

# Why Is the Aggregate Supply Curve Non-Linear?

—Asymmetric Effects of Money Supply  
Shocks and a Sticky Price Theory—

Takashi Senda

## **Abstract**

This paper asks why the aggregate supply curve is non-linear, and examines whether a sticky price theory can explain asymmetric effects of money supply shocks. A sticky price theory predicts that money supply shocks have asymmetric effects on output when trend inflation is positive while the shocks have symmetric effects when trend inflation is zero. The purpose of this paper is to test this prediction empirically by using annual data for the United States. The gold standard period is considered to be the period of zero trend inflation, and the postwar period to be the period of positive trend inflation. In conclusion, this paper shows a null hypothesis that the effects of money supply shocks on output are symmetric is rejected when trend inflation is positive, but that the same null hypothesis cannot be rejected when trend inflation is zero. This result is consistent with the sticky price theory.

## **1. Introduction**

In the last few years, a number of articles have reported that money

supply shocks have asymmetric effects on output. An unexpected fall in the money supply reduces output substantially, while a rise in money supply has a smaller effect on output. In the context of monetary policy, this asymmetry implies that easy monetary policy is powerless against recessions, whereas tight policy can check a boom. Examples of this line of work are Cover (1992), De Long and Summers (1988), Morgan (1993), Rhee and Rich (1995), Karras (1996a, b) and Chu and Ratti (1997).

Many economists (e.g. Tobin. 1972) have attributed the asymmetric effects of money supply shocks to asymmetric price adjustment, or in other words, a convex aggregate supply curve. Price adjustment is asymmetric because prices are more sticky downwards than upwards. Asymmetric price adjustment is equivalent to a convex aggregate supply curve because, when price adjustment is asymmetric, the aggregate supply curve becomes relatively flat for decreases in demand but steep for increases in demand. Asymmetric price adjustment (or a convex aggregate supply curve) can explain why the effects of money supply shocks are asymmetric: Decreases in the money supply reduce real output substantially because prices are downward rigid. On the other hand, increases in the money supply often fail to increase real output because prices are flexible in the upward direction.<sup>1)</sup>

Then, why is the aggregate curve convex (or nonlinear)? To put it another way, why are prices more flexible when going up than when going down? Though it has been argued that nominal rigidities are asymmetric, these asymmetries are often not explained but rather assumed in theoretical economic models – and such theoretically arbitrary assumptions are attacked by new classical economists.

---

1) De Long and Summers (1988) regress changes in real output on (nominal) aggregate demand shocks and find that shifts in aggregate demand have asymmetric effects on real output. Their finding suggests that the aggregate supply curve is indeed convex.

Several researchers such as Tsiddon (1993), Ball and Mankiw (1994a), and Caballero and Engel (1992) have attempted to solve the puzzle by providing a possible microeconomic foundation for asymmetric price adjustment—and, let us call it a *sticky price theory*. This paper examines a sticky price theory, in particular the one developed by Ball and Mankiw (1994a). By employing a sticky price model, Ball and Mankiw show that positive trend inflation can produce the asymmetric effects of money supply shocks. The logic of their theory is the following: along with price adjustment costs, positive trend inflation brings about the downward rigidity of prices, and this downward rigidity of prices induces asymmetry in the effects of money supply shocks.

Since trend inflation plays an important role in the sticky price theory, it is important to look carefully into the relationship between trend inflation and the degree of asymmetry in the effects of money supply shocks. The theory speculates about the relationship between the asymmetric effects of money supply shocks and trend inflation:

*(\*) With price adjustment costs, positive trend inflation brings about asymmetric price adjustment—prices are adjusted upward more quickly than they are adjusted downward—and then this asymmetric price adjustment leads to the asymmetric effects of money supply shocks. By contrast, zero trend inflation induces price adjustment to be symmetric, and that leads to the symmetric effects of money supply shocks.*

As mentioned above, a number of empirical studies have already shown that the effects of money supply shocks are asymmetric. Since those studies analyze the postwar period when trend inflation is positive, those findings are consistent with the theory. Yet, no studies have ever tried to examine the effects of money supply shocks with zero inflation.<sup>2)</sup> If positive trend inflation causes asymmetric price adjustment and if this asymmetric

price adjustment brings about the asymmetric effects of money supply shocks, then one should observe *symmetric* effects of money supply shocks when trend inflation is zero. The purpose of this paper is to conduct an empirical investigation to see if there is empirical evidence to support the prediction of the sticky price theory (\*). This test procedure will determine whether the sticky price theory offers a valid explanation for the asymmetric responses to money supply shocks.

This study considers the gold standard period to be the period of zero inflation. In conclusion, a null hypothesis that money supply shocks have symmetric effects on output cannot be rejected under price stability. In contrast, the same null hypothesis is rejected under positive trend inflation. This empirical evidence supports the sticky price theory.<sup>3)</sup>

The rest of the paper is organized as follows: Section 2 discusses preceding theoretical and empirical research on the asymmetric effects of money supply shocks. Section 3 describes the data set. Section 4 explains my empirical procedure and section 5 presents the results. I use those results to evaluate the predictions of the sticky price theory. Finally, section 6 offers conclusions.

## 2. Literature Survey

### 2.1 Evidence of Asymmetry

In recent years, a number of empirical studies have presented evidence that money supply shocks have asymmetric effects; that is, unexpected

---

2) Until the end of the 1920's, it was believed that the impact of monetary policy was symmetric. See Hansen (1941). My concern is to examine whether the effects of monetary policy were indeed symmetric during that period.

3) My companion study (Senda 1998) examines prewar and postwar data for OECD countries and finds that the cross-country evidence also supports the predictions of the sticky price theory. This companion study, however, does not perform any hypothesis testing on individual regression coefficients.

negative changes in the money supply slow the economy more than unexpected positive changes accelerate the economy. Research on the asymmetric effects of money supply shocks started from Cover's (1992) robust and convincing fact finding, and his findings were later confirmed by De Long and Summers (1988) and Morgan (1993). What these researchers found is a nonlinear relationship between money supply shocks and their effects on output: unanticipated increases in the money supply raise output less than unanticipated decreases in the money supply reduce output.

In the late 1970s and the 1980s, a large number of studies have been conducted on the effects of unanticipated money growth on output. In most of these studies, changes in money supply are decomposed into anticipated components and unanticipated components, and then the decomposed components are used to test the "rational expectation" monetary models. The rational expectation theories argue that only unanticipated movements in money affect output while anticipated movements have no effect on output. The method of the decomposition is the following: First, one specifies a money supply equation that is supposed to be used by agents to make a one-period-ahead forecast of money movements. The money supply equation can be specified based on either economic theory or an atheoretical statistical procedure.<sup>4)</sup> Using the money supply equation, one can estimate anticipated and unanticipated monetary movements. Since unanticipated movements are the portions of monetary movements that the money supply equation fails to capture, the unanticipated component is equal to the residual in the money supply

---

4) There are at least two ways to specify the money supply equation, that is, a procedure based on economic theory such as Barro (1977, 1978), and an atheoretical statistical procedure such as Mishkin (1982). Another important empirical study on this topic is by Frydman and Rappoport (1987).

equation. Next, by regressing output on both the anticipated and unanticipated changes in the money supply, one can determine whether these anticipated and unanticipated components affect output. Barro's (1977, 1978) research is a typical empirical study showing that only the unanticipated part of money movements has an effect on output.

Thus far, research on the effects of unanticipated changes in the money supply (or money supply shocks) on output such as in Barro (1977, 1978) and Mishkin (1982) has implicitly assumed that the effects are symmetric, i.e., that positive (unanticipated) changes in the money supply affect output as much as negative changes do. In contrast to this symmetric assumption, Cover (1992) shows that it is important to distinguish between positive money supply shocks and negative money supply shocks. He divides money supply shocks into those that are positive vs. negative, and regresses output on positive and negative shocks separately. By employing well-tested money supply models such as Barro and Rush (1980) and Mishkin (1982), he examines postwar U.S. quarterly data and shows that positive and negative money supply shocks have asymmetric effects on output. In reaction to Cover's finding, De Long and Summers (1988) analyze annual U.S. data for a variety of sample periods (post-WWII, pre-WWII, and pre-Depression); they also find that negative shocks have larger effects on output than positive shocks. Morgan (1993) uses the federal funds rate and the Boschen-Mill index (which is constructed from the statements of policymakers) in place of the money supply, and examines how unexpected changes in the federal funds rate or the stance of monetary policy affects output. Again, the results indicate that the impact of monetary policy is asymmetric. For international evidence, Karras (1996a) applies a similar analysis to European countries and concludes that this asymmetric effect is a European phenomenon as well. Chu and Ratti (1997) show in full detail that an asymmetry exists between the effects of

positive and negative money shocks for Japan.<sup>5)</sup>

## 2.2 Theoretical Studies

Theoretical reasons for this asymmetric effect can be classified into two main groups. In order to illustrate two groups of reasons, it is useful to divide the monetary transmission mechanism from money supply shocks to real output into two stages. The first stage is a transmission from money supply shocks to (nominal) aggregate demand. The monetary authorities control monetary aggregates as their policy instruments. Unanticipated changes in the money supply induce changes in interest rates, which lead aggregate demand (or nominal output) to vary. In the aggregate supply-aggregate demand (AS-AD) diagram, the changes in aggregate demand caused by monetary policy can be described as shifts in the aggregate demand curve. In the second stage, the variations of nominal output are decomposed into changes in the price level and real output. This decomposition corresponds to the slope of the aggregate supply curve.

In view of the argument above, one can classify reasons for asymmetry

---

5) There is a reason for economists to be excited about finding this asymmetry. This asymmetric effect suggests that demand stabilization is desirable: policymakers could raise average output by reducing fluctuations in aggregate demand. Large fluctuations in aggregate demand imply a large boom and a severe recession. Since the output gain from a boom is smaller than the output loss from a recession, the net output loss is large when demand fluctuates a lot. By contrast, since small fluctuations in aggregate demand mean a small boom and a mild recession, the net output loss is small when the variation in aggregate demand is small. Hence, if policymakers respond promptly to demand shocks and reduce the variance of aggregate demand, they can raise average output because the net output loss becomes small. A theoretical study by Ball and Mankiw (1994a) does not conclusively support this De Long and Summers' (1988) conjecture. For an empirical work, Laxton, Meredith, and Rose (1995) use data for the G-7 countries, and find that their results support the conjecture.

into two groups:

(1) *A convex aggregate supply curve.*

Changes in the money supply induce symmetric shifts in aggregate demand, but the shifts in aggregate demand have asymmetric effects on real output. When aggregate demand rises, real output may not increase much because prices are flexible upward. In contrast, since prices are sticky downward, a fall in aggregate demand will reduce real output substantially. This asymmetric response is caused by asymmetric price adjustment, and this idea is often illustrated with a convex aggregate supply curve (see Figure 1).

(2) *“Pushing on a string.”*

Changes in money supply have asymmetric effects on aggregate demand; that is, positive money supply shocks shift aggregate demand upward less than negative money supply shocks shift aggregate demand downward (see

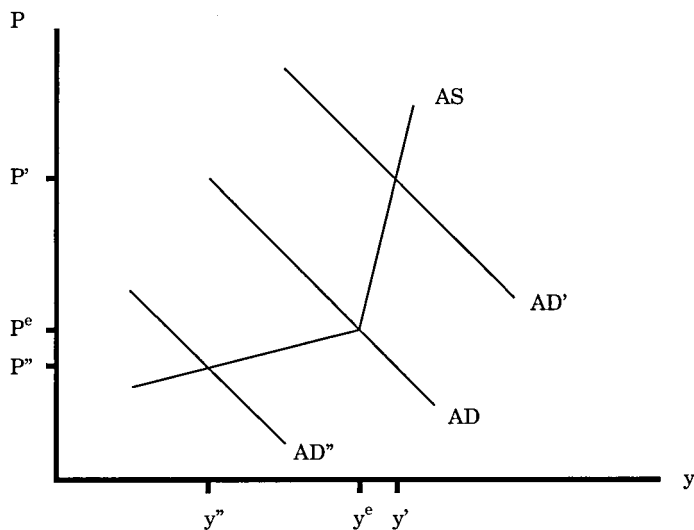


Figure 1 A Convex Aggregate Supply



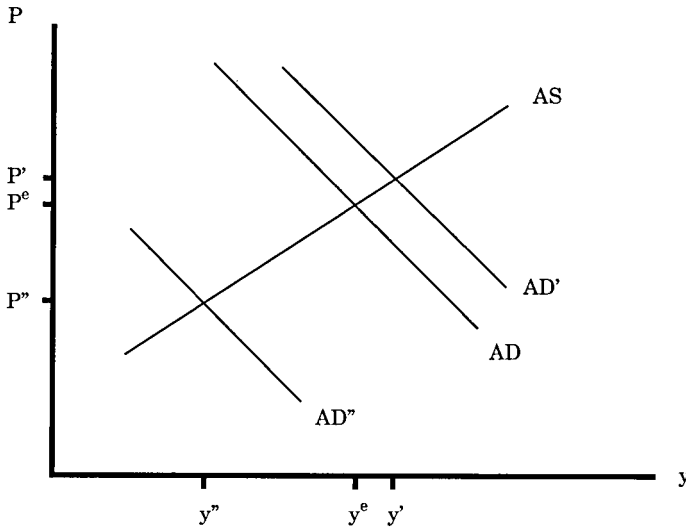


Figure 2 “Pushing on a String”

Figure 2). Possible reasons are the interest unresponsiveness of expenditures, the liquidity trap, credit constraints, etc.

This paper focuses on the first reason—a convex aggregate supply curve.<sup>6)</sup> While traditional Keynesian economists have explained the asymmetric effects of shocks by simply assuming a convex aggregate supply curve, Tsiddon (1993), Ball and Mankiw (1994a), and Caballero and Engel (1992) advance the argument one step further and attempt to provide a reason why the aggregate supply curve is convex. By doing so, they provide new insights into price adjustment. A common feature in their models is *positive trend inflation*. The logic of the theory is the following: along with price adjustment costs, positive trend inflation brings about the

---

6) Though there are two groups of reasons that can account for the asymmetric effects of money supply shocks, if one is able to find predictions that are unique to the first reason but irrelevant to the second one, he or she can test the validity of the first reason based on the predictions. This is what I do in this paper.

downward rigidity of prices, and this downward rigidity of prices induces asymmetry in the effects of money supply shocks.

Tsiddon (1993) tries to solve a non-zero drift two-sided ( $s, S$ ) model analytically, but in the end, he settles for 'an approximation' of the solution. Ball and Mankiw (1994a) add some time-contingency to an ( $s, S$ ) model in order to make their model more tractable than a pure ( $s, S$ ) model. Caballero and Engel (1992) simulate a pure ( $s, S$ ) model.

### 2.3 Recent Development of Empirical Studies

Though the purpose of the first empirical studies of asymmetry was simply to find evidence in support of asymmetry, recent empirical studies such as Rhee and Rich (1995), Karras (1996b), and Buckle and Carlson (1996) have attempted to identify the possible reasons for asymmetry. Inspired by the progress made in the theoretical work, these researchers conduct tests of the predictions of the theoretical models, namely, the implied relationship between trend inflation and the degree of asymmetry in the effects of money supply shocks.

Rhee and Rich (1995) examine postwar U.S. data and investigate the relationship between average inflation and the asymmetric effects. By using a Markov switching model, they divide the postwar period into three inflation regimes: low-inflation (mean inflation is 3.0 %), medium-inflation (5.8 %), and high-inflation (8.8 %) regimes. They then compare three inflation regimes with the asymmetric effects, and find that the degree of asymmetry is positively related to movements in average inflation. (In other words, the higher the average inflation, the larger the degree of asymmetry.) Karras (1996b) attempts to measure the convexity of the aggregate supply curve by estimating the effects of money supply shocks on *prices*. As shown in Figure 1, if the aggregate supply curve is convex, positive money supply shocks should raise the price level from its expected

level more than negative shocks push the price level down. Unfortunately, the results of Karras' experiments are ambiguous. Buckle and Carlson (1996) use a unique micro data set, and directly analyze the relationship between inflation and asymmetric price adjustment. They find pervasive evidence of price asymmetry that is systematically related to inflation.

Similar to the studies by Rhee and Rich (1995), Karras (1996b), and Buckle and Carlson (1996), my research is also intended to be an empirical investigation of the reason for the asymmetric effects of money supply shocks.

### **3. Data**

This study compares the gold standard period (the stable price period) with the post WWII period (the positive inflation period).<sup>7</sup> The sample for the gold standard period is 1873-1913 and the sample for the postwar period is 1956-1995.

To ensure that the results for the gold standard period are robust, I employ three output series that are obtained from different sources: Balke-Gordon I (1986), Balke-Gordon II (1989) and Romer (1989). The money supply data for the gold standard period are from Friedman and Schwartz (1982). In this paper, all data are annual averages. For the gold standard period, most of the data are taken from Backus and Kehoe (1992) provided by Backus and from Bordo and Joung (1987) provided by Bordo. For the postwar period, most of the data are taken from the International Monetary Fund's *International Financial Statistics* on CD-ROM. The monetary data are measures of broad money which are frequently called M2 (Money plus Quasi-Money). Output numbers are real GDP or real GNP, whichever is

---

7) In this paper, I do not split the postwar period into the Bretton Woods and post Bretton Woods periods. This is because annual data give us only a small number of samples.

available. Since sticky price models give weight to the change in the price of services as well as the change in the price of goods, trend inflation is computed from the consumer price index (CPI).<sup>8)</sup>

## 4. Empirical Procedure

### 4.1 The Models of Money Supply and Output

An econometric model consists of two equations—a money supply equation and an output equation. In this section, these two equations are specified. In the next section, the two-equation system is estimated by two-step OLS and nonlinear full-information-maximum-likelihood (nonlinear FIML).

#### (a) The Money Supply Equation

There are at least two ways to specify the money supply equation, that is, a procedure based on economic theory such as Barro (1977, 1978), and an atheoretical statistical procedure such as Mishkin (1982). In this paper, the latter procedure is used to specify the money supply equation, because we do not have any established theory of money supply process for the gold standard period and it may not be proper to apply the postwar money supply equation to the gold standard period.

Following the atheoretical framework, the growth rate of money supply ( $Gm_t$ ) is regressed on lagged values of a wide range set of macro variables. The macro variables are two lagged values of money growth rate ( $Gm_{t-1}$ ,  $Gm_{t-2}$ ), one lagged value of the growth rate of high-powered money ( $Gh_{t-1}$ ), one lagged value of the inflation rate ( $\pi_{t-1}$ ), one lagged value of the short-run and long-run interest rates ( $si_{t-1}$ ,  $li_{t-1}$ ) and their first differences ( $Dsi_{t-1}$ ,  $Dli_{t-1}$ ), and one lagged value of the growth rate of nominal and real GDP ( $GY_{t-1}$ ,  $Gy_{t-1}$ ). The growth rate of a variable  $X$  ( $GX$ ) is calculated by

$$GX_t = (\ln X_t - \ln X_{t-1}) \times 100.$$

---

8) See Ball and Mankiw (1994b).

To select the independent variables of the money supply equation, I employ the method of stepwise regression.<sup>9)</sup> Suppose I wish to establish a linear regression equation for a dependent variable  $Y$  in terms of a constant term and independent variables  $X_1, X_2, \dots, X_k$ . The stepwise regression method begins with the smallest regression (suppose I start with no independent variable). First, I find the  $X$  variable that is most correlated with  $Y$  (suppose it is  $X_1$ ) and insert the variable in the regression. Then, for the second stage, I select another  $X$  variable that has the highest partial correlation with  $Y$  (suppose this is  $X_2$ ). Now I have two independent variables,  $X_1$  and  $X_2$ . Before I add another  $X$  variable ( $X_3$ ), I need to check if  $X_1$  is still important to explain the response of  $Y$ . A partial  $F$ -test is used to determine whether I should retain  $X_1$  in the regression. This process continues until the partial  $F$  value of the most recent entered  $X$  variable becomes insignificant.<sup>10)</sup>

Table 1 presents OLS estimates of money supply equations. Two money supply equations are estimated for each data set. One money supply equation selects the  $X$  variables by using the stepwise procedure with no restriction on the independent variables. The other money supply equation is also specified by the stepwise procedure but it always has to include one lagged value of the money growth rate ( $Gm_{t-1}$ ). I estimate the latter version of the money supply equation as well as the unrestricted one, because the results show that  $Gm_{t-2}$  is always included in the money supply equation and it is unnatural to ignore  $Gm_{t-1}$ . <B-G I> stands for the output series of Balke and Gordon (1986), <B-G II> is Balke and Gordon (1989), and

---

9) See Draper and Smith (1981). An alternative method is to choose the specification that maximizes an adjusted coefficient of determination ( $\bar{R}^2$ ). Greene (1993) mentions a computer program that will automatically find the maximum  $\bar{R}^2$ .

10) Fortunately, RATS has a program of the stepwise regression procedure and thus I use this package to specify the money supply equation.

**Table 1** OLS Estimates of Money Supply Equations

	(1.1)	(1.2)	(1.3)	(1.4)
Period	1873-1913	1873-1913	1873-1913	1956-1995
Output Series	B-G I and Romer	B-G II	B-G I, II and Romer	Postwar
Specification	No Restriction	No Restriction	Always Include $Gm_{t-1}$	
Constant	10.104** (3.860)	3.510*** (1.019)	3.486*** (1.659)	2.771*** (0.963)
$Gm_{t-1}$			0.179 (0.169)	0.554*** (0.128)
$Gm_{t-2}$	-0.224 (0.141)	-0.288** (0.134)	-0.310** (0.140)	
$Gh_{t-1}$	0.844*** (0.179)	0.849*** (0.184)	0.798*** (0.217)	-0.252*** (0.076)
$\pi_{t-1}$				0.400*** (0.126)
$li_{t-1}$	-1.615* (0.887)			
$Dli_{t-1}$	-6.578 (4.533)			
$GY_{t-1}$		0.200 (0.135)		
$\bar{R}_2$	0.419	0.406	0.389	0.474
S. E.	4.151	4.197	4.255	2.387
D-W	1.984	2.085	2.047	1.897

Note Standard errors are in parentheses.

\*, \*\*, and \*\*\* significant at the 0.10, 0.05, and 0.01 levels, respectively.

D-W=Durbin-Watson statistics.

<Romer> is Romer (1989). Equations (1.1), (1.2) and (1.3) in Table 1 are the regressions for the gold standard period, and equation (1.4) is for the postwar period. Equations (1.1), (1.2) and (1.4) have no restriction on the selection of independent variables, and equation (1.3) is specified on the assumption that  $Gm_{t-1}$  is always included in the independent variables. In the case when the money supply equation is not restricted, the specification of the money supply equation depends on an output series that is employed in the stepwise regression. Both B-G I and Romer output

series yield equation (1.1) for the money supply equation, whereas B-G II gives equation (1.2). In the case when the money supply equation is restricted, all three output series yield the same money supply equation (1.3). Finally, I define money supply shocks as the residual series of the money supply equation  $\{\varepsilon_t\}$ .

**(b) The Output Equation**

In general, output is considered to be a nonstationary process, but it is not yet clear whether output is trend-stationary or difference-stationary. To understand whether the output process has a unit root or not, I studied papers by Nelson and Plosser (1982) and Perron (1989). I apply their unit root tests to the annual real GDP series for the U.S. The results are mixed and they are reported in the appendix. At this moment, I cannot say for certain whether the output process is trend-stationary or difference-stationary. Thus, here I leave the question of a unit root and simply adopt Cover's (1992) output equation, because to argue this point would carry us too far away from the purpose of this paper.

In Cover's output equation, the growth rate of output ( $Gy_t = (\ln y_t - \ln y_{t-1}) \times 100$ ) is specified as a function of a constant term, lagged output growth ( $Gy_{t-1}$ ) and positive and negative money supply shocks. Negative money supply shocks are defined as

$$\varepsilon_t^- = \min(\varepsilon_t, 0),$$

and positive shocks are defined as

$$\varepsilon_t^+ = \max(\varepsilon_t, 0).$$

The output equation can be written as

$$Gy_t = \beta_0 + \beta_1 Gy_{t-1} + \gamma_0^+ \varepsilon_t^+ + \gamma_1^+ \varepsilon_{t-1}^+ + \gamma_0^- \varepsilon_t^- + \gamma_1^- \varepsilon_{t-1}^- + \eta_t.$$

To obtain the cumulative effect of a money supply shock, the output equation is estimated with current and lagged money supply shocks. This assumes that both current and lagged shocks are important in explaining movements in output. I use  $\{\eta_t\}$  to represent the residual series of the

output equation.

## 4.2 Methods of Estimation

The two-equation system is estimated by two-step OLS and nonlinear FIML. For nonlinear FIML, the residual terms  $\{\varepsilon_t\}$  and  $\{\eta_t\}$  are assumed to be uncorrelated and normally distributed. I follow Barro's two-step OLS and Mishkin's nonlinear FIML procedures. Mishkin (1982, pp.41-42) discusses the advantages of his joint-estimation procedure. He argues that nonlinear FIML is more desirable method than two-step OLS because the two-step OLS test statistics are invalid and its estimates are less efficient.

Since I cannot find a statistical package for nonlinear FIML, I wrote a computer program in GAUSS. In order to check that my program is indeed correct, nonlinear FIML estimates are obtained from two different methods—nonlinear FIML and iterative generalized-nonlinear-least-squares (iterative GNLS)—and they are examined whether one estimate is equal to the other. Mishkin (1982) shows that, for this particular model, the iterative GNLS procedure converges to the nonlinear FIML estimates. This can be explained as follows:<sup>11)</sup>

Let us start with nonlinear FIML. Let  $\mathbf{Y}_t$  denote a  $g$ -vector dependent variables (in this case  $g = 2$ ) and  $\mathbf{X}_t$  is a set of independent variables. Suppose an equation system can be written for all  $n$  observations as

$$\mathbf{h}_t(\mathbf{Y}_t, \mathbf{X}_t, \theta) = \mathbf{U}_t,$$

where  $\mathbf{U}_t$  is a  $1 \times g$  vector of error terms and is distributed NID  $(\mathbf{0}, \Sigma)$ ,  $\theta$  is a vector of parameters,  $\mathbf{h}_t$  is a  $1 \times g$  vector of nonlinear functions. The density of the vector  $\mathbf{U}_t$  is

$$(2\pi)^{-g/2} |\Sigma|^{-1/2} \exp\left(-\frac{1}{2} \mathbf{U}_t \Sigma^{-1} \mathbf{U}_t^T\right),$$

where  $\mathbf{x}^T$  is the transpose of a matrix  $\mathbf{x}$ . By replacing  $\mathbf{U}_t$  by  $\mathbf{h}_t(\mathbf{Y}_t, \mathbf{X}_t, \theta)$  and multiplying by the Jacobian factor  $|\det \mathbf{J}_t|$ , where  $\mathbf{J}_t \equiv \partial \mathbf{h}_t(\theta) / \partial \mathbf{Y}_t$ , I obtain

---

11) Davidson-MacKinnon (1993), p. 289 and p. 666. See also Gallant (1987).



the density of  $\mathbf{Y}_t$ ,

$$(2\pi)^{-g/2} |\det \mathbf{J}_t| |\Sigma|^{-1/2} \exp \left( -\frac{1}{2} \mathbf{h}_t(\mathbf{Y}_t, \mathbf{X}_t, \theta) \Sigma^{-1} \mathbf{h}_t^T(\mathbf{Y}_t, \mathbf{X}_t, \theta) \right).$$

Hence, the loglikelihood function is

$$(1) \quad l(\theta, \Sigma) = -\frac{ng}{2} \log(2\pi) + \sum_{t=1}^n \log |\det \mathbf{J}_t| - \frac{n}{2} \log |\Sigma| - \frac{1}{2} \sum_{t=1}^n \mathbf{h}_t(\mathbf{Y}_t, \mathbf{X}_t, \theta) \Sigma^{-1} \mathbf{h}_t^T(\mathbf{Y}_t, \mathbf{X}_t, \theta).$$

Since the determinant of the Jacobian for this model equals one, I get

$$\sum_{t=1}^n \log |\det \mathbf{J}_t| = 0,$$

so that equation (1) becomes

$$(2) \quad l(\theta, \Sigma) = -\frac{ng}{2} \log(2\pi) - \frac{n}{2} \log |\Sigma| - \frac{1}{2} \sum_{t=1}^n \mathbf{h}_t(\mathbf{Y}_t, \mathbf{X}_t, \theta) \Sigma^{-1} \mathbf{h}_t^T(\mathbf{Y}_t, \mathbf{X}_t, \theta).$$

Maximizing this likelihood function gives the nonlinear FIML estimator.<sup>12)</sup>

On the other hand, the iterative GNLS estimator can be yielded in the following manner. If the matrix  $\Sigma$  is known, it is clear that the likelihood function (2) can be maximized by minimizing the generalized sum of squared residuals

$$(3) \quad SSR(\theta | \Sigma) = \sum_{t=1}^n \mathbf{h}_t(\mathbf{Y}_t, \mathbf{X}_t, \theta) \Sigma^{-1} \mathbf{h}_t^T(\mathbf{Y}_t, \mathbf{X}_t, \theta).$$

A vector of parameters,  $\theta$ , that minimizes this  $SSR$  is called the GNLS estimator.

As the variance-covariance matrix  $\Sigma$  is not known, I try to find  $\Sigma$  by iteration. To begin with, I compute the first-stage variance-covariance

12) When one maximizes the likelihood function (2), one needs to take into account an identifying assumption that  $\Sigma$  is diagonal. Furthermore, the function that I actually maximized is not equation (2) but the concentrated likelihood function

$$l^c(\theta) = -\frac{ng}{2} (\log(2\pi) + 1) - \frac{n}{2} \log \left| \frac{1}{n} \sum_{t=1}^n \mathbf{h}_t^T(\mathbf{Y}_t, \mathbf{X}_t, \theta) \mathbf{h}_t(\mathbf{Y}_t, \mathbf{X}_t, \theta) \right|,$$

yet this does not change the estimated values at all.

matrix ( $\Sigma_0$ ) from two-step OLS:

$$\Sigma_0 = \begin{bmatrix} \frac{SSR_m}{n} & 0 \\ 0 & \frac{SSR_y}{n} \end{bmatrix},$$

where  $SSR_m$  is the sum of squared residuals from the money supply equation  $\left(\sum_{i=1}^n \epsilon_i^2\right)$  and  $SSR_y$  is the sum of squared residuals from the output equation  $\left(\sum_{i=1}^n \eta_i^2\right)$ . Then, equation (3) is minimized with  $\Sigma_0$  to yield a GNLS estimator,  $\theta_1$ . For the next stage, a new matrix ( $\Sigma_1$ ) is constructed with  $\theta_1$  in the same way. Then, again, the system is re-estimated with  $\Sigma_1$  and a new GNLS estimator,  $\theta_2$ , is obtained. This procedure is iterated until there is little change in the  $\Sigma$  matrix, and that yields iterative GNLS estimates.

Now I am ready to check if my program is correct or not. First of all, I find that the two estimates—nonlinear FIML and iterative GNLS—coincide when a model converges.<sup>13)</sup> Secondly, the nonlinear FIML estimates are not much different from the two-step OLS estimates. I may, therefore, reasonably conclude that my statistical program is credible.<sup>14)</sup>

### 4.3 Test Procedures

My primary concern is to examine the coefficients on positive and negative money supply shocks. A hypothesis which I want to test is the following:

*Hypothesis: If trend inflation is zero, then money supply shocks*

- 
- 13) I also find that if one of the two procedures does not converge, then the other procedure does not converge, either.
- 14) To ensure that the estimates are robust, I maximized the loglikelihood function with various algorithms. The results show that those algorithms yield the same estimates.

*have symmetric effects on real output. If trend inflation is positive, then money supply shocks have asymmetric effects on real output.*

Let  $\text{Sum} (Pos)$  denote the sum of coefficients on positive money supply shocks, and  $\text{Sum} (Neg)$ , the sum of coefficients on negative shocks. That is,

$$\text{Sum} (Pos) = \gamma_0^+ + \gamma_1^+,$$

$$\text{Sum} (Neg) = \gamma_0^- + \gamma_1^-.$$

Then a null hypothesis will be  $\text{Sum} (Pos) = \text{Sum} (Neg)$ , namely, the sum of coefficients on positive money supply shocks equals the sum of coefficients on negative money supply shocks.<sup>15)</sup> If the sticky price theory offers a valid explanation for the asymmetric effects of money supply shocks, then the null hypothesis should not be rejected when trend inflation is zero. On the other hand, when trend inflation is positive, the null hypothesis should be rejected and negative money supply shocks reduce output more than positive shocks increase output (i.e.,  $\text{Sum} (Pos) < \text{Sum} (Neg)$ ). This hypothesis is tested in the next section. Wald tests are performed for nonlinear FIML and  $t$ -tests for two-step OLS.

## 5. Results

Table 2 summarizes the means and standard deviations of inflation for the gold standard and postwar periods. Tables 3 and 4 show results estimated by two-step OLS and by nonlinear FIML, respectively. Six models are estimated for the gold standard period:

---

15) I do not test Cover's (1992) null hypothesis of symmetry (the coefficients on  $\epsilon^+$  are jointly equal to the coefficients on  $\epsilon^-$ ):

$$H_0: \gamma_0^+ = \gamma_0^- \text{ and } \gamma_1^+ = \gamma_1^-,$$

because this null hypothesis can be rejected even if  $\text{Sum} (Pos) = \text{Sum} (Neg)$ .

**Table 2**

	Gold Standard Period	Postwar Period
Average Inflation (%)	-0.469	4.486
Standard Deviation of Inflation Rate	2.766	3.060

**Table 3** Output Equation Estimates (two-step OLS)

Period	B-G I	B-G II	Romer	Postwar
	1873-1913	1873-1913	1873-1913	1956-1995
Constant	4.142** (1.556)	3.493*** (1.239)	3.681*** (0.983)	3.424*** (0.890)
$Gy_{t-1}$	-0.086 (0.168)	-0.201 (0.163)	0.068 (0.168)	0.097 (0.142)
$Pos_t$	0.907** (0.360)	0.891*** (0.269)	0.412** (0.201)	-0.004 (0.261)
$Pos_{t-1}$	-0.280 (0.399)	0.115 (0.301)	-0.210 (0.215)	0.209 (0.269)
$Neg_t$	0.475 (0.296)	0.460** (0.220)	0.243 (0.167)	0.279 (0.288)
$Neg_{t-1}$	0.094 (0.308)	-0.150 (0.236)	0.092 (0.172)	0.800*** (0.284)
Sum ( $Pos$ ) = Sum ( $Neg$ ) <sup>a</sup>	0.063	1.043	0.259	1.189
Sum ( $Pos$ ) <sup>b</sup>	0.627	1.005**	0.202	0.205
Sum ( $Neg$ ) <sup>c</sup>	0.569	0.310	0.335	1.079**

*Note* Standard errors are in parentheses.

\*, \*\*, and \*\*\* significant at the 0.10, 0.05, and 0.01 levels, respectively.

a. *t*-statistics for the hypothesis that the sum of the coefficients on *Pos* equals the sum of the coefficients on *Neg*.

b. Sum of the coefficients on *Pos*.

c. Sum of the coefficients on *Neg*.

Output Series

Money Supply Equation

- |     |        |  |
|-----|--------|--|
| [1] | B-G I  | No restriction for selecting independent variables |
| [2] | B-G I  | Always include $Gm_{t-1}$                          |
| [3] | B-G II | No restriction for selecting independent variables |
| [4] | B-G II | Always include $Gm_{t-1}$                          |

**Table 4** Output Equation Estimates (nonlinear FIML)

	B-G I	B-G II	Romer	Postwar
Period	1873-1913	1873-1913	1873-1913	1956-1995
Constant	3.801*** (1.432)	3.002** (1.293)	3.855*** (0.913)	4.246*** (0.839)
$Gy_{t-1}$	-0.116 (0.157)	0.019 (0.260)	0.054 (0.156)	0.026 (0.136)
$Pos_t$	1.019*** (0.339)	0.987*** (0.207)	0.434** (0.182)	-0.138 (0.239)
$Pos_{t-1}$	-0.185 (0.330)	-0.153 (0.301)	-0.200 (0.190)	0.098 (0.261)
$Neg_t$	0.489 (0.309)	0.477** (0.189)	0.279* (0.165)	0.498** (0.252)
$Neg_{t-1}$	-0.034 (0.300)	-0.007 (0.203)	0.145 (0.197)	0.921*** (0.254)
Sum ( $Pos$ )=Sum ( $Neg$ ) <sup>a</sup>	0.231	0.477	0.189	4.300**
Sum( $Pos$ ) <sup>b</sup>	0.835*	0.834**	0.234	-0.040
Sum( $Neg$ ) <sup>c</sup>	0.455	0.470	0.424	1.419***

Note Standard errors are in parentheses.

\*, \*\*, and \*\*\* significant at the 0.10, 0.05, and 0.01 levels, respectively.

a. Wald-statistics for the hypothesis that the sum of the coefficients on  $Pos$  equals the sum of the coefficients on  $Neg$ .

b. Sum of the coefficients on  $Pos$ .

c. Sum of the coefficients on  $Neg$ .

[5] Romer No restriction for selecting independent variables

[6] Romer Always include  $Gm_{t-1}$

Out of these six models, [2], [3] and [6] do not converge for nonlinear FIML. Hence, only the results of [1], [4] and [5] and shown for the gold standard period in Tables 3 and 4.

Let us consider the gold standard period first. During the period, as Table 2 indicates, trend inflation was  $-0.469$  percent at an annual rate and the standard deviation of inflation rate was  $2.766$  (which is no greater than the postwar's number  $3.060$ ). Thus one can safely say that trend inflation

during the gold standard period was close to zero and that the price level was stable. As shown in Table 4, the null hypothesis,  $\text{Sum} (Pos) = \text{Sum} (Neg)$ , is not rejected for all three models. It is worth noting that, for Balke-Gordon's output data (both B-G I and B-G II), the sum of the coefficients on positive money supply shocks is significantly different from zero. This implies that easy monetary policy was effective in stimulating the economy during the gold standard period.

By contrast, for the postwar period in which trend inflation is positive, the hypothesis,  $\text{Sum} (Pos) = \text{Sum} (Neg)$ , is rejected at the 0.05 level of significance for the nonlinear FIML estimates.<sup>16)</sup> Moreover, in each method of estimation, one can observe that (i) the condition on the coefficients,  $\text{Sum} (Pos) < \text{Sum} (Neg)$ , holds and (ii)  $\text{Sum} (Neg)$  is significantly different from zero but  $\text{Sum} (Pos)$  is not. These results lead us to the conclusion that negative money supply shocks have larger effects on output than positive shocks during the postwar period. This part of the exercise confirms previous researchers' findings.

## 6. Conclusion

By analyzing the annual U.S. data for the gold standard and postwar periods, this study finds that monetary policy has symmetric effects under price stability. This paper offers evidence that asymmetric price adjustment is one of the main causes of asymmetric effects of money supply shocks.<sup>17)</sup>

The main contribution of this empirical exercise is that this study shows

---

16) For the two-step OLS estimates, the null hypothesis is not rejected. But, remember that the test statistics of two-step OLS are invalid.

17) There is, however, a finding that does not seem to be consistent with the sticky price theory. The theory predicts that tight monetary policy should be as effective as easy monetary policy under price stability. Yet,  $\text{Sum} (Neg)$  is not significantly different from zero during the gold standard period in Tables 3 and 4.

the degree of asymmetry in the effects of money supply shocks is related to trend inflation in the same manner as the sticky price theory has predicted. This finding leads to the conclusion that the asymmetric effects of money supply shocks result from positive trend inflation, and that asymmetric price adjustment is one of the main causes of the asymmetric effects of money supply shocks. Furthermore, based on the evidence, one may reasonably argue that the degree of asymmetry in price adjustment (i.e., the nonlinearity of the aggregate supply curve) also depends on trend inflation. It is positive inflation that induces price adjustment to be rigid downward (or the aggregate supply curve to be convex). In fact, asymmetric responses are widely observed during the postwar period when trend inflation is positive. Conversely, the aggregate supply curve appears to be linear and thus price adjustment symmetric in the prewar period when price stability was achieved.

## Appendix

Modeling time series of real output is by no means easy. The traditional approach (for example, Blanchard (1981)) specifies the output equation as

$$(A1) \quad \ln y_t = \beta_1 \ln y_{t-1} + \beta_2 \ln y_{t-2} + \beta_3 t + \gamma_a \varepsilon_t + \eta_t,$$

where  $y$  is real output,  $t$  is a time trend, and  $\varepsilon$  is a money supply shock. This equation implies that real output can be decomposed into a trend component and a cyclical component. The trend component is considered to be determined by real factors, while the cyclical component is assumed to be transitory (stationary) and induced by monetary disturbances. The traditional approach assumes that the detrended output process is stationary, in other words, the output process is “trend-stationary.”

Another approach will be the one that is studied by Nelson and Plosser (1982). They show that the output process has a unit root and that the process is “difference-stationary.” If the output series has a unit root, one

can obtain a stationary process by differencing the series. For example, the output equation can be written as

$$(A2) \quad Gy_t = \beta_0 + \beta_1 Gy_{t-1} + \gamma_b \varepsilon_t + \eta_t,$$

where  $Gy_t = (\ln y_t - \ln y_{t-1}) \times 100$ . Note that, in this equation, a money supply shock ( $\varepsilon_t$ ) has a permanent effect on output.<sup>A1)</sup>

In this appendix I examine whether a real GDP (GNP) series for the U.S. has a unit root or not. The sample periods are 1872-1913 and 1951-1995. Test procedures that I use are the same as those in Nelson and Plosser (1982) and Perron (1989).<sup>A2)</sup> The results are not clear. For the prewar period, in two out of six cases, the unit root hypothesis is rejected. In the case of the postwar period, the null hypothesis of a unit root is not rejected when the Nelson-Plosser method is used, but the same hypothesis is rejected at the 0.01 level of significance for the Perron method.

The plan of the appendix is as follows: Section A1 explains Perron's idea of "a change in the slope of a trend function." Then, Section A2 shows some descriptive analyses. Finally, Section A3 presents empirical results.

---

A1) For reasons mentioned above, equations (A1) and (A2) are different in that the output process is assumed to be either trend - stationary or difference - stationary. In addition, these equations will differ in the interpretation of the coefficient on the money supply shock. To take a simple example, consider the output equation (A1). If  $\gamma_a = 1$ , then a 1% current money supply (growth) shock changes the current output *level* by 1%. In contrast, for the output equation (A2), if  $\gamma_b = 1$ , then a 1% current money supply (growth) shock changes the current output *growth rate* by 1%.

A2) Diebold and Senhadji (1996) use longer GNP samples for unit root tests, and conclude that U.S. aggregate output is not likely to be difference - stationary. They suggest that the output process is better described with long - memory but mean - reverting, or short - memory with roots local to unity.



### A1 A Change in the Slope of a Trend

When one regards the output series  $\{y_t\}$  as a trend-stationary process, output is often decomposed into a trend component and a cyclical component. The trend component is assumed to be determined by real factors. The cyclical component, on the other hand, is believed to be caused by monetary disturbances, whose effects on output eventually wear off over time. Thus the output series is characterized by stationary fluctuations around a deterministic trend.

Perron (1989) claims that the slope of the output trend has decreased after 1973 (Figure A). The trend in Figure A tries to capture the slowdown in the growth rate of real GDP since the mid-seventies. Hence, the “detrended” output series  $\{\tilde{y}_t\}$  should be computed not by subtracting the trend  $\mu + \beta t$  from the output series  $\{y_t\}$  such as

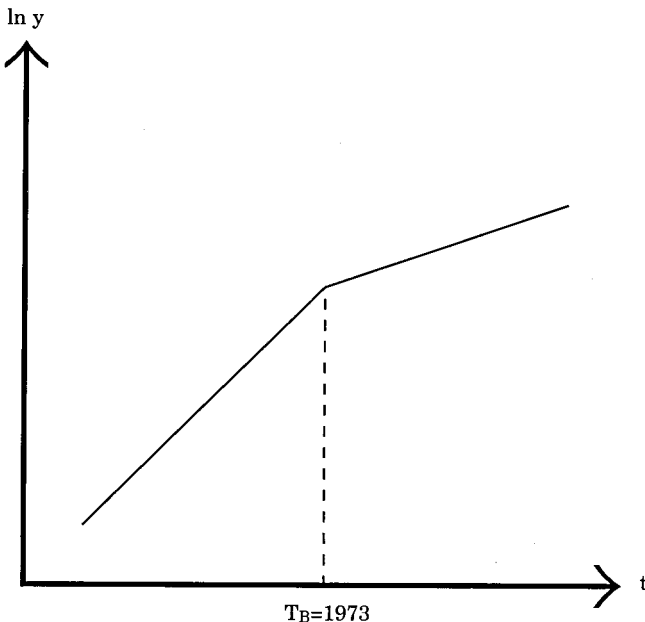


Figure A A Change in the Slope of a Trend

$$(A3) \quad y_t = \mu + \beta t + \tilde{y}_t,$$

but by allowing a one-time change in the trend at a time  $T_B$  ( $1 < T_B < T$ ), that is,

$$(A4) \quad y_t = \mu + \beta_1 t + (\beta_2 - \beta_1) DT_t^* + \tilde{y}_t,$$

where

$$DT_t^* = \begin{cases} t - T_B & \text{if } t > T_B, \\ 0 & \text{otherwise.} \end{cases}$$

In this case,  $T_B = 1973$ .

## A2 Some Descriptive Analyses

The sample for the gold standard period is 1873-1913 and the sample for the postwar period is 1956-1995. To make sure that the results for the gold standard period are robust, I employ three output series that are obtained from different sources: Balke and Gordon (1986, B-G I), Balke and Gordon (1989, B-G II), and Romer (1989).

Table A1 presents the sample autocorrelations of the deviations from trend. I detrended the prewar output series by using equation (A3), since it appears that the slope of the trend does not change during the prewar period. For the postwar output series, both equations (A3) and (A4) are used to detrend the series.

The first line in Table A1 shows the expected sample autocorrelations for deviations of random walks of 45 observations from a trend line. One can see in Table A1 that the detrended random walk has a similar pattern of decay to Romer output series and the postwar output series detrended by equation (A3). This suggests that the Romer and postwar output series detrended by equation (A3) are not stationary. On the other hand, as for the Balke and Gordon (I and II) output series and the postwar output series detrended by equation (A4), their autocorrelations decay quite rapidly, and

**Table A1** Sample autocorrelations of the “detrended” series.<sup>a</sup>

		Sample autocorrelations						
Real GNP (GDP) Series	Period	<i>T</i>	<i>r</i> <sub>1</sub>	<i>r</i> <sub>2</sub>	<i>r</i> <sub>3</sub>	<i>r</i> <sub>4</sub>	<i>r</i> <sub>5</sub>	<i>r</i> <sub>6</sub>
Detrended random walk <sup>b</sup>		45	0.80	0.62	0.46	0.32	0.20	0.09
B-G I	1869-1913	45	0.62	0.42	0.24	0.17	0.06	-0.06
B-G II	1869-1913	45	0.70	0.55	0.30	0.13	-0.10	-0.22
Romer	1869-1913	45	0.78	0.54	0.37	0.30	0.18	0.05
Postwar eq. (A3)	1948-1995	48	0.81	0.56	0.38	0.30	0.24	0.18
Postwar eq. (A4)	1948-1995	48	0.65	0.18	-0.16	-0.27	-0.32	-0.39

a. The data are residuals from linear least squares regression of the logs of the series (except Postwar eq. (A4)) on time.

b. Approximate expected sample autocorrelations based on Nelson-Kang (1981).

thus these series seem to be stationary.

### A3 Tests for a unit root

I consider two kinds of unit root tests. Their alternative hypotheses assume that:

- (a) the slope of the trend does not change during the sample period, and
- (b) the slope of the trend changes once during the sample period.

The prewar output series are all tested by (a), whereas the postwar output series are examined using both (a) and (b).

#### (a) No Change in the Slope of the Trend

In this section, I apply the standard unit root test; that is, the null hypothesis is that the series has a unit root ( $\alpha = 1$ ), and its alternative hypothesis is that the series is stationary around a trend *with no change in its slope*. Table A2 presents the results from estimating a regression of the Dickey-Fuller type, i.e.:

$$y_t = \bar{\mu} + \bar{\beta}t + \tilde{\alpha}y_{t-1} + \sum_{i=1}^k \tilde{c}_i \Delta y_{t-i} + \tilde{e}_t.$$

**Table A2** Tests for a unit root (a)

$$\text{Regression: } y_t = \bar{\mu} + \tilde{\beta}t + \tilde{\alpha}y_{t-1} + \sum_{i=1}^k \tilde{c}_i \Delta y_{t-i} + \tilde{e}_t$$

Real GNP (GDP)	$k$	$\bar{\mu}$	$t_{\bar{\mu}}$	$\tilde{\beta}$	$t_{\tilde{\beta}}$	$\tilde{\alpha}$	$t_{\tilde{\alpha}}$	$S(\tilde{e})$
[A] Prewar (1872-1913)								
B-G I	2	1.515	3.075	0.016	2.773	0.580	-2.917	0.049
B-G II	2	1.393	2.609	0.012	2.491	0.681	-2.528	0.039
Romer	2	1.444	3.583	0.011	3.154	0.677	-3.394*	0.028
[B] Postwar								
1951-1995	2	1.329	2.200	0.005	1.970	0.824	-2.136	0.022
1951-1973	2	3.448	2.678	0.016	2.642	0.527	-2.656	0.021
1974-1995	2	6.337	3.298	0.021	3.311	0.157	-3.289*	0.018

Note \*, \*\*, and \*\*\* significant at the 0.10, 0.05, and 0.01 levels, respectively.

We start with the prewar data. The values of  $\tilde{\alpha}$  are 0.580 (B-G I), 0.681 (B-G II) and 0.677 (Romer).  $T(\tilde{\alpha}-1)$  statistics and  $t_{\tilde{\alpha}}$  statistics are

$$\text{B-G I: } T(\tilde{\alpha}-1) = -17.64 \quad t_{\tilde{\alpha}} = -2.917$$

$$\text{B-G II: } T(\tilde{\alpha}-1) = -13.40 \quad t_{\tilde{\alpha}} = -2.528$$

$$\text{Romer: } T(\tilde{\alpha}-1) = -13.57 \quad t_{\tilde{\alpha}} = -3.394$$

Thus, the null hypothesis  $\alpha = 1$  cannot be rejected except that the B-G I  $T(\tilde{\alpha}-1)$  test and the Romer  $t_{\tilde{\alpha}}$  test reject the unit root hypothesis at the 0.10 level.

For the postwar data, I analyze three series (one full sample 1951-1995 and two split subsamples, 1951-1973 and 1974-1995). For the full sample, the estimated value of  $\alpha$  is 0.824. Notice that the estimated values of  $\alpha$  for the split samples are much smaller than 0.824, i.e., 0.527 for the pre-1973 sample and 0.157 for the post-1973 sample. The test statistics for these samples are

$$\text{Full: } T(\tilde{\alpha}-1) = -7.92 \quad t_{\tilde{\alpha}} = -2.136$$

$$\text{Pre-1973: } T(\tilde{\alpha}-1) = -10.88 \quad t_{\tilde{\alpha}} = -2.656$$

$$\text{Post-1973: } T(\tilde{\alpha}-1) = -18.55 \quad t_{\tilde{\alpha}} = -3.289$$

For the full and pre-1973 samples, one accepts the null hypothesis  $\alpha = 1$  by

both  $T(\hat{\alpha}-1)$  and  $t_{\hat{\alpha}}$  tests. For the post-1973 samples, the null hypothesis is rejected by the  $T(\hat{\alpha}-1)$  test at the 0.05 level and by the  $t_{\hat{\alpha}}$  test at the 0.10 level.

**(b) A One-Time Change in the Slope of the Trend**

As seen above, when there is a change in the slope of a trend, one way of dealing with it is to split the sample. Yet, Perron (1989) shows that this procedure has low power. Instead of splitting the sample into two subperiods, Perron proposes a more powerful test procedure based on the full sample. His hypotheses are parameterized as follows:

*Null hypothesis:*

$$y_t = \mu_1 + y_{t-1} + (\mu_2 - \mu_1) DU_t + e_t,$$

$$DU_t = \begin{cases} 1 & \text{if } t > T_B, \\ 0 & \text{otherwise;} \end{cases} \text{ and}$$

$$A(L)e_t = B(L)v_t,$$

where  $v_t \sim i.i.d.(0, \sigma^2)$ , with  $A(L)$  and  $B(L)$  are  $p$ th and  $q$ th order polynomials, respectively, in the lag operator  $L$ .

*Alternative hypothesis:*

$$y_t = \mu + \beta_1 t + (\beta_2 - \beta_1) DT_t^* + e_t,$$

where

$$DT_t^* = \begin{cases} t - T_B & \text{if } t > T_B, \\ 0 & \text{otherwise.} \end{cases}$$

Table A3 presents estimated results for regressions,

$$y_t = \bar{\mu} + \bar{\beta}t + \bar{\gamma}DT_t^* + \bar{\eta}_t; \quad \hat{y}_t = \hat{\alpha}\hat{y}_{t-1} + \sum_{i=1}^k \hat{c}_i \Delta \hat{y}_{t-i} + \hat{\epsilon}_t.$$

The value of  $k$  is chosen in the same way as Perron and  $k = 5$ .<sup>A3)</sup> The test statistics are

---

A3) Table A4 presents the estimated value for  $\alpha$  and its  $t$  statistic for the null hypothesis that  $\alpha = 1$ , for all values of the truncation lag parameter  $k$  between 1 and 8.

**Table A3** Tests for a unit root (b)

$$\text{Regression: } y_t = \tilde{\mu} + \tilde{\beta}t + \tilde{\gamma}DT_t^* + \tilde{y}_t; \tilde{y}_t = \tilde{\alpha}\tilde{y}_{t-1} + \sum_{i=1}^k \tilde{c}_i\Delta y_{t-i} + \tilde{e}_t$$

$T_{1973}$	$T$	$\lambda$	$k$	$\tilde{\mu}$	$t_{\tilde{\mu}}$	$\tilde{\beta}$	$t_{\tilde{\beta}}$	$\tilde{\gamma}$	$t_{\tilde{\gamma}}$	$\tilde{\alpha}$	$t_{\tilde{\alpha}}$	$S(\tilde{e})$
Real GDP	48	0.54	5	7.292	661.47	0.035	55.69	-0.011	-9.10	0.159	-4.39***	0.017

Note See footnote for Table A2.

**Table A4** Extended set of results for tests of a unit root using split and full samples

$$\text{Regression: } y_t = \tilde{\mu} + \tilde{\beta}t + \tilde{\alpha}\tilde{y}_{t-1} + \sum_{i=1}^k \tilde{c}_i\Delta y_{t-i} + \tilde{e}_t$$

		$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$	$k=7$	$k=8$
Real GDP(Pre-1973)	$\tilde{\alpha}$	0.54	0.53	0.58	0.41	0.08	0.09	-0.35	0.45
	$t_{\tilde{\alpha}}$	-3.17	-2.66	-2.24	-2.73	-3.69	-2.30	-2.14	-0.51
Real GDP(Post-1973)	$\tilde{\alpha}$	0.28	0.16	0.03	-0.15	-0.67	-0.66	-0.98	-1.08
	$t_{\tilde{\alpha}}$	-3.87	-3.29	-2.87	-2.63	-3.35	-2.37	-2.31	-2.00

$$\text{Regression: } y_t = \tilde{\mu} + \tilde{\beta}t + \tilde{\gamma}DT_t^* + \tilde{y}_t; \tilde{y}_t = \tilde{\alpha}\tilde{y}_{t-1} + \sum_{i=1}^k \tilde{c}_i\Delta y_{t-i} + \tilde{e}_t$$

		$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$	$k=7$	$k=8$
Real GDP(Full sample)	$\tilde{\alpha}$	0.48	0.46	0.49	0.37	0.16	0.16	-0.03	-0.03
	$t_{\tilde{\alpha}}$	-4.81	-4.09	-3.40	-3.71	-4.39	-3.48	-3.71	-3.29

$$T(\tilde{\alpha}-1) = -40.37$$

$$t_{\tilde{\alpha}} = -4.39$$

and  $\tilde{\alpha}$  is equal to 0.159. The null hypothesis  $\alpha = 1$  is therefore rejected by both tests at the 0.01 level of significance.

## REFERENCES

- Backus, D. K. and Kehoe, P. J. (1992). "International Evidence on the Historical Properties of Business Cycles." *American Economic Review*, **82**, 864-88.
- Balke, N. and Gordon, R. (1986). "Appendix B: Historical Data." *The American Business Cycle: Continuity and Change*, Robert Gordon ed.
- Balke, N. and Gordon, R. (1989). "The Estimation of Prewar Gross National Product:

- Methodology and New Evidence.” *Journal of Political Economy*, **97**, 38-92.
- Ball, L. and Mankiw, N. G. (1994a). “Asymmetric Price Adjustment and Economic Fluctuations.” *Economic Journal*, **104**, 247-61.
- Ball, L. and Mankiw, N. G. (1994b). “A Sticky-Price Manifesto.” *Carnegie-Rochester Series on Public Policy*, **41**, 127-151.
- Barro, R. J. (1977). “Unanticipated Money Growth and Unemployment in the United States.” *American Economic Review*, **67**, 101-115.
- Barro, R. J. (1978). “Unanticipated Money, Output, and the Price Level in the United States.” *Journal of Political Economy*, **86**, 549-80.
- Barro, R. J. and Rush, M. (1980). “Unanticipated Money and Economic Activity.” *Rational Expectations and Economic Policy*. Stanley Fischer ed. The University of Chicago Press.
- Blanchard, O. J. (1981). “What Is Left of the Multiplier-Accelerator?” *American Economic Review Proceeding*, **71**, 150-154.
- Bordo, M. D., and Jonung, L. (1987). *The Long-run Behavior of the Velocity of Circulation: the International Evidence*. Cambridge Mass.: Harvard University Press.
- Buckle, R. A. and Carlson, J. A. (1996). “Inflation and Asymmetric Price Adjustment.” Victoria University of Wellington Graduate School of Business and Government Management Working Paper #12/96.
- Caballero, R. and Engel, E. M. R. A. (1992). “Price Rigidities, Asymmetries, and Fluctuations.” NBER Working Paper #4091.
- Chu, J. and Ratti, R. A. (1997). “Effects of Unanticipated Monetary Policy on Aggregate Japanese Output: The Role of Positive and Negative Shocks.” *Canadian Journal of Economics*, **30**, 722-741.
- Cover, J. P. (1992). “Asymmetric Effects of Positive and Negative Money-Supply Shocks.” *Quarterly Journal of Economics*, **107**, 1261-82.
- Davidson, R. and MacKinnon, J. G. (1993). *Estimation and Inference in Econometrics*. Oxford University Press.
- De Long, J. B. and Summers, L. H. (1988). “How Does Macroeconomic Policy Affect Output?” *Brookings Papers on Economic Activity*, **2**, 433-60.
- Diebold, F. X. and Senhadji, A. S. (1996). “The Uncertain Unit Root in Real GNP: Comment.” *American Economic Review*, **86**, 1291-98.
- Draper, N. and Smith, H. (1981). *Applied Regression Analysis*. New York: Wiley.
- Friedman, M. and Schwartz, A. J. (1982). *Monetary Trends in the United States and the United Kingdom, 1867-1975*. Chicago: University of Chicago Press.
- Frydman, R. and Rappoport, P. (1987). “Is the Distinction Between Anticipated and

- Unanticipated Money Growth Relevant in Explaining Aggregate Output?" *American Economic Review*, **77**, 693-703.
- Gallant, A. R. (1987). *Nonlinear Statistical Models*. New York: John Wiley & Sons.
- Greene, W. H. (1993). *Econometric Analysis 2nd ed.* New York: Macmillan Publishing Company.
- Hansen, A. H. (1941). *Fiscal Policy and Business Cycles*. New York: W.W. Norton and Company.
- Karras, G. (1996a). "Are the Output Effects of Monetary Policy Asymmetric?: Evidence from a Sample of European Countries." *Oxford Bulletin of Economics and Statistics*, **58**, 267-278.
- Karras, G. (1996b). "Why Are the Effects of Money-Supply Shocks Asymmetric? Convex Aggregate Supply or "Push on a String"?" *Journal of Macroeconomics*, **18**, 605-619.
- Laxton, D., Meredith, G. and Rose, D. (1995). "Asymmetric Effects of Economic Activity on Inflation: Evidence and Policy Implications." *IMF Staff Papers*, **42**, 344-74.
- Mishkin, F. S. (1982). "Does Anticipated Policy Matter? An Econometric Investigation." *Journal of Political Economy*, **90**, 22-51.
- Morgan, D. P. (1993). "Asymmetric Effects of Monetary Policy." Federal Reserve Bank of Kansas City *Economic Review*, **78**, 20-33.
- Nelson, C. R. and Kang, H. (1981). "Spurious Periodicity in Inappropriately Detrended Time Series." *Econometrica*, **49**, 741-751.
- Nelson, C. R. and Plosser, C. I. (1982). "Trends and Random Walks in Macroeconomic Time Series: Some Evidence and Implications." *Journal of Monetary Economics*, **10**, 139-162.
- Perron, P. (1989). "The Great Crash, the Oil Price Shock and the Unit Root Hypothesis." *Econometrica*, **57**, 1361-1402.
- Rhee, W. and Rich, R. W. (1995). "Inflation and the Asymmetric Effects of Money on Output Fluctuations." *Journal of Macroeconomics*, **17**, 683-702.
- Romer, C. (1989). "The Prewar Business Cycle Reconsidered: New Estimates of GNP, 1869-1908." *Journal of Political Economy*, **97**, 1-37.
- Senda, T. (1998). "Asymmetric Effects of Money Supply Shocks and Trend Inflation." Hiroshima University, Faculty of Economics, mimeo.
- Tobin, J. (1972). "Inflation and Unemployment." *American Economic Review*, **62**, 1-18.
- Tsiddon, D. (1993). "The (Mis)Behavior of the Aggregate Price Level." *Review of Economic Studies*, **60**, 889-902.