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Abstract: This paper evaluates the ability of a statistical regime-switching model to identify turning points in U.S. economic activity in real time. The authors work with Markov-switching models of real GDP and employment that, when estimated on the entire post-war sample, provide a chronology of business cycle peak and trough dates very close to that produced by the National Bureau of Economic Research (NBER). Next, they investigate how accurately and quickly the models would have identified turning points had they been used in real-time for the past forty years. In general, the models identify turning point dates in real-time that are close to the NBER dates. For both business cycle peaks and troughs, the models provide systematic improvement over the NBER in the speed at which turning points are identified. Importantly, the models achieve this with few instances of "false positives." Overall, the evidence suggests that the regime-switching model could be a useful supplement to the NBER Business Cycle Dating Committee for establishing turning point dates. The model appears to capture the features of the NBER chronology in an accurate, timely way, and does so in a transparent and consistent fashion.

JEL classification: C32, C50, E3

Key words: business cycles, real time forecasting, Markov switching, turning points

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1. Introduction

A primary stylized fact of industrialized economies is that economic activity moves between periods of expansion, in which there is broad economic growth, and periods of recession, in which there is broad economic contraction. Understanding these phases, collectively called the business cycle, has been the focus of much macroeconomic research over the past century. In the United States, the National Bureau of Economic Research (NBER), a private, non-profit research organization, serves a very useful role in cataloging stylized facts about business cycles and providing a historical accounting of the dates at which regime shifts occur. This task began soon after the founding of the NBER in 1920 and has continued to the present day.[1] Since 1980, the specific task of dating "turning points" in U.S. business cycles, or those dates at which the economy switches from the expansion regime to the contraction regime and vice-versa, has fallen to the NBER's Business Cycle Dating Committee.[2]

The NBER dates a turning point in the business cycle when a consensus of the Committee that a turning point has occurred is reached. Although each Committee member likely brings different techniques to bear on this question, the decision is framed by the working definition of a business cycle provided by Arthur Burns and Wesley Mitchell (1946, pg. 3):

> Business cycles are a type of fluctuation found in the aggregate economic activity of nations that organize their work mainly in business enterprises: a cycle consists of expansions occurring at about the same time in many economic activities, followed by similarly general recessions, contractions and revivals which merge into the expansion phase of the next cycle.

[1] For an interesting history of the NBER's role in defining and dating the business cycle, see Moore and Zarnowitz (1986).

A fundamental element of this definition is the idea that business cycles can be divided into distinct phases, with the phase shifts characterized by changes in the dynamics of the economy. In particular, expansion phases are periods when economic activity tends to trend up while recession phases are periods when economic activity tends to trend down. In practice, to date the shift from an expansion phase to a recession phase, or a business cycle peak, the NBER looks for clustering in the shifts of a broad range of series from a regime of upward trend to a regime of downward trend. The converse exercise is performed to date the shift back to an expansion phase, or a business cycle trough.

The NBER's announcements garner considerable publicity. Given this prominence, it is not surprising that the business cycle dating methodology of the NBER has come under some criticism. These criticisms can be generally described as follows: First, because the NBER's decisions represent the consensus of individuals who bring differing techniques to bear on the question of when turning points occur, the dating methodology is not transparent nor reproducible. Second, the NBER dates, once set, are not revised. This is true even though the data on which these decisions are based can be revised extensively, sometimes decades later. Given that economic researchers often rely on the NBER dates in econometric modeling of this revised data, the fact that the NBER dates are not revised may be problematic. Finally, the NBER business cycle peaks or troughs are often determined well after the fact. This appears to be largely the result of the NBER's desire to avoid calling false turning points.

Of course the NBER is not the only source of information regarding business cycle turning points. Economists and statisticians have developed many statistical methods that automate the dating of business cycle peaks and troughs (see Boldin 1994 for a summary). One such technique is the Markov-switching model. This model, popularized by Hamilton (1989) in

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[2] There are currently six members of the Committee: Robert Hall of Stanford University, Martin Feldstein of Harvard University, Jeffrey Frankel of the University of California at Berkeley, Robert Gordon of Northwestern

the economics profession, is capable of statistically identifying shifts in the parameters of a statistical process driving a time-series of interest. These models are quite simple, making them transparent and reproducible. They can also be used to revisit the dates of business cycle turning points after data have been revised, providing a systematic technique for revising business cycle dates. Also, Layton (1996) provides some evidence that Markov-switching models provide timely identification of business cycle turning points.

In this paper we take it as given that the NBER correctly identifies the dates of business cycle turning points. We then evaluate the real-time performance of the Markov-switching model in replicating the NBER's business cycle dates. We apply the model to two data sets, growth in quarterly real Gross Domestic Product (GDP) and growth in monthly economy-wide employment. We first confirm the result found elsewhere that the models are able to replicate the historical NBER business cycle dates very closely when estimated using all available data. Second, we evaluate the real-time performance of the model at dating business cycles over the last 40 years. This is accomplished by estimating the model on recursively increasing samples of data and evaluating the evidence for a new turning point at the end of each sample.

This approach builds on the exercise undertaken in Layton (1996), extending it in two main ways. First, while Layton used fully revised data in his recursive estimations, here we use "real-time" data. That is, for each recursive sample we use only data that would have been available at the end of the sample period being considered. This provides a more realistic assessment of how the model would have performed, as it does not assume knowledge of data revisions that were not available at the time the model would have been used. Second, we extend Layton's sample to include the 2001 recession, in order to investigate the properties of the model in the most recent business cycle.

University, N. Gregory Mankiw of Harvard University and Victor Zarnowitz of Columbia University.

The results of this exercise suggest that the model chooses turning points in real-time that are very close to the NBER dates. In addition, we find evidence that the model would have identified business cycle turning points faster than the NBER Business Cycle Dating Committee. The model calls both business cycle peaks and troughs faster than the NBER, with a larger lead-time in the case of troughs. The switching model achieves this performance with few incidences of false positives. Finally, the initial turning point dates identified in real time are generally not revised significantly as the sample period is extended or the underlying data are revised, providing some justification for using switching models to call business cycle turning points in real time. Overall, these results suggest that the Markov-switching model is a potentially very useful tool to be used alongside the traditional NBER analysis.

Of course, this line of research is predicated on the assumption that turning point dates are interesting concepts. However, some might question whether they have any interesting intrinsic meaning. We argue that they do. There is much evidence that the two regimes defined by the NBER turning point dates are quite different, beyond one being a period of expansion and the other contraction. First, knowledge of which regime the economy is in can improve forecasts of economic activity (see, for example, Hamilton 1989). Second, there is evidence that the relationship between economic variables changes over NBER identified phases. For example, McConnell (1998) and Gavin and Kliesen (2002) have shown that the relationship between initial claims for unemployment insurance and employment growth is stronger during NBER dated recessions. Third, there is growing evidence that fluctuations in output during NBER recession episodes are purely temporary while those during NBER expansion episodes are permanent (see, for example, Beaudry and Koop 1993 and Kim, Morley and Piger 2002). This is suggestive of a "plucking" model for U.S. output, in which the business cycle is characterized more by negative deviations from trend output than by positive deviations.[3] Such a pattern is not generally implied by linear macroeconomic models of the business cycle, suggesting that the NBER dates define interesting economic episodes from a modeling perspective. Finally, the NBER dates, regardless of whether they have intrinsic meaning, are important in the political arena, as they influence some important economic policy decisions. Thus, if the economics community is going to produce estimates of turning points, we should be interested in developing accurate, timely and transparent methods for doing so.

In the next section we provide a review of the Markov-switching models that will be used in this paper. Section 3 discusses the full sample and "real-time" performance of the models for dating turning points in the business cycle. Section 4 concludes.

2. The Markov-Switching Model of Business Cycles Dynamics

As was discussed above, the NBER definition of a business cycle places heavy emphasis on regime shifts in the process driving economic activity. In the last 15 years there have been enormous advances in formally modeling regime shifts in a rigorous statistical framework. In a paper published in 1989, James Hamilton developed an extremely useful tool for statistically modeling regime shifts in autoregressive time series models. In order to understand this model, it is useful to begin with a simple linear time-series framework for the growth rate of some measure of economic activity, y_t:

$$\begin{aligned}(y_t - \mu) &= \rho(y_{t-1} - \mu) + \varepsilon_t \\ \varepsilon_t &\sim N(0, \sigma^2)\end{aligned} \tag{1}$$

[3] The "plucking" terminology is due to Milton Friedman (1964, 1993).

In this model, the growth rate of economic activity has a mean denoted by μ. Deviations from this mean growth rate are created by the stochastic disturbance ε_t. These deviations are serially correlated, modeled as an AR(1) time series process with parameter ρ.

Hamilton's innovation was to allow the parameters of the model in (1) to switch between two regimes, where the switching is governed by a state variable, $S_t = \{0,1\}$. When $S_t = 0$ the parameters of the model are different than when $S_t = 1$. Clearly, if S_t were an observed variable, this model could simply be estimated using dummy variable methods. However, Hamilton showed that even if the state is *unobserved*, the parameters of the model in each state could be estimated as long as one is willing to place restrictions on the probability process governing S_t. Hamilton derives an estimation technique that could be used to estimate the model when the probability process governing S_t is a first order Markov chain. This simply means that any persistence in the state is completely summarized by the value of the state last period. Under this assumption, the probability process driving S_t is captured by the following four transition probabilities:

$$\begin{aligned} P(S_t = 1 \mid S_{t-1} = 1) &= p \\ P(S_t = 0 \mid S_{t-1} = 1) &= 1 - p \\ P(S_t = 0 \mid S_{t-1} = 0) &= q \\ P(S_t = 1 \mid S_{t-1} = 0) &= 1 - q \end{aligned} \tag{2}$$

Clearly, conclusions regarding when S_t changes may depend on which parameters of the model are allowed to change. For example, the data may support regime shifts in the variance of the disturbance, σ^2, at different times than the autoregressive parameter, ρ. Thus, if we are interested in using this model for identifying the NBER's turning point dates we should allow regime-switching in those parameters of the model that seem to change from expansion to recession. Hamilton showed that allowing the mean growth rate parameter, μ, to vary with S_t seems to be adequate for this task. In particular, Hamilton specified the following augmented version of (1):

$$
\begin{aligned}
&(y_t - \mu_{S_t}) = \rho(y_{t-1} - \mu_{S_{t-1}}) + \varepsilon_t \\
&\varepsilon_t \sim N(0, \sigma^2) \\
&\mu_{S_t} = \mu_0 + \mu_1 S_t \\
&\mu_1 < 0
\end{aligned}
\tag{3}
$$

where S_t depends on the transition probabilities in (2). Here, when S_t switches from 0 to 1, the growth rate of economic activity switches from μ_0 to $\mu_0 + \mu_1$. Since $\mu_1 < 0$, the model will estimate these switches at times when economic activity switches from high growth to low growth states. Hamilton applied this technique to the growth rate of U.S. Gross National Product and found the best fit when $\mu_0 > 0$ and $\mu_0 + \mu_1 < 0$, suggesting the model was capturing regimes when the economy was expanding vs. regimes when the economy was contracting. The estimated probability that S_t was equal to one conditional on all the data in the sample, denoted $P(S_t = 1 | T)$, corresponded very closely to NBER recession dates. This was particularly striking in that Hamilton estimated his model with only one variable describing economic activity.

Since the publication of Hamilton's paper, a large number of alternative Markov-switching models of the business cycle have been studied. Boldin (1994) fits the Hamilton model to an alternative measure of economic activity, namely the unemployment rate. Other authors, for example Hansen (1992), allow for regime-switching in parameters other than the mean growth rate, such as the residual variance or autoregressive parameters. The Hamilton model was modified to allow for additional phases in business cycle dynamics by Sichel (1994), Kim and Nelson (1999) and Kim, Morley and Piger (2002). Finally, building on work by Diebold and Rudebusch (1996), Chauvet (1998) and Kim and Yoo (1995) extended the Hamilton model to a multivariate framework, estimating a coincident index of economic activity with a regime-switching mean growth rate.

In this paper we work with the model given in equations 2-3 applied to two different measures of economic activity for which rich unrevised "real-time" data sets are available. The first is the growth rate of quarterly real U.S. GDP, yielding a model very similar to that originally estimated by Hamilton. The second is a higher frequency measure of economic activity, monthly non-farm payroll employment. In order to estimate the models we use a Bayesian estimation methodology based on Gibbs-sampling first applied to Markov-switching models by Albert and Chib (1993). We will not provide detail of the Gibbs-sampling procedure here. The interested reader is referred to Kim and Nelson (1999), where an excellent treatment of the Hamilton model and other Markov-switching models is provided. Consistent with Albert and Chib (1993), we found that a version of equations 2-3 in which $\rho = 0$ provided a good description of the data for both real GDP and employment. In the next section we evaluate the ability of these models to identify business cycle turning points in real time.

3. Dating Business Cycles with the Switching Model

3.1 Full Sample Business Cycle Dates

Before analyzing the real-time ability of the models to date turning points, we are first interested in their ability to replicate the NBER business cycle chronology using all available data. Thus, we first estimate the models using data on growth in real GDP from the second quarter of 1947 through the second quarter of 2002 and data on non-farm payroll employment growth from February 1947 through July 2002. The GDP data are from the July 31, 2002 release from the Bureau of Economic Analysis while the employment data are from the August 2, 2002 release from the Bureau of Labor Statistics.

As a first step in evaluating the ability of the model to replicate the NBER turning point dates, consider Figure 1a and 1b, which hold the estimated probability that $S_t = 1$ conditional on all the data in the sample, or $P(S_t = 1 | T)$, for both models. The shading in the graphs display periods labeled as recessions by the NBER. The graphs are suggestive that the models capture the NBER chronology fairly closely. During periods that the NBER classifies as expansions $P(S_t = 1 | T)$ is usually close to zero. At around the point where the NBER recession begins $P(S_t = 1 | T)$ spikes upward and remains high until around the time when the NBER dates the end of the recession.

While visual inspection of the probabilities is suggestive, it is difficult to tell how close the turning points from the Markov-switching models are to the NBER dates without the tabulation of specific dates based on the probabilities produced by the models. In order to do this a formal definition is needed to convert the probabilities produced by the switching model into turning point dates. One approach, used by Hamilton (1989) among others, is to classify a turning point as occurring when $P(S_t = 1 | T)$ moves from below 50% to above 50% or vice versa. This has an intuitive appeal as it separates times when an expansion state is more likely from those when a recession state is more likely. This rule would be problematic if $P(S_t = 1 | T)$ fluctuated around 50%, in which case many business cycle peaks and troughs would be called. However, since the Markov switching model applied to the GDP and employment series produces probabilities that are generally close to zero or one, we adopt this simple definition.

We augment this definition with one of two rules specifying how long a phase must persist before a turning point is identified. For example, suppose $P(S_t = 1 | T)$ moves from below 50% to above 50%. Should we immediately declare a business cycle peak has occurred and the economy has entered a recession phase? Or should we require confirmation of the recession phase, by verifying that $P(S_{t+1}=1|T)$, $P(S_{t+2}=1|T)$, … $P(S_{t+k}=1|T)$ are all above 50%? A smaller value for *k* increases the speed at which a turning point might be identified, but increases the chances of calling a false positive. Our first rule is defined for maximum speed, requiring only that a single occurrence of a probability moving from above (below) 50% to below (above) 50% must be observed before a turning point is determined. Our second rule, consistent with the NBER tradition of not classifying very short downturns or expansions as separate regimes, requires that a recession or expansion last at least 3 months before a new turning point is defined. Note that for real GDP, which is measured quarterly, this requirement is met with only a single occurrence of a probability crossing 50%, meaning that rule 1 is identical to rule 2. For employment data, which is measured monthly, rule 2 requires three consecutive probabilities above (below) 50% and will thus differ from rule 1.

Formally, our turning point rules for employment and GDP growth can be specified using the following definitions:

Monthly Employment Growth

Definition 1: The economy is said to be in an *expansion* if the most recent turning point was a business cycle trough.

Definition 2. The economy is said to be in a *recession* if the most recent turning point was a business cycle peak.

Definition 3: A business cycle *peak* is said to occur at time $t+1$ if the economy was in an expansion at time *t* and $P(S_{t+k}=1) \geq P(S_{t+k}=0)$:

rule 1: for $k = 1$ month.

rule 2: for k = 1,2,3 months.

Definition 4: A business cycle *trough* is said to occur at time t if the economy was in a recession at time t and $P(S_{t+k}=0) \geq P(S_{t+k}=1)$:

rule 1: for k = 1 month

rule 2: for k = 1,2,3 months.

GDP Growth

Definition 1: The economy is said to be in an *expansion* if the most recent turning point was a business cycle trough.

Definition 2. The economy is said to be in a *recession* if the most recent turning point was a business cycle peak.

Definition 3: A business cycle *peak* is said to occur at time $t+1$ if the economy was in an expansion at time t and $P(S_{t+k}=1) \geq P(S_{t+k}=0)$ for k = 1 quarter.

Definition 4: A business cycle *trough* is said to occur at time t if the economy was in a recession at time t and $P(S_{t+k}=0) \geq P(S_{t+k}=1)$ for k = 1 quarter.

Table 1a contains the NBER turning point dates and the dates obtained from the Markov-switching model applied to real GDP growth based on the above definition. The correspondence between the two is striking. The Markov-switching model captures each of the NBER business cycle peaks and troughs in the sample. The average discrepancy between the ten NBER business cycle peaks and the business cycle peaks from the switching model applied to real GDP growth is approximately 2.4 months, with a maximum discrepancy of six months and a standard deviation of 1.8 months. Business cycle troughs are dated even closer. There is no discrepancy on average between the nine NBER business cycle troughs and the business cycle troughs from the switching model (the two dates are the same for six of the nine troughs), with a maximum discrepancy of six months and a standard deviation of around 2.7 months. Generally the model tends to determine turning points at or before the ones established by the NBER. The only exception is for the 1990-1991 recession trough, for which the switching model dates the trough two quarters after the NBER date. In fact, the trough of this recession is somewhat controversial as the economy exhibited a very slow recovery in 1992. The uncertainty about the end of this recession led the NBER to announce the trough date only 21 months after the fact.

Notably, the switching model applied to GDP growth generates no false positives, based on the definition of a turning point given. That is, for the whole sample, the probability of recession only increased (decreased) above (below) 50% around the beginning or end of an actual recession. Thus, for the model applied to real GDP an increase or decrease in the probability of recession above or below 50% sends a very strong signal that a turning point has actually occurred.

Table 1b shows the NBER turning point dates and the dates obtained from the Markov-switching model applied to monthly employment growth under rule 1 defined above. The correspondence between the two sets of dates is very close although somewhat less so than that obtained from GDP. There are two reasons for this. First, we are using employment at the monthly frequency, which is a much more noisy series than quarterly GDP. Second, employment slightly lags the business cycle. Generally employment falls after the beginning of recessions and increases after its end, as employers are reluctant to fire (or hire) until recessions gain intensity (or there are clear signs of its end). Nevertheless, the switching model applied to monthly employment captures each of the NBER business cycle peaks and troughs in the sample. The average discrepancy between the NBER peaks and the peaks from the switching model is approximately 1 month with a maximum discrepancy of 9 months and a standard deviation of 3.6 months. Similarly, the average discrepancy between the NBER trough dates and the trough dates from the switching model is 1.8 months, with a maximum discrepancy of 10 months and a standard deviation of 3.2 months.

The trough dates from the switching model applied to employment tend to slightly lag the NBER dates. In particular, all troughs from employment either lag (5 out of 9) or coincide (4 out of 9) with the NBER's. The results are mixed for peak dates: Half of the peak dates from the model either coincide or lead the NBER peak dates whereas half lag the NBER dates.

Under turning point rule 1, which was used to generate Table 1b, there were three false positives identified, all early in the sample. If the minimum number of consecutive months that $P(S_t = 1 | T)$ is required to be above (below) 50% before a turning point is identified were increased to two, only a single false positive occurs (February of 1948). Under turning point rule 2 defined above, in which $P(S_t = 1 | T)$ is required to be above (below) 50% for three consecutive months before a turning point is defined, there are no false positives. This is achieved with no tradeoff in terms of missed turning points - rule 2 still captures all of the NBER business cycle peaks and troughs in the sample.

3.2 "Real-time" Business Cycle Dates

In this section we investigate the "real-time" performance of the switching models for dating business cycles. This will involve an out-of-sample evaluation of the model's performance. Our out-of-sample period will be the last 40 years of data, with prior data used for initial estimation of the model. We are interested in the following question: Had the switching model been used to date business cycles in the past how would it have performed? We will be particularly interested in the ability of the model to capture the six NBER peaks and five NBER troughs over this period. We will also be interested in the incidence of false positives.

There are two features of conducting such a real-time exercise. First, only data over the sample period that the business cycle analyst would have had available in real-time should be used. We achieve this first requirement by using a recursive estimation routine. This routine works as follows: we begin with data that extends from the second quarter of 1947 to the third quarter of 1965 for real GDP and from February of 1947 to October 1964 for employment. The models are estimated and the probability of a new turning point at the end of the sample evaluated. The sample is then extended by one data point, the models re-estimated, and the probability of a turning point evaluated. This process is repeated until the final sample is reached, which extends from the second quarter of 1947 to the second quarter of 2002 for real GDP and from February 1947 to July of 2002 for employment.

The second feature of the real-time exercise is to assume no more knowledge of data revisions than what would have been known by an econometrician estimating the model at the time. Thus, for each end of sample date in the recursive estimation routine we use the first release of this data that was available. For example, for our first sample for real GDP data, which extends from the second quarter of 1947 through the third quarter of 1965, we use the first release of data that included the third quarter of 1965. For real GDP these data were available by the beginning of the second month of the fourth quarter of 1965, which we refer to as the *vintage* of this data set. The monthly employment data sets are similar, except they are more timely than the GDP data. In particular, the first release of employment data for a given month is usually available by the first week of the subsequent month. We obtained the real-time data sets for quarterly real GDP and payroll employment from the Federal Reserve Bank of Philadelphia's real-time data set.[4]

[4] See Croushore and Stark (2001) for information regarding this data set.

In evaluating the evidence for a turning point we consider the probability of a recession at the end of the sample for that particular vintage, that is $P(S_T = 1 | T)$, where *T* denotes the end of the sample period. This will be referred to as the "real-time recursive probability" throughout the remainder of the paper. Such an estimated probability, which is estimated for time *t* using time *t* information, is often called a "filtered" probability. This is of course less information than the econometrician would have available to them at the time, as the econometrician would also have the so-called "smoothed" probabilities for prior dates, that is $P(S_t = 1 | T)$, where $t < T$. Thus, while the model might miss a turning point at time *t* for the data set that ends at time *t,* it might catch this turning point for the data set that ends at *T*. We do not allow for this possibility in the following, thus placing the model at a disadvantage for dating turning points. However, as will be shown, the model's performance is still quite good despite this disadvantage.

Figures 2a and 2b plot the real time recursive probability of a recession at the end of the sample against the NBER business cycle dates. That is, the point on the graph for date *t* represents the estimated probability of recession at date *t* for the recursive sample that ended on date *t*. The probabilities are closely related to the NBER turning points, tending to increase or decrease substantially only around NBER peaks and troughs. The real time recursive probabilities of recession from the employment data are noisier than those from GDP growth, which is not surprising given the higher frequency of the employment data.

We next move to tabulation of business cycle dates using turning point rule 1 for converting probabilities into business cycle dates defined in Section 3.1. Tables 2a and 2b contain the business cycle peak and trough dates identified by the switching models using this rule. The top frame of each table evaluates the performance of the model in capturing business cycle peaks. The bottom frame evaluates business cycle troughs. The first column gives the first date a turning point was assigned in real-time by the switching model. The second column gives the date this turning point would have first been available. For example, the first entry in the second column of Table 2A is February 1970. This is the date at which the business cycle peak of the fourth quarter of 1969, listed in the first column, would have first been identified using the switching model, as early February is approximately when the first GDP data for the fourth quarter of 1969 would have been available. The third and fourth columns give the official NBER business cycle dates and when they were announced. Note that the NBER Business Cycle Dating Committee only started dating peaks and troughs in real time in June of 1980. Thus, the dates of these announcements are only recorded in the table from this date on. The fifth column records the discrepancy between the peak or trough date first assigned by the switching model and the corresponding date assigned by the NBER, which is the amount of time the date in column 1 precedes that in column 3. The final column gives the amount of time before the NBER date that the switching model date would have been available, that is the amount of time the date in column 2 anticipates that in column 4.

Tables 2a and 2b demonstrate that the switching model calls turning point dates in real-time that are fairly close to the NBER dates. Table 2a shows that for the six NBER peaks in the last 40 years, the switching model applied to real GDP growth yields business cycle dates in real time exactly equal to the NBER's in two cases and 1 or 2 quarters away in the other cases. The average discrepancy for peaks is 2.4 months with a standard deviation of 2.4 months. For the five NBER business cycle troughs, the trough dates from the model applied to real GDP growth coincide with the NBER dates in two cases and lag 1 or 4 quarters in the other cases. The average discrepancy is 3.6 months with a standard deviation of 4.8 months. Table 3a summarizes the errors in identifying turning points. Over this 40-year period the dating algorithm did not miss any turning points, even in real-time. In only one instance is a false business cycle identified, in the second quarter of 1979. This increase in the probability of recession signaled an actual slowdown in the US economy in 1979 associated with the second oil shock, which preceded the 1980 recession.

With respect to employment, the real time probabilities of recession generally lag the NBER turning points, especially in the case of peak dates. From Table 2b, which was generated under turning point rule 1, the average discrepancy between the model and the NBER peak dates is 5.7 months with a standard deviation of 3.3 months. For trough dates, the average discrepancy is only 1.6 months with a standard deviation of 2.1 months. As summarized in Table 3b, the model applied to employment does not miss any turning points under either rule 1 or rule 2. In addition, using turning point rule 2, no false business cycles are identified. Under turning point rule 1, two false business cycles are identified. The first of these was in June and July of 1971, when the probabilities increased above 50% and no recession followed. This would have been ruled out as a peak using rule 2 since the probabilities dropped below 30% in the following month. The other false turning point for employment occurs immediately following the 1990-1991 recession. Using turning point rule 1, the switching model initially dated the trough of this recession as August 1991. However $P(S_T = 1 | T)$ then increased above 50% again from November 1991 to January 1992, thus dating a double-dip recession following the 1990-1991 recession. As mentioned previously, the NBER dated trough of March 1991 is controversial since the economy, particularly as measured by employment, displayed a very slow recovery following the trough. This is what the real-time recursive probabilities for the model applied to employment appear to be capturing.

We now turn to the issue of whether the switching model applied in real time would have identified turning points any faster than the NBER Business Cycle Dating Committee. The sixth column of Tables 2a and 2b suggests that the answer is yes for both peak and trough dates obtained from the model applied to either real GDP or employment growth (using rule 1).

Business cycle peak dates were determined with an average lead time of 0.5 months over the NBER announcement using the model applied to real GDP growth and 1.8 months using the model applied to employment growth. The model improves on the timeliness of the NBER even more in determining business cycle trough dates. For the three business cycle troughs in the last 25 years, the model applied to GDP would have determined these dates an average of 5.7 months prior to the NBER, with a maximum of 8 months for the 1980 trough. When applied to employment, the model would have determined trough dates with an average lead time of 10.7 months over the NBER announcements. The additional lead time of the model applied to employment over that applied to real GDP comes partially from the fact that the employment series is released more quickly than the GDP series.

As was mentioned in the introduction, one criticism of the NBER methodology is that it does not allow for revisions of business cycle dates, even though the data on which these dates are based can be revised extensively. One advantage of the switching models used here is that they can be re-estimated on revised data, thus providing a straightforward mechanism with which to revise business cycle dates. How large might we expect these revisions to be? A comparison of Tables 1 and 2 provides some insight into this question. For business cycle peak dates, column 2 from Tables 1a and 1b and column 1 from the top panel of Tables 2a and 2b show that the initial peak dates obtained in real time are relatively close to the final peak dates obtained using the entire sample of data and all data revisions. This is also the case for business cycle trough dates, as evidenced by comparing column 4 from Tables 1a and 1b with column 1 from the bottom panel of Tables 2a and 2b. In the case of the model applied to real GDP growth there are 12 turning points identified in Table 2a, 6 peaks and 6 troughs. The average revision of the date from the initial date established in real time to the final date based on all available data is approximately 1.5 quarters and is never larger than 3 quarters. The revisions are even smaller for the model applied to employment growth. There are 11 turning points identified in Table 3b, 6 peaks and 5 troughs. The average revision is only 3 months and is never larger than 8 months. For both models the revisions are smaller for the trough dates than the peak dates, suggesting trough dates are more clearly defined in real-time than peak dates. In sum, it appears that adding more data beyond that needed to establish the initial business cycle dates has in general resulted in fairly minor revisions of these dates. This is important, for if these revisions were large it would reduce the importance given to the initial dates identified by the switching model, making the improved timeliness of the turning point identification over the NBER less interesting. The fact that these revisions are small thus provides some justification for using switching models to call business cycle turning points in real time.

3.3 The 2001 Recession

The most recent U.S. recession merits further discussion for at least two reasons. First, data revisions in recent months have caused significant revisions in the real-time peak date established by the switching model. Indeed, this revision matches or exceeds the largest seen in the sample period considered in Table 2. It is worth exploring the reasons for these large revisions further. Second, the trough date for this recession had not yet been established when this paper was written, providing us with an out-of-sample experiment of the usefulness of the switching model.

In November 2001 the NBER Dating Committee dated the peak of the last expansion as March 2001. In contrast, the real-time recursive probability of a recession, given by $P(S_T = 1 | T)$, first rose above 50% in the third quarter of 2001 for the model applied to real GDP and in September of 2001 for the model applied to employment growth (Table 2a and 2b). A more detailed look at these recession probabilities are given in the first column of Tables 4a and 4b. This shows the real-time recursive probability of a recession at each date over the last several years.

The recent large revisions in GDP and employment data changed the peak date obtained from the switching model. The second column of Tables 4a and 4b show the smoothed probability of a recession using the most recent data available, which was the July 31, 2002 vintage for real GDP and the August 2, 2002 vintage for employment. Using this data, the switching model dates the recession as beginning much earlier, in the fourth quarter of 2000 for real GDP growth and in February 2001 for employment growth. The large revision in the peak date stems from recent data revisions that indicated significantly slower growth in the first six months of 2001 than previously recorded. For example, the release of real GDP data dated June 27, 2002 from the Bureau of Economic Analysis recorded quarterly annualized growth of 1.3 and 0.3 percent for the first and second quarters of 2001. However, the data released on July 31, 2002 instead recorded declines in GDP of 0.6 and 1.6 percent in these quarters. These data revisions altered the peak date established by the switching model, pushing it much earlier into late 2000 and early 2001. This revision can be seen graphically in Figure 3, which shows the smoothed probabilities of a recession over the last several years based on real GDP data from the February 28, 2002 vintage, which was prior to the large GDP revisions, and those based on the July 31, 2002 vintage, which was after the large revisions.

The NBER had not yet dated the end of the 2001 recession at the time this paper was written. However, the switching model applied to real GDP growth has already dated the business cycle trough. The real time probabilities indicate that the end of the recession occurred in the fourth quarter of 2001. This date would have been available with the initial release of the fourth quarter 2001 GDP data, in February of 2002. Using the revised GDP data released in late July, the model dates the trough even earlier, to the third quarter of 2001. The switching model applied to employment growth had not yet dated the end of the recession, using data up to the August 2, 2002 vintage.

4. Conclusions

In this paper we have explored the real-time performance of Markov-switching models of real GDP and employment for replicating the NBER business cycle chronology over the past 40 years. The models produce business cycle peak and trough dates that are relatively close to the NBER dates, even in real time when setting the dates using only information that would have been available at the time the dates were initially established. An important feature of the model is that it generally determines turning-point dates more quickly than the NBER Business Cycle Dating Committee. This timing advantage can be large, especially for business cycle troughs. It accomplishes this performance with a minimum of "false positive" business cycle peak or trough dates over the 40 year period.

Overall, the evidence presented above suggests that a statistical regime-switching model like the one used in this paper could be a useful supplement to the NBER Business Cycle Dating Committee for establishing turning point dates. It appears to capture the features of the NBER chronology in an accurate, timely way, and does so in a transparent and consistent fashion. It would be interesting to evaluate the real-time performance of multivariate switching models that incorporate another feature of NBER recessions, comovement across many economic variables over the business cycle, to see if additional improvements can be made. We leave this for future research

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Figure 1a

Full Sample Estimated $P(S_t = 1)$ From Markov-Switching Model of Quarterly Real GDP (Data Vintage July 31, 2002, Shaded Areas Denote NBER Recession Dates)

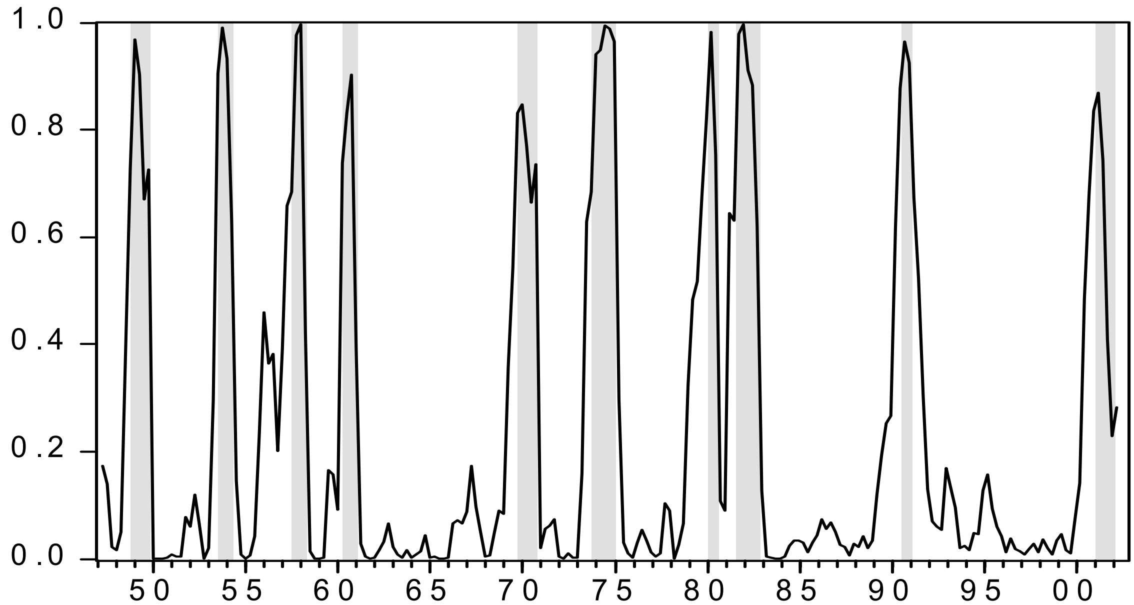

Figure 1b

Full Sample Estimated $P(S_t = 1)$ From Markov-Switching Model of Monthly Non-Farm Payroll Employment (Data Vintage August 2, 2002, Shaded Areas Denote NBER Recession Dates)

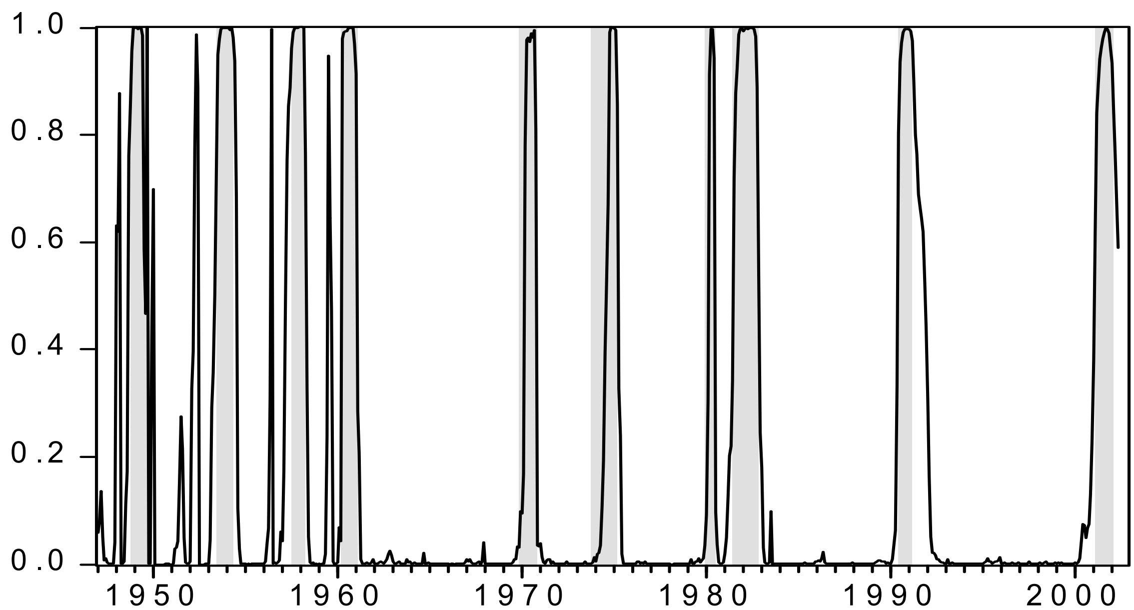

Figure 2a

Real Time Recursively Estimated $P(S_t = 1)$ (1966 on) From Markov-Switching Model of Quarterly Real GDP (Shaded Areas Denote NBER Recession Dates)

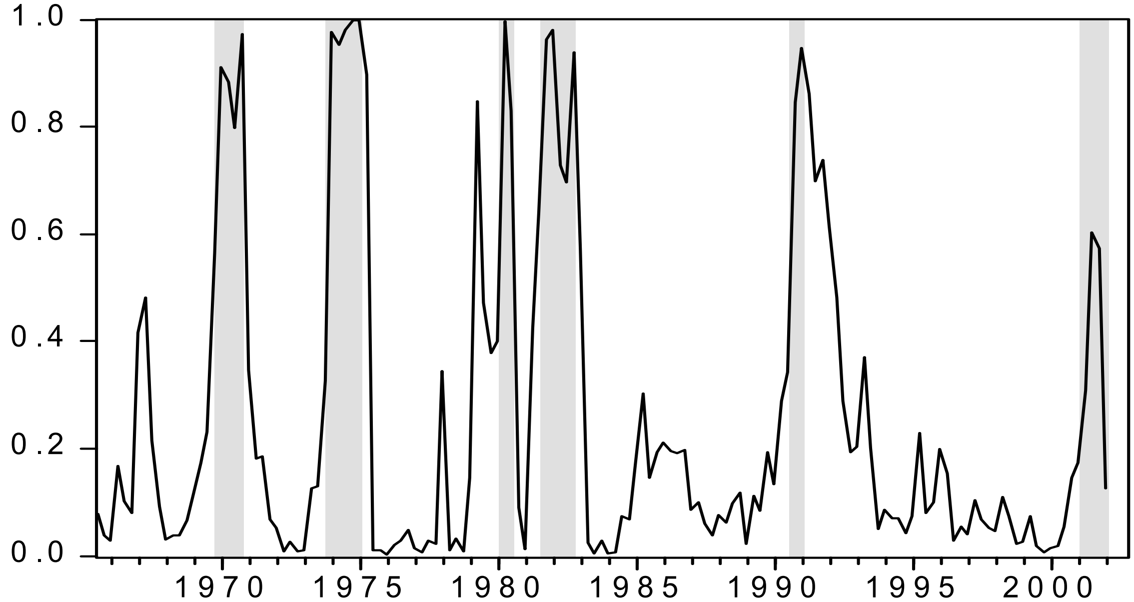

Figure 2b

Real Time Recursively Estimated $P(S_t = 1)$ (1966 on) From Markov-Switching Model of Monthly Non-Farm Payroll Employment (Shaded Areas Denote NBER Recession Dates)

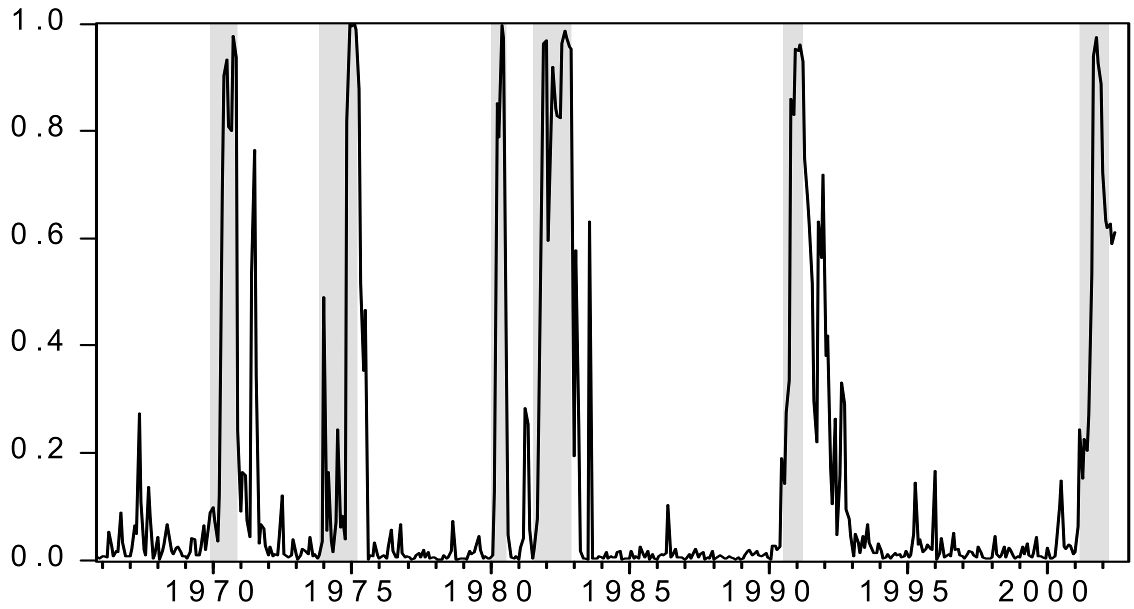

Figure 3
Full Sample Recursively Estimated $P(S_t = 1)$ for the 2001 Recession from Markov-Switching Model of Quarterly Real GDP (Data Vintage February 28, 2002 (---) and Data Vintage July 31, 2002 (—), Vertical Line is NBER Peak Date)

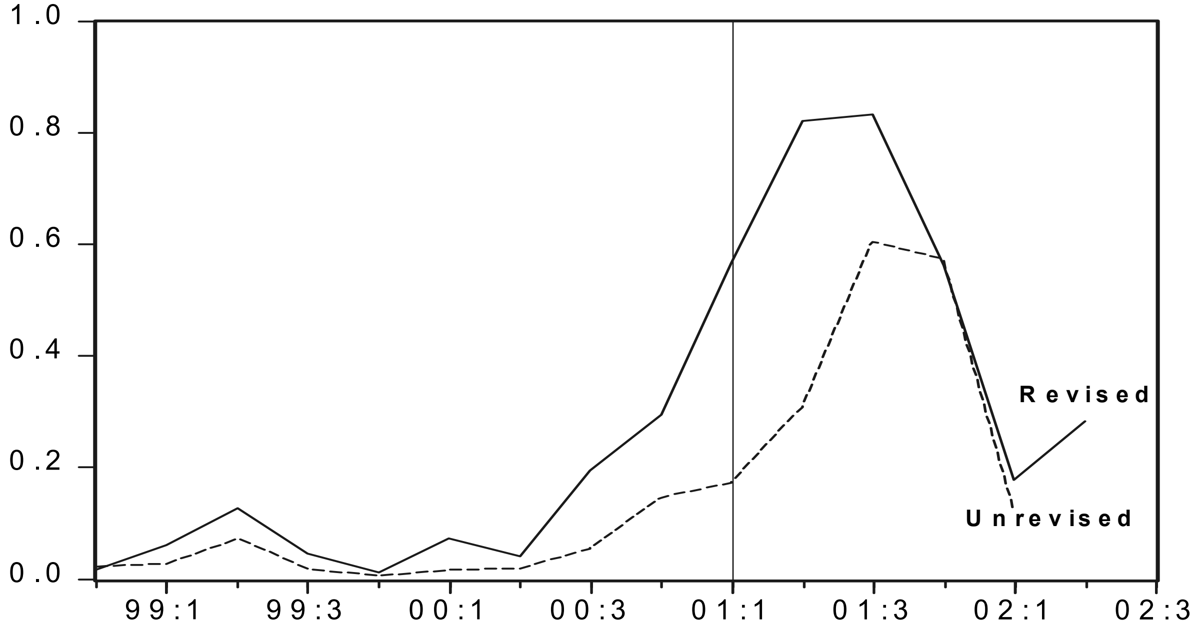

Table 1a
Business Cycle Dates – NBER and Markov-Switching Model of Real GDP Estimated Over Full Sample

Peak			Trough		
NBER	**Switching Model**	**Lead / Lag Discrepancy**	**NBER**	**Switching Model**	**Lead / Lag Discrepancy**
Nov 1948	1948:Q4	0	Oct 1949	1949:Q4	0
Jul 1953	1953:Q3	0	May 1954	1954:Q2	0
Aug 1957	1957:Q2	1Q	Apr 1958	1958:Q1	1Q
Apr 1960	1960:Q2	0	Feb 1961	1960:Q4	1Q
Dec 1969	1969:Q3	1Q	Nov 1970	1970:Q4	0
Nov 1973	1973:Q3	1Q	Mar 1975	1975:Q1	0
Jan 1980	1979:Q3	2Q	Jul 1980	1980:Q3	0
Jul 1981	1981:Q2	1Q	Nov 1982	1982:Q4	0
Jul 1990	1990:Q2	1Q	Mar 1991	1991:Q3	-2Q
Mar 2001	2000:Q4	1Q	Not Yet Announced	2001:Q3	-
Mean		**0.8Q**			**0.0Q**
Median		**1.0Q**			**0.0Q**
Standard Dev.		**0.6Q**			**0.9Q**

Note: Leads (lags) are represented by + (-) and indicate how many quarters the switching model anticipates (lags) the NBER dating, whereas 0 indicates that the two dating systems coincide.

Table 1b

Business Cycle Dates – NBER and Markov-Switching Model of Non-Farm Payroll Employment Estimated Over Full Sample

Peak			Trough		
NBER	**Switching Model**	**Lead / Lag Discrepancy**	**NBER**	**Switching Model**	**Lead / Lag Discrepancy**
Nov 1948	Oct 1948	1M	Oct 1949	Oct 1949	0
Jul 1953	Jun 1953	1M	May 1954	Aug 1954	-3M
Aug 1957	Apr 1957	4M	Apr 1958	May 1958	-1M
Apr 1960	May 1960	-1M	Feb 1961	Feb 1961	0
Dec 1969	Apr 1970	-4M	Nov 1970	Nov 1970	0
Nov 1973	Aug 1974	-9M	Mar 1975	Apr 1975	-1M
Jan 1980	Apr 1980	-3M	Jul 1980	Jul 1980	0
Jul 1981	Aug 1981	-1M	Nov 1982	Dec 1982	-1M
Jul 1990	Jul 1990	0	Mar 1991	Jan 1992	-10M
Mar 2001	Feb 2001	1M	Not Yet Announced	Not Yet Identified	-
Mean		**-1.1M**			**-1.8M**
Median		**-0.5M**			**-1.0M**
Standard Dev.		**3.6M**			**3.2M**

Note: Leads (lags) are represented by + (-) and indicate how many months the switching model anticipates (lags) the NBER dating, whereas 0 indicates that the two dating systems coincide.

Table 2a
Recession Dates Obtained in Real Time – NBER and Markov-Switching Model of Real GDP Estimated Over Recursive Samples

Peak Date: Switching Model	Peak Date Available: Switching Model	Peak Date: NBER	Peak Date Announced: NBER	Lead / Lag Discrepancy	Lead Announcement Date: Switching Model
1969:Q4	Feb. 1970	Dec. 1969	_	0	_
1974:Q1	May 1974	Nov. 1973	_	-1Q	_
1980:Q2	Aug. 1980	Jan. 1980	June 3, 1980	-1Q	-2M
1981:Q3	Nov. 1981	July 1981	Jan. 6, 1982	0	2M
1990:Q4	Feb. 1991	July 1990	Apr. 25, 1991	-1Q	2M
2001:Q3	Nov. 2001	Mar. 2001	Nov. 26, 2001	-2Q	0
Mean				**-0.8Q**	**0.5M**
Median				**-1.0Q**	**1.0M**
Standard Dev.				**0.8Q**	**1.9M**
Trough Date: Switching Model	**Trough Date Available: Switching Model**	**Trough Date: NBER**	**Trough Date Announced: NBER**	**Lead / Lag Discrepancy**	**Lead Announcement Date: Switching Model**
1970:Q4	Feb. 1971	Nov. 1970	_	0	_
1975:Q2	Aug. 1975	Mar. 1975	_	-1Q	_
1980:Q3	Nov. 1980	July 1980	July 8, 1981	0	8M
1983:Q1	May 1983	Nov. 1982	July 8, 1983	-1Q	2M
1992:Q1	May 1992	Mar. 1991	Dec. 22, 1992	-4Q	7M
2001:Q4	Feb. 2002	Not Yet Announced	Not Yet Announced	_	_
Mean				**-1.2Q**	**5.7M**
Median				**-1.0Q**	**7.0M**
Standard Dev.				**1.6Q**	**3.2M**

Table 2b
Recession Dates Obtained in Real Time – NBER and Markov-Switching Model of Non-Farm Payroll Employment Estimated Over Recursive Samples

Peak Date: Switching Model	**Peak Date Available: Switching Model**	**Peak Date: NBER**	**Peak Date Announced: NBER**	**Lead / Lag Discrepancy**	**Lead Announcement Date: Switching Model**
May 1970	Jun 1970	Dec 1969	_	-5M	_
Nov 1974	Dec 1974	Nov 1973	_	-12M	_
Apr 1980	May 1980	Jan 1980	Jun 3, 1980	-3M	1M
Nov 1981	Dec 1981	Jul 1981	Jan 6, 1982	-4M	1M
Nov 1990	Dec 1990	Jul 1990	Apr 25, 1991	-4M	4M
Sept 2001	Oct 2001	Mar 2001	Nov 26, 2001	-6M	1M
Mean				**-5.7M**	**1.8M**
Median				**-4.5M**	**1.0M**
Standard Dev.				**3.3M**	**1.5M**

Trough Date: Switching Model	**Trough Date Available: Switching Model**	**Trough Date: NBER**	**Trough Date Announced: NBER**	**Lead / Lag Discrepancy**	**Lead Announcement Date: Switching Model**
Nov 1970	Dec 1970	Nov 1970	_	0	_
May 1975	Jun 1975	Mar 1975	_	-2M	_
Jul 1980	Aug 1980	Jul 1980	Jul 8, 1981	0	11M
Dec 1982	Jan 1983	Nov 1982	Jul 8, 1983	-1M	6M
Aug 1991	Sept 1991	Mar 1991	Dec 22, 1992	-5M	15M
Jul 2002?	Not Yet Identified	Not Yet Announced	Not Yet Announced	_	_
Mean				**-1.6M**	**10.7M**
Median				**-1.0M**	**11.0M**
Standard Dev.				**2.1M**	**4.5M**

Table 3a – Real Time Turning Point Signal Error – Markov Switching Model of Real GDP Growth

Turning Point Evaluation (6 Recessions: 6 NBER peaks, 5 troughs)	
Correct TP	11
Missed TP	0
False TP	1
TP error	1

Table 3b – Real Time Turning Point Signal Error – Markov Switching Model of Real Employment Growth

Turning Point Evaluation (6 Recessions: 6 NBER peaks, 5 troughs)	Rule 1	Rule 2
Correct TP	11	11
Missed TP	0	0
False TP	2	0
TP error	2	0

Note: Correct TP refers to prediction of a turning point when one does occur
Missed TP refers to prediction of no turning point when one does occur
False TP refers to prediction of a turning point when one does not occur
TP error refers to the total of Missed and False TP. A perfect forecast is when TP error is zero

Table 4a
Probabilities of Recession from the Markov Switching Model Applied to GDP Growth (%)

Period	Recursive in Real Time (%)	Full Sample using Revised Data (07/2002)
2000 – Q1	1.6	7.8
Q2	1.9	14.2
Q3	0.5	48.7
Q4	14.6	**67.8**
2001 – Q1	17.4	83.6
Q2	30.9	86.9
Q3	**60.4**	**74.2**
Q4	**57.3**	41.0
2002 – Q1	12.7	22.9
Q2	28.4	28.4

Table 4b
Probabilities of Recession from the Markov Switching Model Applied to Employment Growth (%)

Period	**Recursive Real Time**	**Full Sample Using Revised Data (7/2002)**
2001 – Jan	1.1	36.3
Feb	1.5	**50.0**
Mar	6.4	68.2
Apr	24.4	85.0
May	15.2	89.8
Jun	22.6	94.2
Jul	20.3	96.3
Aug	27.2	97.8
Sep	**53.4**	99.1
Oct	94.0	99.8
Nov	97.6	99.7
Dec	92.8	98.8
2002 – Jan	88.8	96.4
Feb	72.2	94.2
Mar	63.3	88.0
Apr	61.9	81.6
May	62.8	73.8
Jun	59.0	66.4
Jul	61.2	61.2