynamics.

Before leaving the behavior of the common stochastic trend we should discuss the estimate of the two cointegrating vectors in the system. Recall, the theoretical cointegrating vectors for y_t, i_t, c_t are (1, -1, 0)' and (1, 0,-1)'. From Table 1 we see that the estimated cointegrating vectors are (1, -1.06, 0)' and (1, 0, -.95)' which are very close to those suggested by theory. The fact that g_c is less than unity is consistent with the fact that the ratio of consumption of non-durables and services to private GNP drifted down approximately 10% over the sample. However, as pointed out by Bai, Lumsdaine and Stock, the ratio of total consumption to GNP has drifted up over the sample. This suggests a rise in the share of consumption allocated to durables.

Now we consider the other type of asymmetry discussed above, transitory deviations of output below a common stochastic trend. Such "plucking" behavior is also well supported by the parameter estimates. The null hypothesis that $t_y = t_y^k = t_i = t_i^k = 0$, performed by comparing the log-likelihood from models 1 and 2, is rejected with a p-value equal to zero to 3 decimal places. Thus, there is strong evidence that, even after accounting for switching in trend growth rate, there is a "bounce-back" effect in real GNP and fixed investment. These transitory deviations are driven by large negative shocks, or plucks. However, there also appears to be a role for symmetric shocks. The variances of the symmetric shocks in the common transitory component and the idiosyncratic components are both large and statistically significant at the 1% level using Wald tests. This suggests there are periods where output and investment are above the common stochastic trend.

The parameter estimates are suggestive of a one-time structural break in the long run growth rate of the common stochastic trend and the relative importance of the Hamilton vs. Friedman types of asymmetry. Our estimation results suggest a productivity slowdown – the

estimate of m_0^* is 1.11 when $D_t = 0$ vs. 0.88 when $D_t = 1$. The two types of asymmetry have also undergone changes in their relative importance. The Hamilton type asymmetry has become more important, with the point estimate of m_1^k 1.4 times that of m_1. The dramatic change however, is in the relative importance of the Friedman type asymmetry. For output, t_y is large and highly significant using a Wald test. However, the point estimate of t_y^k is essentially zero, suggesting that the Friedman type asymmetry in output is less important for recessions after the structural break. Similarly, the Friedman type asymmetry is less important for investment, with t_i^k half that of t_i. Thus, it appears that the Hamilton type asymmetry, driven by shifts in the common stochastic trend, has become more important over the sample relative to the Friedman type asymmetry.

The estimated date of the structural break can be seen graphically in Figures 6 and 7 which present the filtered and smoothed probabilities that $D_t = 1$. Both graphs suggest that the structural break was complete by the first quarter of 1974. However, the results are suggestive of a gradual structural break which began in the mid 1960's. This is consistent with recent work by Bai, Lumsdaine, and Stock (1998), who, using a model of real GNP, investment, and consumption, identify 1966 - 1971 as the confidence interval for the date of a break in the growth rate of the common stochastic trend.

Our model also can comment on the relative responsiveness of fixed investment and real GNP to transitory shocks. In this sample the standard deviation of growth rates of fixed investment is 2.5, nearly twice that of output. Given that fixed investment and GNP have almost identical responses to the common stochastic trend, this increased variability can only come from an increased responsiveness to symmetric common transitory shocks, $l_i > l_y = 1$, relatively

larger symmetric idiosyncratic shocks, $s_{ei}^2 > s_{ey}^2$, or relatively larger "plucks", $t_i > t_y$ and $t_i^k > t_y^k$. The parameter estimates provide evidence for all three explanations. Fixed investment is 2.4 times as responsive to symmetric common transitory shocks as GNP. Also, the variance of idiosyncratic symmetric shocks are roughly twice as big for investment relative to GNP. Finally, plucks in investment were slightly larger than those for GNP before 1974 and much larger after 1974.

Figures 8 and 9 display the implications of the above discussion graphically. Figure 8 contains real GNP and its permanent component while Figure 9 contains business fixed investment and its permanent component. The effects of the transitory type asymmetry are clear in the graph. The majority of deviations of GNP and investment from the stochastic trend are downwards, and are characterized by quick rebounds to the stochastic trend. For real GNP the graph confirms that this type of asymmetry was more important for the recessions before 1974. After 1974 the existence of "plucks" is less clear, as GNP seems to track its stochastic trend fairly closely, with deviations failing to display clear asymmetric behavior. For fixed investment, "plucking" type behavior is evident over the entire sample. There are also periods where output and investment are above the stochastic trend, although these periods are not common. Thus, despite the parameter estimates indicating the importance of symmetric transitory shocks, there is still graphical evidence of a production ceiling.

4. Summary and Conclusion

Many recent papers have presented evidence regarding two types of business cycle asymmetry, shifts in a stochastic trend which have permanent effects on the level of output, and transitory "plucks" downward away from a stochastic trend. We have presented a model to

investigate the relative importance of these two types of shocks which improves on the existing literature in two main ways: 1) it is a multivariate model of real GNP, fixed investment and consumption which allows us to consider both types of asymmetry in unison and 2) it allows for tests of the statistical significance of each type of asymmetry when the other is allowed to be present. Hypothesis tests suggest that both types of asymmetry played a role in postwar recessions. We also search for a structural break in the growth rate of the common stochastic trend and in the relative importance of the two types of asymmetry. This search yields evidence of a productivity slowdown and an increase in the relative importance of shifts in the common stochastic trend vs. the "plucking" type of asymmetry. The evidence suggests a gradual structural break which begins in the mid 1960's and is complete by the end of 1973.

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Appendix

State Space Representation

In this section of the appendix we present the state-space representation of the model given by equations 4-13 for the case where all transitory dynamics are AR(2).

Observation Equation:

$$\begin{bmatrix} Dy_t \\ Di_t \\ Dc_t \end{bmatrix} = \begin{bmatrix} g_y * (m_1^* S_t + m_0^*) \\ g_i * (m_1^* S_t + m_0^*) \\ g_c * (m_1^* S_t + m_0^*) \end{bmatrix} + \begin{bmatrix} l_y & -l_y & 1 & 0 & -1 & 0 \\ l_i & -l_i & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} z_t \\ z_{t-1} \\ e_{yt} \\ e_{it} \\ e_{yt-1} \\ e_{it-1} \end{bmatrix} + \begin{bmatrix} g_y * (v_t) \\ g_i * (v_t) \\ g_c * (v_t) \end{bmatrix}$$

Transition Equation:

$$\begin{bmatrix} z_t \\ z_{t-1} \\ e_{yt} \\ e_{it} \\ e_{yt-1} \\ e_{it-1} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ t_y^* * S_t \\ t_i^* * S_t \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} f_1 & f_2 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & y_{y1} & 0 & y_{y2} & 0 \\ 0 & 0 & 0 & y_{y1} & 0 & y_{y2} \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} * \begin{bmatrix} z_{t-1} \\ z_{t-2} \\ e_{yt-1} \\ e_{it-1} \\ e_{yt-2} \\ e_{it-2} \end{bmatrix} + \begin{bmatrix} w_t \\ 0 \\ e_{yt} \\ e_{it} \\ 0 \\ 0 \end{bmatrix}$$

where, $m_0^*, m_1^*, t_y^*, t_i^*$ are defined in equation 10-13. The covariance matrix of the disturbance vector in the observation equation is given by:

$$E\left(\begin{bmatrix} g_y * (v_t) \\ g_i * (v_t) \\ g_c * (v_t) \end{bmatrix} * \begin{bmatrix} g_y * (v_t) & g_i * (v_t) & g_c * (v_t) \end{bmatrix} \right) = \begin{bmatrix} g_y^2 * s_{vt}^2 & g_y * g_i * s_{vt}^2 & g_y * g_c * s_{vt}^2 \\ g_i * g_y * s_{vt}^2 & g_i^2 * s_{vt}^2 & g_i * g_c * s_{vt}^2 \\ g_c * g_y * s_{vt}^2 & g_c * g_i * s_{vt}^2 & g_i^2 * s_{vt}^2 \end{bmatrix}$$

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

$$E\left(\begin{bmatrix} w_t \\ 0 \\ e_{yt} \\ e_{it} \\ 0 \\ 0 \end{bmatrix} * \begin{bmatrix} w_t & 0 & e_{yt} & e_{it} & 0 & 0 \end{bmatrix} \right) = \begin{bmatrix} s_{wt}^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & s_{ey}^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{ei}^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Table 1: Maximum Likelihood Estimates of Models 1 – 4
Quarterly data from 1952:1 – 1998:3
(Standard Errors in Parentheses)

Parameter	Model 1			Model 2			Model 3		
g_y, g_i, g_c	1*	1.06	0.95	1*	1.09	0.93	1*	1.05	0.95
		(0.02)	(0.01)		(0.06)	(0.01)		(0.03)	(0.01)
l_y, l_i	1*	2.40		1*	2.05		1*	2.48	
	---	(0.28)		---	(0.21)		---	(0.43)	
s_{v0}, s_{v1}	0.39	0.58		0.35	0.61		0.40	0.81	
	(0.03)	(0.06)		(0.03)	(0.06)		(0.03)	(0.12)	
s_{w0}, s_{w1}	0.56	0.80		0.42	1.10		0.56	0.69	
	(0.07)	(0.14)		(0.09)	(0.15)		(0.08)	(0.21)	
s_y, s_i	0.54	1.09		0.47	1.31		0.58	1.07	
	(0.07)	(0.15)		(0.08)	(0.13)		(0.09)	(0.19)	
f_1, f_2	1.39	-0.48		1.33	-0.44		1.40	-0.49	
	(0.07)	(0.05)		(0.07)	(0.05)		(0.08)	(0.06)	
y_{y1}, y_{y2}	0.47	0.31		0.06	0.00		0.52	0.27	
	(0.09)	(0.09)		(0.21)	(0.01)		(0.10)	(0.10)	
y_{i1}, y_{i2}	0.95	-0.05		1.19	-0.22		0.95	-.05	
	(0.10)	(0.10)		(0.11)	(0.11)		(0.10)	(0.09)	
m_0, m_0^k	1.10	0.88		1.09	0.84		1.06	0.75	
	(0.05)	(0.06)		(0.10)	(0.05)		(0.05)	(0.05)	
m_1, m_1^k	-0.36	-0.51		-0.15	-0.52		---	---	
	(0.17)	(0.13)		(0.19)	(0.18)				
t_y, t_y^k	-2.82	-0.03		---	---		-2.62	-0.92	
	(0.36)	(0.72)					(0.37)	(0.64)	
t_i, t_i^k	-3.18	-1.72		---	---		-3.06	-3.48	
	(0.38)	(0.58)					(0.68)	(1.43)	
p_{00}, p_{11}	0.93	0.80		0.91	0.89		0.93	0.64	
	(0.03)	(0.07)		(0.04)	(0.07)		(0.03)	(0.11)	
q_{00}	0.99			0.99			0.99		
	(0.01)			(0.01)			(0.01)		
Log Likelihood	-209.15			-220.96			-216.14		

* Normalized to unity for identification.

Table 2: Johansen (1991, 1995) Cointegration Tests
Quarterly data from 1952:1 – 1998:3

Null Hypothesis	Test Statistic[13]	5% Critical Value	1% Critical Value
No Cointegrating Vectors	36.51[++]	29.68	35.65
At Most One Cointegrating Vector	16.95[+]	15.41	20.04
At Most Two Cointegrating Vectors	2.44	3.76	6.65

[13] The test statistic is the Likelihood Ratio statistic discussed in Johansen (1991, 1995) and calculated in Eviews using a levels lag order of 6. As in King, Plosser, Stock and Watson (1991), we assume that each series has a linear trend but the cointegrating equation has only intercepts.
[++] Rejected at the 1% significance level.
[+] Rejected at the 5% significance level.

Figure 1:
A Recession With Only Hamilton Type Asymmetry
(Solid lines indicate trend, dashed lines indicate deviations from trend)

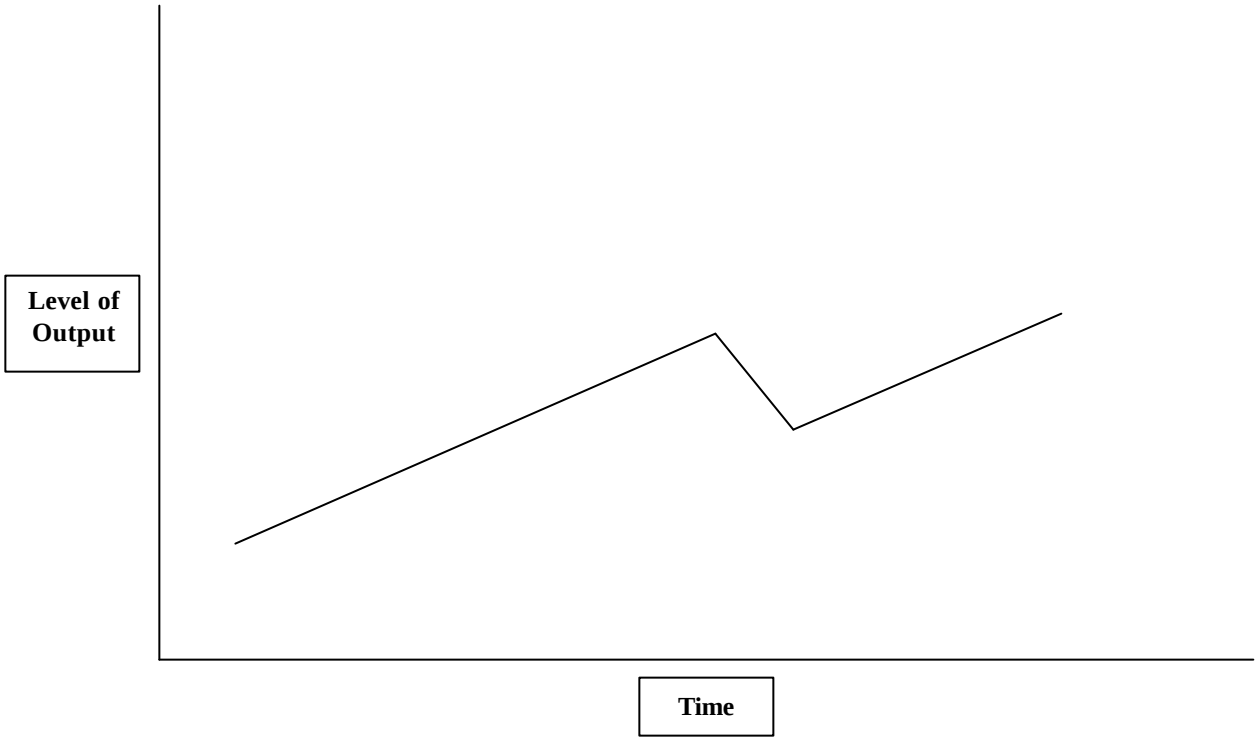

Figure 2:
A Recession With Only "Plucking" Type Asymmetry
(Solid lines indicate trend, dashed lines indicate deviations from trend)

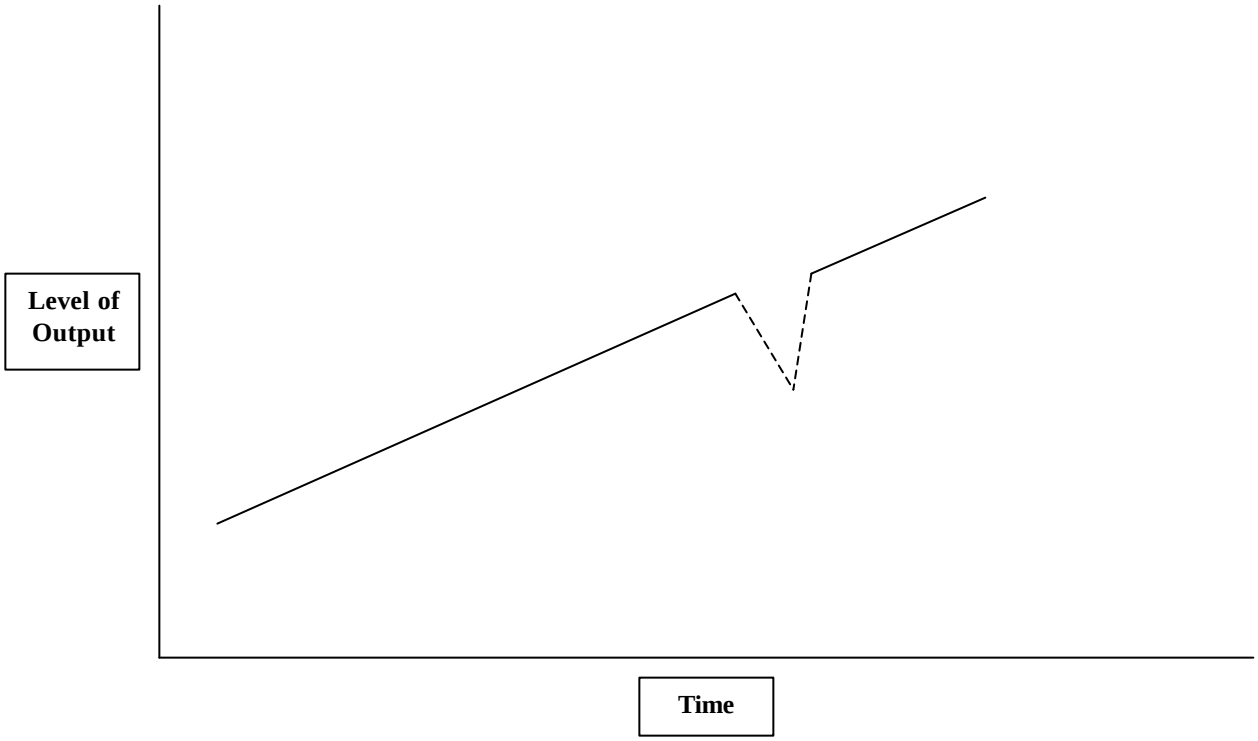

Figure 3:
A Recession with Both Hamilton and "Plucking" Types of Asymmetry
(Solid lines indicate trend, dashed lines indicate deviations from trend)

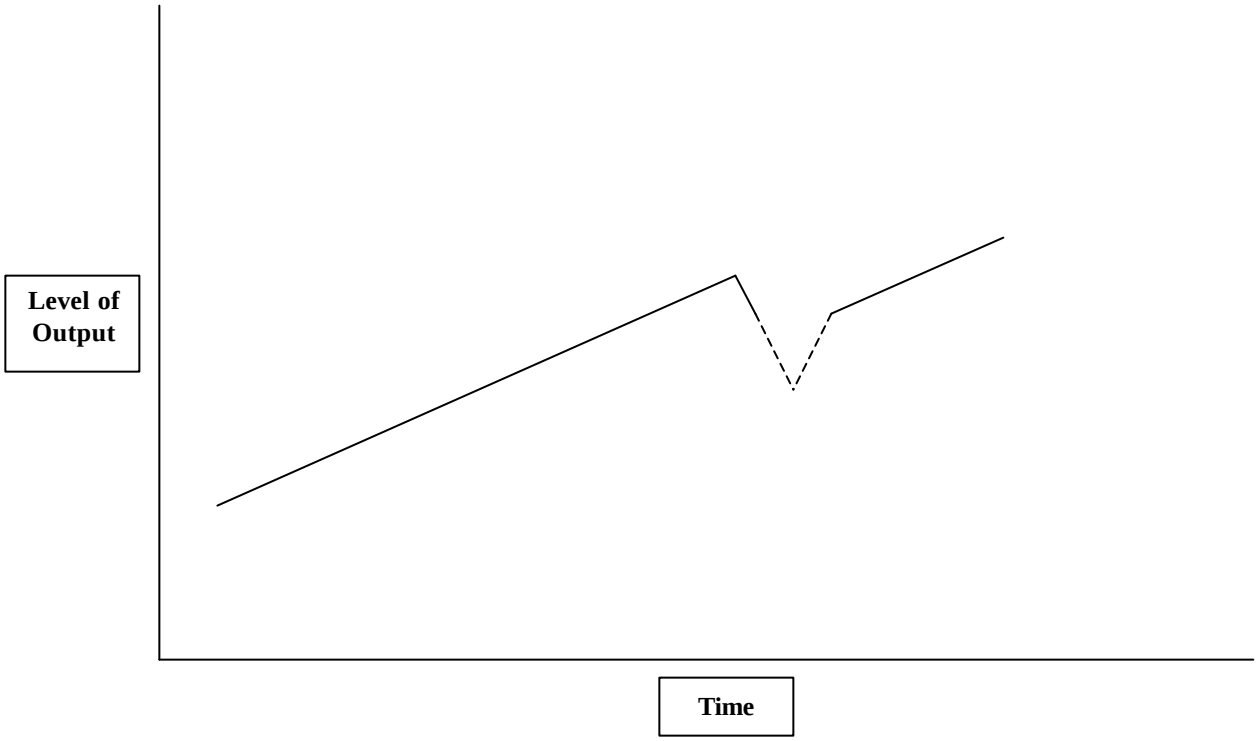

Figure 4: Filtered Probability that $S_t = 1$

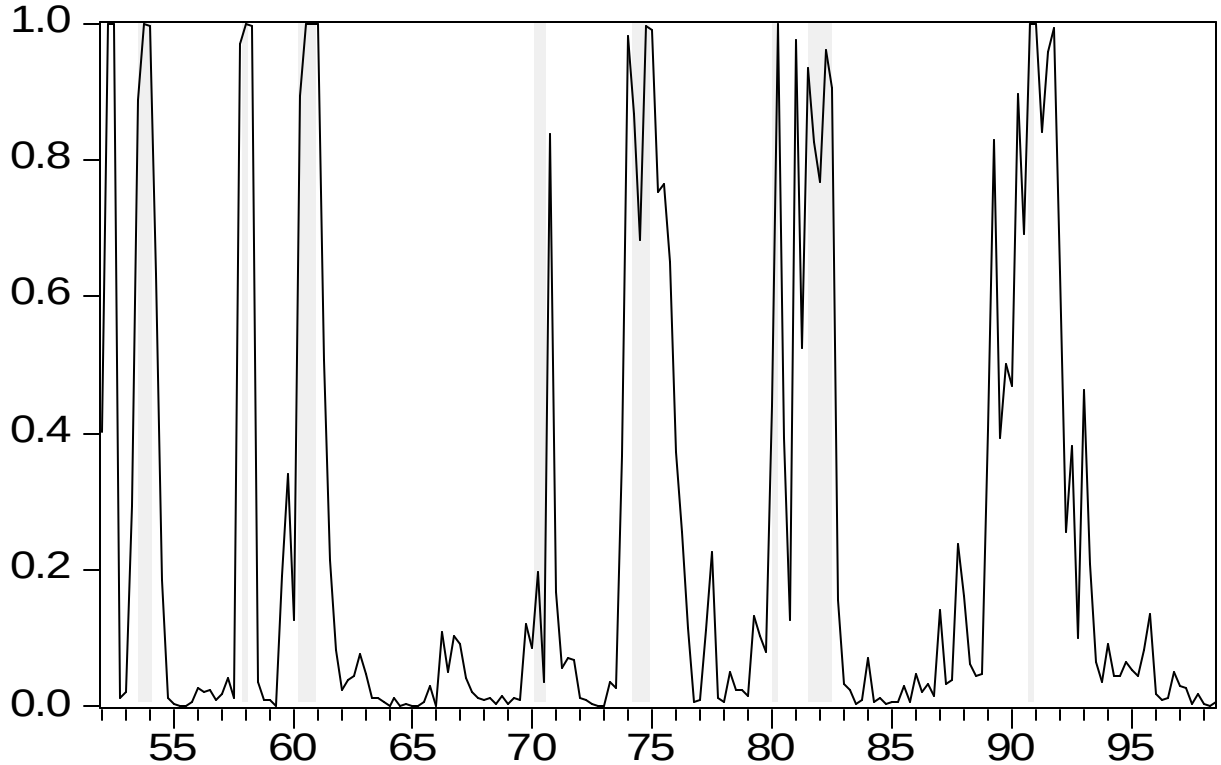

Figure 5: Smoothed Probability that $S_t = 1$

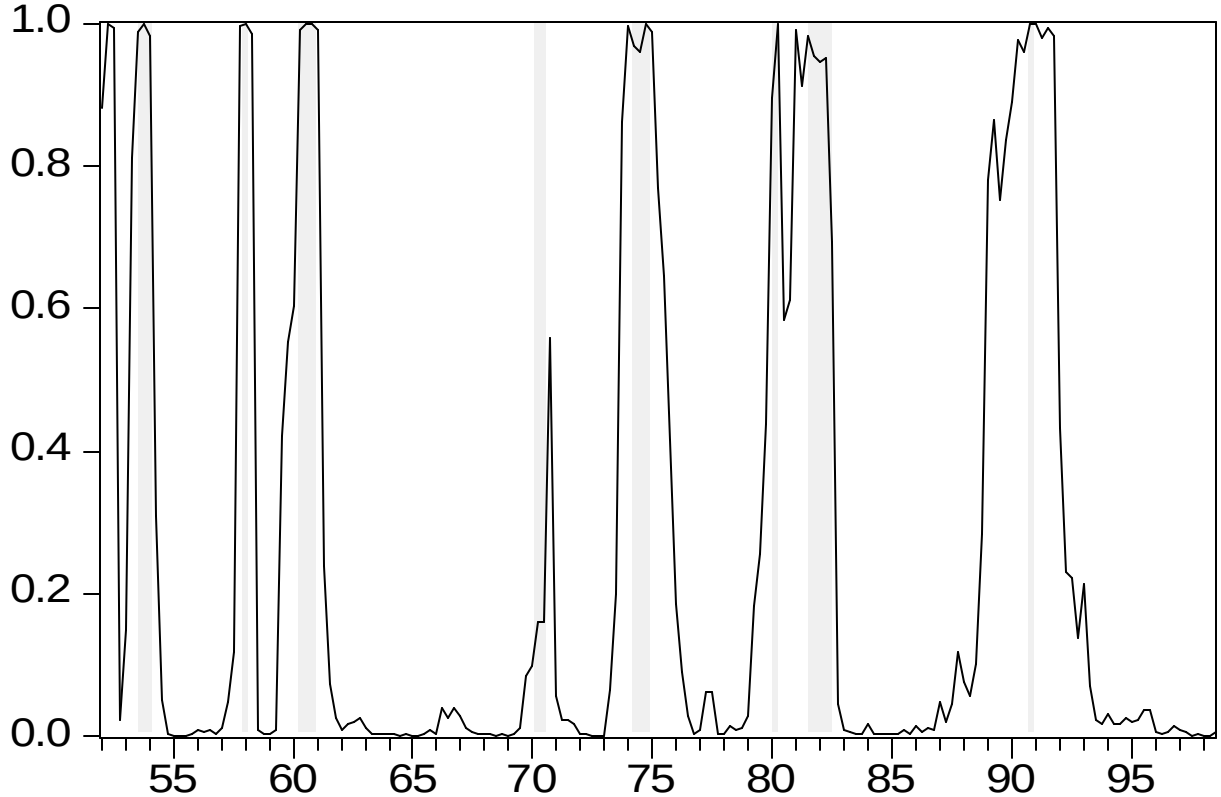

Figure 6: Filtered Probability that $D_t = 1$

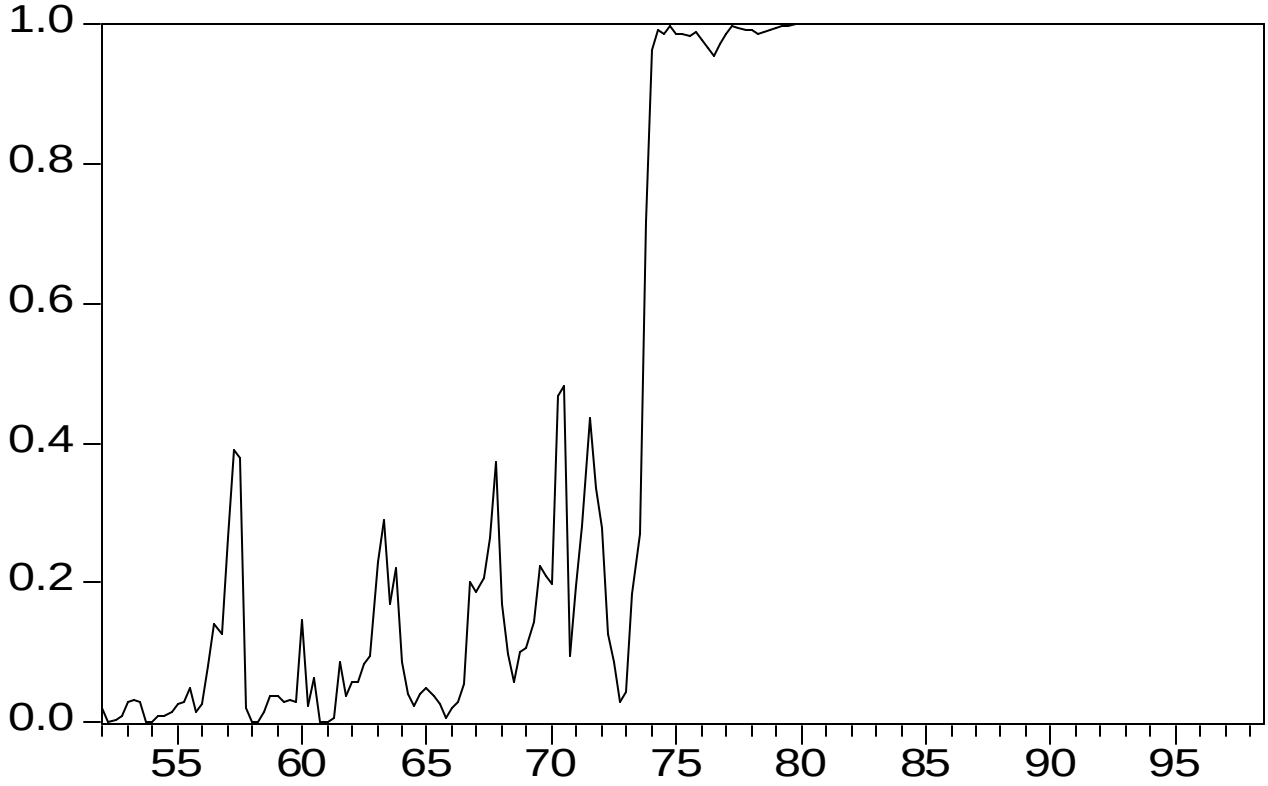

Figure 7: Smoothed Probability that $D_t = 1$

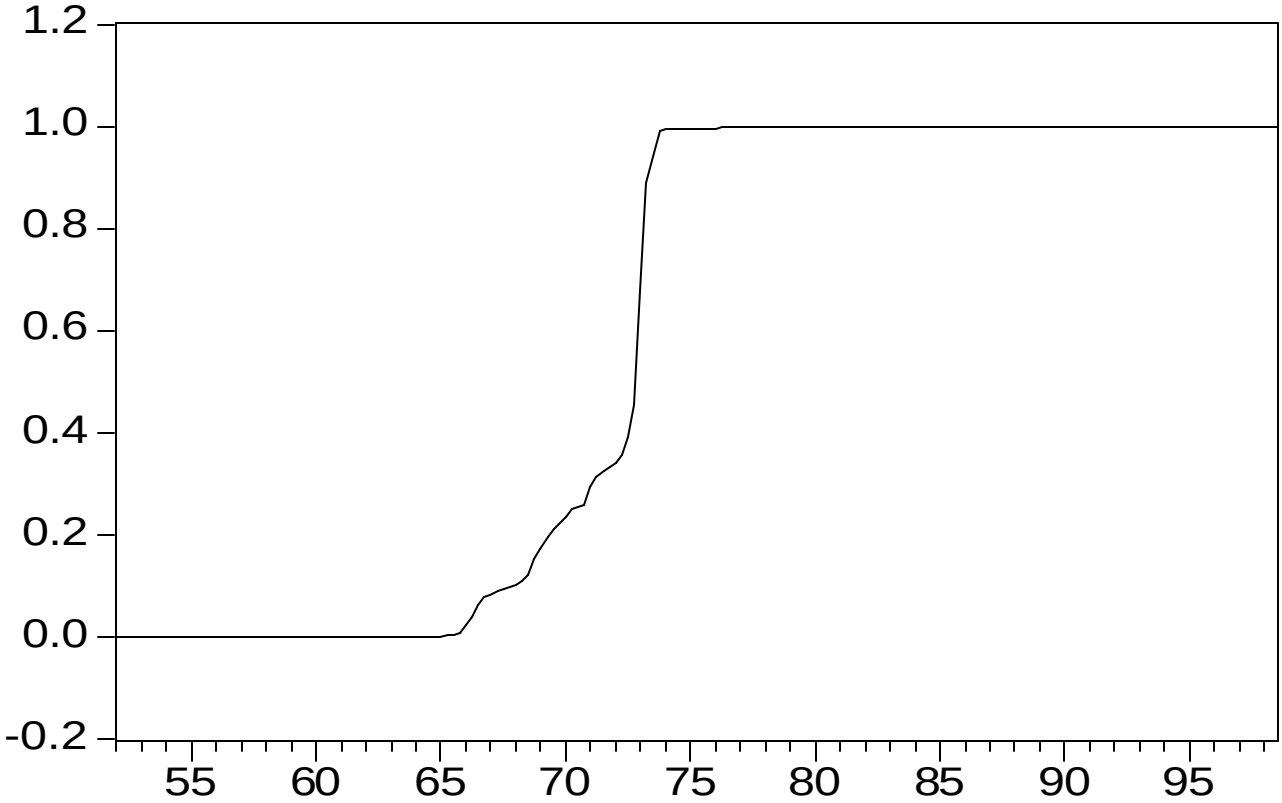

Figure 8: Real GNP and its Permanent Component

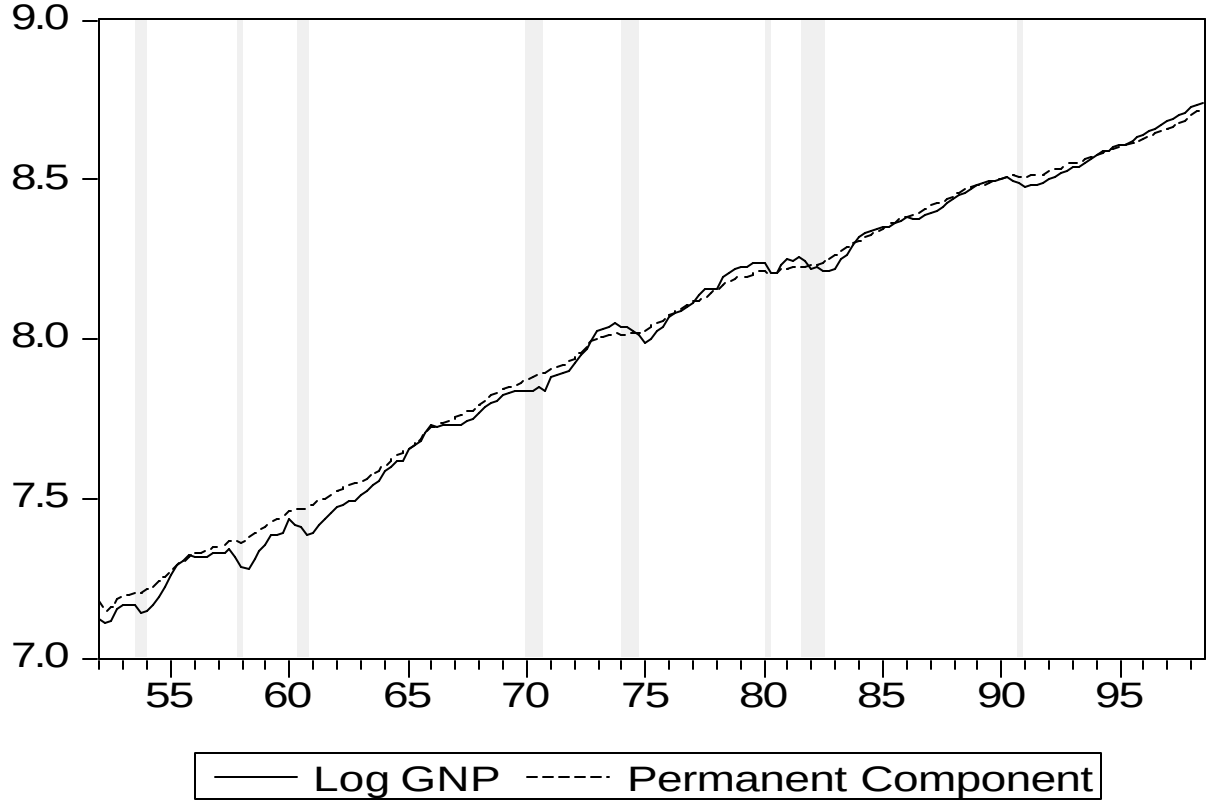

Figure 9: Business Fixed Investment and its Permanent Component