Are recoveries all the same: GDP and TFP?

Yu-Fan Huang, Sui Luo, and Richard Startz*

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Abstract

Recessions and subsequent recoveries are frequently classified as "L-shaped" or "U-shaped," with output losses in the former being permanent and losses in the latter at least partially made up by higher than average growth during the recovery. We estimate the probability of a U-shaped recovery for post-War NBER recessions. Most earlier recessions were U-shaped but more recent recessions have been L-shaped. The shape of recoveries is tracked relatively well by durable consumption, investment, and labor hours, with shapes suggested by nondurable consumption and employment being less well identified. Perhaps surprisingly, total factor productivity appears to recover rapidly after all recessions.

JEL codes: E3, E37, C11

1 Introduction

Whether, or the extent to which, recoveries following recessions return output to trend is of central interest to both policymakers and to the academic study of business cycles.

*Yu-Fan Huang, International School of Economics and Management, Capital University of Economics and Business, Beijing, China, yufanh.cueb@gmail.com; Sui Luo, International School of Economics and Management, Capital University of Economics and Business, Beijing, suiluocueb@gmail.com; Richard Startz, Department of Economics, University of California, Santa Barbara, CA, USA, startz@ucsb.edu.

Friedman [1964, 1993] suggested the "plucking model," arguing that growth following recessions is unusually high. Researchers, notably Kim et al. [2005] and Morley and Piger [2012], have done extensive work asking whether the typical recession is followed by a high speed recovery, answering the question in the affirmative. (For more on recoveries following recessions, see also Beaudry and Koop [1993], Kim and Nelson [1999], Kim and Murray [2002].) We eschew the idea of a universal recovery pattern in favor of a framework in which different recoveries can have different shapes. Specifically, we attempt to identify the shape of each of the 11 NBER recoveries in post-WWII US history.

Post-recession periods may be labeled as either "L-shaped" recoveries or as "U-shaped" recoveries. A simple illustration of the differences between the two types is presented in the right panel of Figure 1, with formal models established in Section 2. In a U-shaped recovery, output returns at least part way toward where it would have been absent a recession. In contrast, in an L-shaped recovery the growth rate is re-established but output is permanently below its pre-recession trend. In what follows, we estimate empirically that a two-quarter recession followed by an L-shaped recovery has an average permanent loss of GDP of 3 percent. In contrast, the permanent loss following a U-shaped recovery is about 0.75 percent.

Departing from the existing literature, we allow the shape of recovery to be different following each recession. We are motivated by the observation that post-recession growth paths seem to vary a great deal across different recessions. The left panel of Figure 1 plots the real GDP path relative to its pre-crisis level in the four-year window after the recession starts for all 11 postwar recessions. Following some recessions, especially the most recent one, the economy seems to recover much more slowly than others.

Our statistical analysis is based on the idea of Bayesian model averaging, in which each of the 11 recessions can be either L-shaped or U-shaped independently. Each possible combination of recovery shapes can be identified by an indicator vector with length of 11, each element of whom is either 0 or 1. Our model space includes the total 2^{11} possible combinations and we obtain posterior probabilities for each model from our Bayesian estimation. The probability that a specific recession is followed by a U-shaped recovery

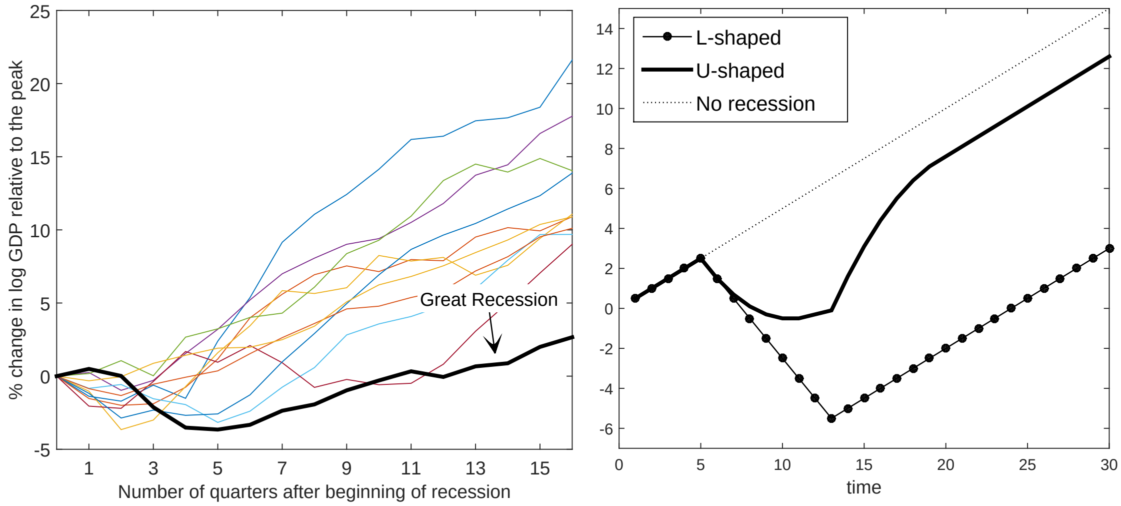

Figure 1: L- and U-shaped recoveries.

can then be calculated based on the weighted average of our shape indicator over the whole model space.

As a preview of our results, we find significant evidence for the existence of U-shaped recoveries, as have others. However, the probability of a U-shaped recovery exhibits large variation across recessions. Specifically, we only find a high probability for U-shaped recoveries for some of the earlier recessions. The recent three recoveries are very likely to be L-shaped according to our estimates. We also compute Beveridge-Nelson trends and cycles during each recession. We find that early recessions were largely due to drops in cyclical activity, but that recent recessions are associated almost entirely with losses in the permanent component of GDP. We also consider the recovery shapes for other macroeconomic variables. Given typical observations on the connection between real GDP and other important economic indicators, we are interested in assessing whether shapes in different series are also closely connected. Possibly unsurprisingly, we find that the shape of recoveries for durable consumption, investment, and labor hours is roughly the same as for GDP overall. We find fewer recoveries are identified as U-shaped by employment data.

In sharp contrast to the results for GDP, *all* recessions appear to be U-shaped according to total factor productivity. In fact, we find that TFP fully recovers ground lost during recessions. While TFP has a significant permanent component, the behavior of TFP during and after recessions is dominated by a cyclical dip and recovery. This strongly argues against a view in which the cyclical part of business cycles is dominated by permanent technology shocks. Of course, *measured TFP* may be picking up something other than technology. While we do not pursue the question of what that "something" might be, our results suggest that macroeconomic models of cyclical behavior need to produce a U-shape for TFP in recession and recovery.

The remainder of the paper is organized as follows. Section 2 presents our econometric model and estimation methodology. Section 3 and 4 report our investigation on total U.S. GDP recessions and on GDP components. In Section 5, we apply our model to labor market data and examine the connection between recoveries of GDP and unemployment. In the final empirical section we look at total factor productivity.

2 An Empirical Model of US Economic Growth Rate

A recession occurs when there is a significant and sustained decline in economic activity spread across the economy—or for our purposes a recession occurs when the NBER says it does. Typically, GDP is observed to dip down for a few quarters before the economy starts to recover. While recoveries can have many different shapes depending on the paths they take to return to the pre-crisis growth trends, we focus on two specific, but representative, shapes in this paper: "L" and "U" shapes.

The L-shaped recovery indicates episodes when losses in the recession are permanent, such that we see no signs of GDP returning to its pre-crisis growth path. As shown in Figure 1, the growth trend line shifts down permanently when GDP growth rate returns to normal.

In contrast, at least part of losses in the recession are offset during a U-shaped recovery. There is a high speed growth period after the recession ends when the economy picks up some or all of its losses before returning to the normal growth rate. U-shaped recoveries are consistent with, for example, the "plucking model" in Friedman [1993, 1964], or the "bounce-back effects" in Kim et al. [2005]. In the model we propose each recovery can be independently either L-shaped or U-shaped.

2.1 "L"-shaped Versus "U"-Shaped Recovery

Our empirical model for GDP growth begins with the model proposed as equation (1) of Kim et al. [2005],

$$\Phi(L)\,(\Delta y_t - m_t) = \epsilon_t, \quad \epsilon_t \sim N(0, \sigma^2) \tag{1}$$

$$m_t = \mu + \gamma s_t + \lambda u_t \tag{2}$$

where $\Phi(L) = 1 - \phi_1 L - \phi_2 L^2 - \ldots - \phi_p L^p$; where p is the order of the autoregressive polynomial and m_t characterizes the average growth rate. γ is the average drop in growth during a recession and λ is the average added growth rate during a recovery. The model for u_t, given below, defines behavior during L-shaped and U-shaped recoveries. In what follows, we define $\Delta y_t = 100(\ln Y_t - \ln Y_{t-1})$ where Y_t is real GDP.

We first depart from Kim et al. [2005] in that we let s_t be indicators (equal to one) for NBER recession periods, during which growth rates will be on average lower by γ, where Kim et al. [2005] treated s_t as an unobserved Markov process. (Kim et al. [2005, page 302] report "the recession dates established by the NBER are closely matched by the contractionary regimes identified by [their] model.") u_t controls for U-shaped recoveries, which is non-zero during rapid post-recession recovering periods. An L-shaped recovery results if u_t remains zero after a recession. Following Kim et al. [2005]and Morley and Piger [2012],we formalize the above idea into the following specification as in (3)

$$u_t = u(s_{t-1}, \ldots, s_{t-q}; \kappa)$$

$$= I(\kappa, t) \sum_{j=1}^{q} s_{t-j} \tag{3}$$

$$= \begin{cases} 0 & , L - shaped\, recovery \\ \sum_{j=1}^{q} s_{t-j} & , U - shaped\, recovery \end{cases}$$

where $I(\kappa, t)$ is an indicator function that takes one if a U-shaped recovery follows the most recent recession up through time t. Corresponding to the 11 post-WII U.S. recessions, κ is a vector of 11 binary numbers, each of which equaling one indicates the presence of a rapid post-recession recovery. Therefore, κ serves as a model indicator in our model space defining 2^{11} models. Lastly, q controls the duration of the rapid recovering effects. Note that we retain the parsimonious recovery specification of Kim et al. [2005] in that recovery is described by the length of the recovery, q, but we do not attempt to identify the within-recovery dynamics. In other words, the model parameters are identified by the entire time series.

Two special cases of our model (1)-(3) are in line with earlier models describing the recession and recovery behaviors. First, if all elements of κ are zero, the model collapses to the one used by Hamilton [1989] as follows:

$$\Phi(L)(\Delta y_t - \mu - \gamma s_t) = \epsilon_t, \quad \epsilon_t \sim N(0, \sigma^2) \tag{4}$$

Equation (4) assumes that during a recession, the percentage growth rate of GDP will decrease to $\mu + \gamma$, and will return to its normal level, μ, whenever a recession ends.[1] Therefore, Hamilton's model implies that the real GDP during and after a recession is L-shaped, and there is no rapid recovery after a recession.

In the second special case in which all elements of κ equal one, $I(\kappa, t) = 1 \forall t$, the

[1]Since $s_t = 1$ represents a recession date, γ can be expected to be negative.

model becomes that used by Kim et al. [2005] to capture the "bounce-back" effect, the high growth recovery phase of post-recession dynamics. Augmenting Hamilton's model with a bounce-back term that is scaled by the length of each recession (as in (5)), their model can generate faster growth in the quarters immediately following every recession as follows:

$$\Phi(L)\left(\Delta y_t - \mu - \gamma s_t - \lambda \sum_{j=1}^{q} s_{t-j}\right) = \epsilon_t, \quad \epsilon_t \sim N(0, \sigma^2), \tag{5}$$

where the parameter λ captures the bounce-back effect.

In the right panel of figure (1) we plot the *level* of log real GDP implied by the mean function of equation (1), m_t, using $\mu = 0.5$, $\gamma = -1.5$, $\lambda = 0.2$, $q = 6$ and initial $y_0 = 0$. The L-shaped line corresponds to the first special case, while the U-shaped line to the second special case. In the left panel, we plot the logarithm of real GDP relative to the previous peak in each recession. There seems to be a similarity among recessions except the Great Recession. In fact, Morley and Piger [2012] show that in general a U-shaped model is better than an L-shaped model using the pre-2008 sample, implying that effect of a recession on real GDP is largely transitory. However, the recent financial crisis challenges the notion that a recession has negligible long-run effects on real GDP. Eo and Kim [forthcoming], who allow for mean growth drift across booms and recessions, write "one important finding ... is the existence of high growth recoveries that *typically* follow deep recessions" (emphasis added). While we also find this a "typical" pattern, the slow recovery from the recent recession demonstrates that not all recoveries are typical, casting doubt on the prediction from the U-shaped model, which says that output will return to its pre-crisis trend level soon after the recession ends.

2.2 Methodology Incorporating Uncertain Shapes of Recoveries

We estimate equations (1)-(3) while allowing for uncertainty in the shape of each recovery. $\Phi, \mu, \gamma, \lambda, \sigma^2$, and q are held constant across business cycles. The above model becomes an autoregressive model given κ. Therefore, the uncertainty in the shape of each recovery depends on the Bayesian models weights among the values of κ for which the appropriate element takes on a 1 versus a 0.

Our approach is based on Bayesian model averaging. Conditional on a specific κ, we draw random samples from the posterior distribution of all model parameters conditional on the data D, $f(\mu, \gamma, \lambda, \Phi, \sigma^2|D, \kappa)$, which is straightforward using Gibbs sampling. Let $M = \{M_1, \ldots, M_K\}$ be the model space considered. The marginal likelihood, $Pr(D|M_k)$, can be evaluated using Chib [1995]'s method. Once the marginal likelihoods for all models are obtained, and posterior probability for model M_k is given by

$$Pr(M_k|D) = \frac{Pr(D|M_k)Pr(M_k)}{\sum_{l=1}^{K} Pr(D|M_l)Pr(M_l)}$$

Following Hoeting et al. [1999], the posterior mean and variance of quantity of interest, denoted by Δ, are as follows:

$$E(\Delta|D) = \sum_{k=0}^{K} \hat{\Delta}_k Pr(M_k|D),$$
$$Var(\Delta|D) = \sum_{k=0}^{K} [Var(\Delta|D, M_k) + \hat{\Delta}_k^2] Pr(M_k|D) - [E(\Delta|D)]^2,$$

where $\hat{\Delta}_k = E(\Delta|D, M_k)$. Specifically, elements in $E(\kappa|D)$ provide us with the posterior probability for the corresponding recession to have a U-shaped recovery.

3 Results for US Real GDP

3.1 Data and Priors

The data set consists of U.S. quarterly real GDP from 1947:1 to 2015:1, available on the website of the Federal Reserve Bank of St. Louis. The number of autoregressive lags is set to 4, even though the preferred specification in Kim et al. [2005] was zero and our posterior results are largely in agreement. We take account of a possible mean growth rate slowdown (Perron and Wada [2009]) by assuming $\mu = \mu_0 + BD_t\mu_1$, where $BD_t = 1$

after 1973:1.[2]

Kim et al. [2005] choose $q = 6$ using the Schwarz information criterion (reporting that their results are robust to other choices for q), meaning that rapid post-recession growth lasts for 6 quarters. In a Bayesian framework, it is easy to expand the choice for q by estimating separate models for q equal to 5, 6 or 7, and then reporting Bayesian model averages. We report Bayesian model averages, although we find results little different from simply setting $q = 6$.

We assume that parameters are *a priori* independently distributed across blocks, so that the joint prior can be expressed as the product of marginal priors. The coefficients of the mean function, $[\mu_0, \mu_1, \gamma, \lambda]'$, are assumed to be normally distributed with mean $[1, 0, -1, 1]'$ and standard deviations equal to 10. The prior mean is largely consistent with the estimate shown in Kim et al. [2005], but the standard deviation is large enough to cover a parameter space in which the nonlinearity in mean function is absent ($\gamma = \lambda = 0$). The autoregressive parameters, ϕ, are assumed to follow a normal prior with mean zero and standard deviation equal to 1. The prior for σ^2 is inverted Gamma $IG(2, 1)$.[3] The same priors are used for all estimates.

Throughout this paper, all inferences are based on 10,000 Gibbs simulations, after discarding the initial 1,000 Gibbs simulations in order to mitigate the effects of initial conditions.

3.2 Posterior Results

Table (1) reports the posterior results, averaging over the three values of q. We find posterior model probabilities of $Pr(q = 5|D) = .16$, $Pr(q = 6|D) = .43$, and $Pr(q = 7|D) = .41$. The posterior distribution of μ_1 indicates that there is a substantial slowdown in the mean growth rate after 1973. Negative γ implies lower GDP growth during recessions, as expected. Positive λ implies the existence of a strong economic recovery after U-shaped

[2]We also estimate our model with a break date at 2006:1, as suggested by Luo and Startz [2014]. Results are robust except for minor quantitative differences.

[3]The density is $f_{IG}(z; a, b) \propto z^{-(a+1)} exp(-b/z)$. Mean is defined for $a > 1$, and variance is defined for $a > 2$.

Table 1: Posterior Results for Real GDP

Parameter	Prior Mean	Prior Std.	Post. Mean	Post. Std.	95% HPD
μ_0	1	10	1.1716	0.0973	[0.9777, 1.3588]
μ_1	0	10	-0.3117	0.1125	[-0.5307, -0.0886]
γ	-1	10	-1.5003	0.1213	[-1.7353, -1.2601]
λ	1	10	0.1843	0.1228	[0.0925, 0.2830]
ϕ_1	0	1	-0.0135	0.0641	[-0.1385, 0.1136]
ϕ_2	0	1	0.0473	0.0627	[-0.0759, 0.1698]
ϕ_3	0	1	-0.0065	0.0632	[-0.1304, 0.1177]
ϕ_4	0	1	-0.0241	0.0634	[-0.1473, 0.1001]
σ^2	1	na	0.7325	0.0323	[0.6723 0.7992]

Notes: Table reports the posterior estimates of the model parameters. Std. is standard deviation. HPD is the highest posterior density region.

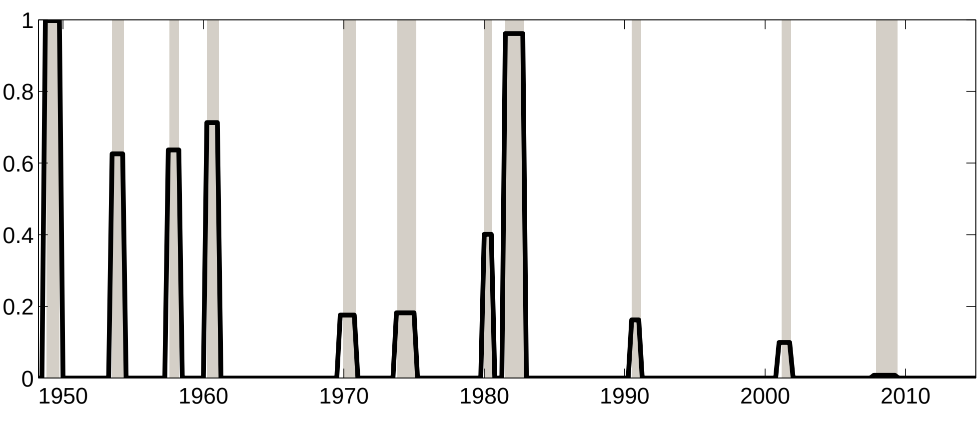

Figure 2: Probability of U-shaped Recession for Real GDP

recessions. Consider a recession that lasts exactly two quarters if the process for GDP were to be described by the posterior means with $q = 6$. An L-shaped recovery would involve a permanent loss of 3 percent of GDP ($2 \times \gamma$) relative to the absence of a recession. In contrast, by the end of the bounce-back period in a U-shaped recession all but 3/4 of one percent of GDP will have been recovered. The latter calculation comes from multiplying γ by 2 and then adding λ times the ones in equation (3) (two periods with a single lagged $s = 1$ and five periods with two lagged s=1).

In Figure (2), we plot the posterior probability of being U-shaped for each recession. There are obvious differences across recessions. Four early recessions before 1970 and the one in 1981 are very likely to have experienced rapid post-recession recovery. For the rest, except the recession started at 1980, the probability of being U-shaped is very small. The losses in output during these recessions, including the most recent one, are likely to be permanent.

3.3 Permanent Component of Real GDP

Note that we assume that real GDP is an I(1) process, the permanent, or trend, component of real GDP consists of a drift component and a stochastic trend component. To investigate the extent to which declines in real output can be attributed to the permanent component in each past recession, we need to conduct a trend-cycle decomposition. In particular, we use the Beveridge and Nelson [1981] decomposition (BN hereinafter).

Given a reduced form autoregressive model, the BN trend is constructed according to the long-horizon conditional forecast of the time series minus any deterministic drift. However, Morley and Piger [2008] show that the BN trend does not generally provide an optimal or even unbiased estimate of trend for a regime-switching process, e.g., our model (1). We thus use a modified BN trend used in Morley and Piger [2012] to obtain the permanent component of real GDP.

We need to take account of the nonlinear dynamic introduced by s_t and u_t. Let

$$H = \begin{bmatrix} 1 & 0 & \dots & 0 \end{bmatrix}, \quad F = \begin{bmatrix} \phi_1 & \phi_2 & \cdots & \phi_4 \\ 1 & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ 0 & 0 & 1 & 0 \end{bmatrix},$$

then equations (1)-(3) can be written in a state-space form as follows:

$$\begin{aligned} \Delta y_t - m_t &= H x_t, \\ x_t &= F x_{t-1} + \tilde{\epsilon}_t, \end{aligned}$$

where $\tilde{\epsilon}_t = [\epsilon_t, 0, \dots, 0]'$. Morley and Piger [2012] define the regime-dependent steady state (RDSS) trend as follows:

$$\begin{aligned} \tau_t^{RDSS}(\tilde{s}_t) =& y_t + HF(I-F)^{-1}(\Delta\tilde{y}_t - \tilde{m}_t) \\ &+ \sum_{j=1}^{\infty} \left(E\left[m_{t+j} | \{s_{t+k} = i^*\}_{k=1}^{j}, \tilde{s}_t, \Omega_t \right] - \bar{m}_{i^*} \right), \end{aligned}$$

where $\tilde{s}_t = (s_t, \dots, s_{t-q})'$ is a vector of relevant current and past regimes for forecasting a time series, $\Delta\tilde{y}_t = (\Delta y_t, \dots, \Delta y_{t-p+1})'$, $\tilde{m}_t = (m_t, \dots, m_{t-p+1})'$, and $\bar{m}_{i^*}$ is the mean function evaluated at regime i^*. The regime i^* is the "normal" regime in which the mean of the transitory component is assumed to be 0, thus it is $i^* = 0$ in our model.[4]

For a given model, we calculate the RDSS trend with the posterior mean of model parameters. Thus, the model-averaged trend component can be computed using the model probabilities as weights.

In Figure (3) we show the "output gap" measured by the difference between real GDP and model-averaged trend during each recession. Because a U-shaped recession implies a relatively small difference between pre- and post-recession trend, we find substantial output gaps during recessions before 1970 and during the 1982 recession. On the other

[4]Because Morley and Piger [2012] treat s_t as unobserved state variable, they then marginalize out s_t using Hamilton filter and obtain a RDSS trend unconditionally on s_t. We do not do this because we treat s_t as an exogenous regressor.

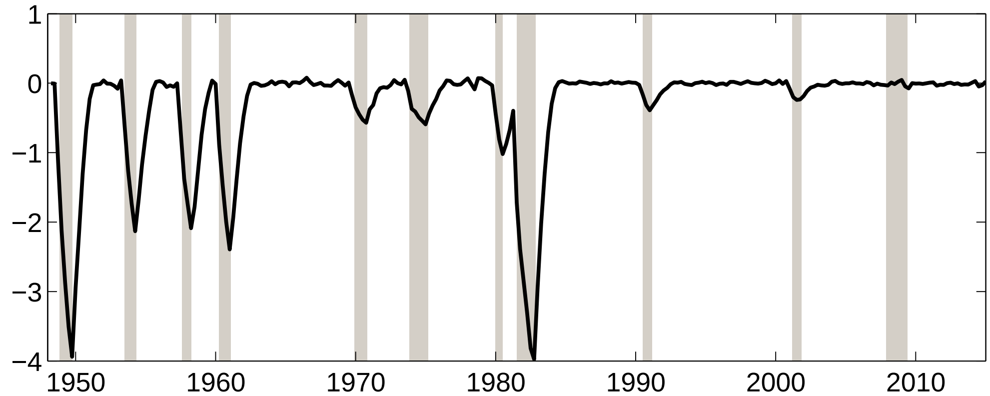

Figure 3: Beveridge-Nelson Cycle of Real GDP During Recessions.

hand, real GDP in the recent three decades has been dominated by stochastic trend component.

4 Components of Real GDP

In this section, we extend our analysis to components of real GDP to see whether components share the same recovery paths as total GDP. Three series are considered: durable consumption, nondurable consumption and domestic investment.[5] A structural break at 1973:1 and same set of priors are assumed as those assumed for total GDP. As with GDP, all variables used here and in the following sections are transformed as $100(\ln X_t - \ln X_{t-1})$.

Posterior estimates are shown in Table 2 and the probabilities of U-shaped recoveries are presented in Figure 4. The drop in growth after the break date is large and significant for nondurable consumption. The posterior mean for the drop is fairly small for durable consumption and while investment shows a moderately sized post-break increase in growth, but in both cases the posterior mean in absolute value is less than one posterior standard deviation.

The relative behavior of the three components during recessions is broadly consistent

[5]Data consist of real personal consumption expenditures: nondurable goods (DNDGRA3Q086SBEA), real personal consumption expenditures: durable goods (DDURRA3Q086SBEA), and real gross private domestic investment, 3 decimal (GPDIC96) from FRED.

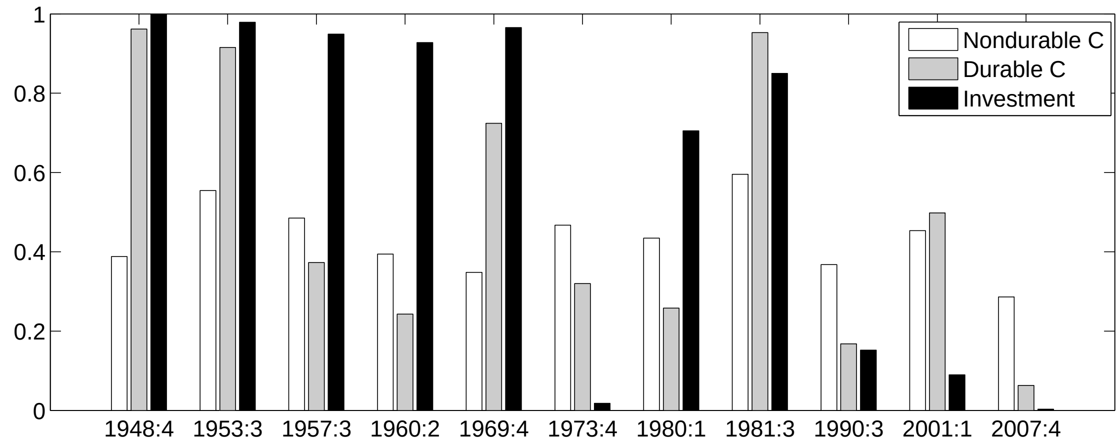

Figure 4: Probability of U-shaped Recession for Consumption and Investment Data

with consumption smoothing for nondurables and accelerator behavior for durables and investment. Nondurable consumption roughly levels off rather than continuing to grow during a (post-break) recession. In contrast durable consumption and investment both decline substantially.

During U-shaped recessions, both durable consumption and investment show significant rapid recovery. For nondurable consumption, λ is estimated to be close to zero but is not well-identified by the data.

In Figure 4 we present the posterior probabilities of U-shaped recoveries following each recession for the three GDP components. The estimates for investment are fairly similar to those for GDP overall, with a slightly greater tendency to be U-shaped during early recessions.[6] Generally durable consumption expenditures are a bit more likely to be U-shaped than is GDP. There is little to be said about whether nondurable consumption is U-shaped, which is unsurprising given that λ for nondurables has a small point estimate and not well-identified.

[6]The results for investment largely reflect the behavior of residential investment. Separate estimates for nonresidential investment result in values of λ with the wrong sign.

Table 2: Posterior Results for Consumption and Investment Data

	Consumption:				Investment:	
	Nondurable		Durable			
	Mean	Std.	Mean	Std.	Mean	Std.
μ_0	0.9080	0.0770	1.5739	0.3552	1.2672	0.4306
	[0.7567, 1.0589]		[0.8754, 2.2729]		[0.4062, 2.1185]	
μ_1	-0.2659	0.0890	-0.1048	0.4171	0.3359	0.5044
	[-0.4424, -0.0925]		[-0.9342, 0.7117]		[-0.6515, 1.3700]	
γ	-0.7709	0.1137	-3.0300	0.4976	-6.5458	0.6207
	[-0.9907, -0.5453]		[-3.9910, -2.0375]		[-7.7502, -5.3174]	
λ	0.0942	2.4798	0.6460	0.2815	1.1175	0.2549
	[-1.4202, 3.4482]		[0.2188, 1.0853]		[0.6497, 1.6267]	
ϕ_1	-0.0952	0.0630	-0.2062	0.0644	-0.0655	0.0613
	[-0.2183, 0.0273]		[-0.3318, -0.0792]		[-0.1849, 0.0559]	
ϕ_2	0.0179	0.0623	0.1035	0.0653	0.0717	0.0582
	[-0.1041, 0.1407]		[-0.0248, 0.2321]		[-0.0412, 0.1855]	
ϕ_3	0.0476	0.0621	-0.0110	0.0641	-0.0005	0.0584
	[-0.0739, 0.1697]		[-0.1366, 0.1157]		[-0.1152 0.1148]	
ϕ_4	-0.0507	0.0614	-0.0546	0.0624	-0.2200	0.0585
	[-0.1709, 0.0695]		[-0.1773, 0.0684]		[-0.3338, -0.1042]	
σ	0.7152	0.0313	3.3451	0.1484	3.7471	0.1659
	[0.6573 0.7796]		[3.0692 3.6516]		[3.4399 4.0916]	

Notes: Table reports the posterior estimates of the model parameters. Std. is standard deviation. HPD in brackets.

5 Labor market data

The labor market is commonly believed to be a procyclical and lagging variable with respect to real GDP. We are interested in whether the post-recession recovery in the labor market has the same shape as that for real output after adjusting for lags. We apply our model to labor hours and to the employment-to-population ratio[7] with the NBER dates lagged one quarter and no structural break considered. We again use the same diffuse priors. Estimation results are presented in Table 3 and recovery shape probabilities are plotted in Figure 5. The probability of U-shaped recoveries for labor hours is remarkably similar to that of real GDP, suggesting that labor plays an important role explaining the sluggish recoveries in US economy. The posterior mean for labor hours is much larger than the mean for GDP, but there is considerable overlap in the respective HPD regions.

For employment data, the post-recession recoveries seem much less likely to have the bounce-back effects. Only three recessions, out of eleven, exhibit a high probability of a U-shaped recovery. The posterior distribution of λ mostly falls on the positive side, but also spreads quite widely. Thus it is unclear whether the post-recovery bounce-back effects are strong or not for the employment-to-population ratio.

Beveridge-Nelson cycles for the employment data are plotted in Figure 6. No large negative gaps are found since the mid-1980s, coinciding with the low probability of U-shaped recoveries in recent years.

6 Total factor productivity

We apply here the same model to total factor productivity(TFP), measured by data constructed by John Fernald (Fernald [2014]), and find a rather different picture from the results above.[8] We estimate that trend TFP growth fell from 2.3 percent to 1 percent after 1973. TFP drops drastically during recessions, with 4.4 percent of TFP lost in quarter of

[7]Labor hours are measured by hours of all persons in the business sector: (HOABS), and for employment we use the Civilian Employment-Population Ratio (EMRATIO) from FRED.

[8]Data set is available at http://www.frbsf.org/economic-research/economists/jfernald/quarterly_tfp.xls

Table 3: Posterior Results using Employment data

	Employment-to-population ratio			Labor Hour		
	Mean	Std.	95% HPD	Mean	Std.	95% HPD
μ	0.1138	0.0392	[0.0337, 0.1891]	1.6536	0.2823	[1.0802 2.2081]
γ	-0.8026	0.0706	[-0.9381, -0.6605]	-5.2734	0.5939	[-6.3990 -4.0730]
λ	0.1376	0.1418	[0.0741, 0.2006]	0.7382	0.5187	[-0.0573 1.3179]
ϕ_1	0.1910	0.0650	[0.0648, 0.3205]	0.3110	0.0698	[0.1749 0.4486]
ϕ_2	0.0042	0.0639	[-0.1205, 0.1307]	0.0018	0.0649	[-0.1249 0.1296]
ϕ_3	0.0679	0.0638	[-0.0566, 0.1927]	0.0079	0.0655	[-0.1205 0.1359]
ϕ_4	0.0392	0.0635	[-0.0854, 0.1633]	-0.0281	0.0650	[-0.1556 0.0997]
σ^2	0.3695	0.0163	[0.3395, 0.4032]	2.5934	0.1156	[2.3795 2.8323]

Notes: Table reports the posterior estimates of the model parameters. Std. is standard deviation. HPD is the highest posterior density region.

Figure 5: Probability of U-shaped Recession for labor market data

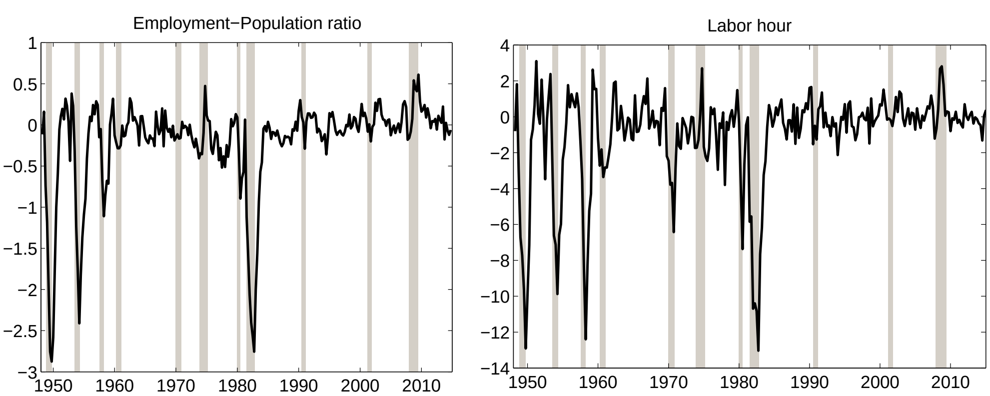

Figure 6: Beveridge-Nelson Cycle of Employment and Labor Hours During Recessions

Table 4: Posterior Results using TFP

Parameter	Prior Mean	Prior Std.	Post. Mean	Post. Std.	95% HPD
μ_0	1	10	2.2977	0.3070	[1.6946, 2.9089]
μ_1	0	10	-1.3287	0.3579	[-2.0410, -0.6263]
γ	-1	10	-4.4126	0.5025	[-5.3823, -3.4048]
λ	1	10	0.7293	0.1396	[0.4573, 1.0002]
ϕ_1	0	1	-0.0758	0.0634	[-0.1987, 0.0491]
ϕ_2	0	1	0.0296	0.0628	[-0.0925, 0.1530]
ϕ_3	0	1	-0.0503	0.0622	[-0.1719, 0.0722]
ϕ_4	0	1	-0.1020	0.0628	[-0.2242, 0.0222]
σ^2	1	na	2.9006	0.1296	[2.6600, 3.1645]

Notes: Table reports the posterior estimates of the model parameters. Std. is standard deviation. HPD is the highest posterior density region.

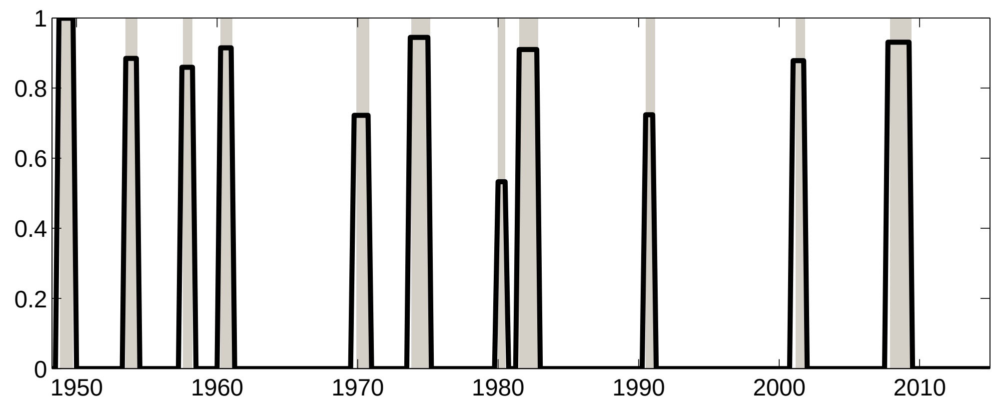

Figure 7: Probability of U-shaped Recession for TFP

a recession. In other words, a two-quarter recession undoes nine quarters of trend growth after 1973. However, the magnitude of the bounce-back is large and well-identified. In fact, with $q = 6$ the bounce-back essentially completely offsets the loss of a two-quarter recession.

Are TFP recoveries U-shaped? Yes. The posterior results shown in Figure 4 indicate that TFP growth exhibits a highly probable bounce-back recovery after every recession, with the possible exception of 1980. This evidence suggests that US recessions are not associated with a permanently lower level of TFP, echoing Fernald's conclusion (page

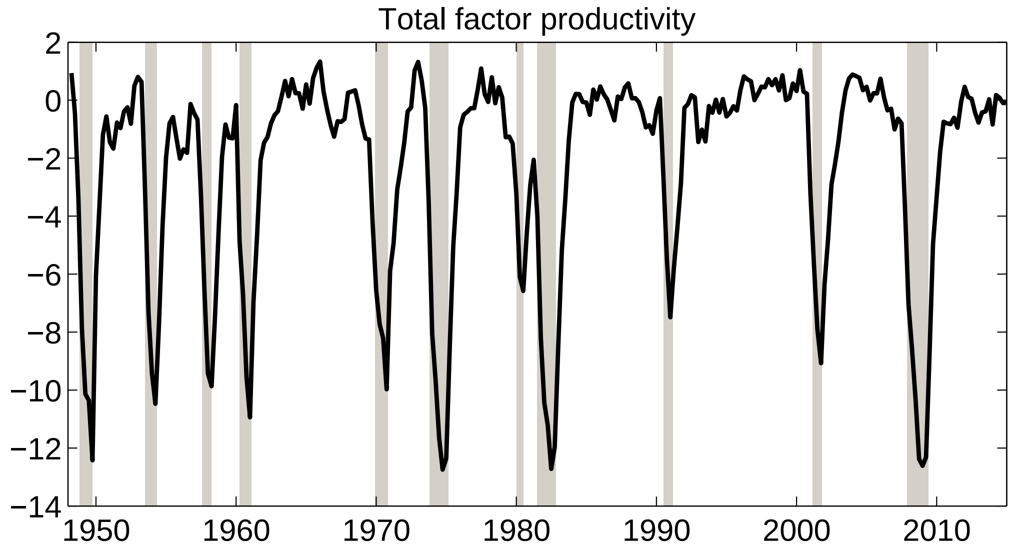

Figure 8: Beveridge-Nelson Cycle for Total Factor Productivity

12) "Overall, there is little empirical evidence for developed countries that business cycles (financially related or otherwise) permanently harm the level or growth rate of TFP." The conclusion is reinforced by Figure 8, which illustrates the complete recovery of cyclical TFP after each recession, with the exception of 1980 where the recovery was cut short by a double-dip.

In addition to calculating TFP, Fernald [2014] provided values for labor productivity and for capital deepening. We applied our model to the data for labor productivity, with results shown in Table 5 and in Figures 9 and 10. Recoveries in terms of labor productivity are very strong. The mean bounce-back effect is the same size as the bounce-back for TFP, despite the fact that the recession drop is only half as large as the drop for TFP. As can be seen in Figure 10, there is essentially full recovery of the cyclical component of labor productivity after every recession. Figure 9 shows that most recessions appear to have been U-shaped, and that this was especially true during the three most recent episodes.

Results for capital deepening were inconclusive and therefore are omitted. Specifically, the 95 percent HPD for the bounce-back effect ranged from -1.0 to 0.7 and the estimated probabilities of a U-shaped recession were all between 0.3 and 0.7.

Table 5: Posterior Results using labor productivity

Parameter	Prior Mean	Prior Std.	Post. Mean	Post. Std.	95% HPD
μ_0	1	10	3.0733	0.3288	[2.4298 3.7207]
μ_1	0	10	-1.3938	0.3854	[-2.1581, -0.6385]
γ	-1	10	-2.2335	0.5055	[-2.1581, -0.6385]
λ	1	10	0.7460	0.1467	[0.4544, 1.0327]
ϕ_1	0	1	-0.0321	0.0621	[-0.1546 0.0902]
ϕ_2	0	1	0.0441	0.0618	[-0.0770 0.1666]
ϕ_3	0	1	-0.0303	0.0614	[-0.1504 0.0904]
ϕ_4	0	1	-0.0882	0.0617	[-0.2089 0.0328]
σ^2	1	na	2.8719	0.1273	[2.6359 3.1348]

Notes: Table reports the posterior estimates of the model parameters. Std. is standard deviation. HPD is the highest posterior density region.

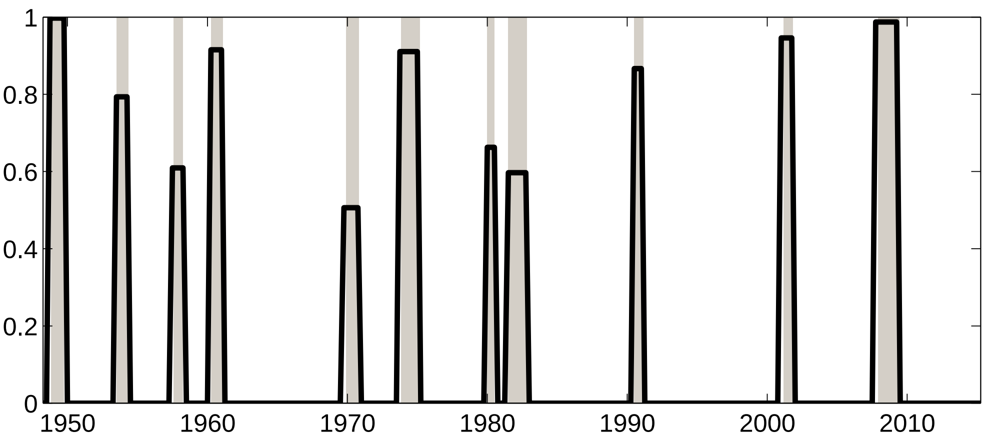

Figure 9: Probability of U-shaped Recession for Labor Productivity

Figure 10: Beveridge-Nelson Cycle for Labor Productivity

7 Conclusion

We use a Bayesian model averaging framework to identify the individual shapes for each recession's recovery phase. We find that for recessions before 1970s and the one starting in 1982, there is a high probability for rapid post-recession growth. Thus these recessions had mostly temporary effects on the growth path. For other recessions, especially the recent ones, recessions likely leave permanent effects shifting down the growth path. Some components of GDP, durable consumption and investment, as well as labor hours and the employment-to-population ratio largely share the same recovery patterns. Total factor productivity appears to always have a rapid, U-shaped recovery.

Our empirical findings make two points that may inform business cycle theory. The first point is a question: What seems to have changed in the nature of the economy between the first half and the second half of the post-War period? Why do recessions now seem to have longer lasting effects? The second point is to emphasize how different is the behavior of TFP, as TFP appears to recover more quickly from recessions than does GDP. Models which wish to account for the cyclical behavior of the macroeconomy ought to take this into account.

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