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MODELING THE PHILLIPS CURVE IN CHINA: A NONLINEAR PERSPECTIVE

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This paper investigates the nonlinear dynamics of the inflation–output type of Phillips curve based on a multiple-regime smooth transition regression model using data from China. The empirical results indicate significant nonlinearities in China's Phillips curve. The relationship between inflation and output can be modeled by a four-regime smooth transition regression model in which the responses of inflation to output depend on both inflation and economic growth rates. The inflation–output type Phillips curve may be positively sloped, negatively sloped, or even vertical in the short term, depending on different business cycles. Furthermore, we analyze business cycle fluctuations based on the nonlinear Phillips curve, indicating a coexisting zone of stable inflation rate and rapid growth rate.

Keywords: Phillips Curve, Multiple-Regime Smooth Transition Regression Model, Business Cycle

1. INTRODUCTION

In a seminal paper, Phillips (1958) indicates a negative relationship between unemployment and wage inflation in the United Kingdom from 1861 to 1957. Since then, the short-term trade-off between inflation and unemployment, which implies a trade-off between inflation and output, has been widely studied in various Phillips curve frameworks. These frameworks include the adaptive and rational expectations-augmented short-term Phillips curve proposed by Friedman (1968), Phelps (1968), and Lucas (1973), the New Keynesian Phillips curve (NKPC) developed by Roberts (1995), and the hybrid versions with both expected and lagged inflation in the model as indicated in Galí and Gertler (1999) and Gali et al. (2005). The continuously growing literature on the Phillips curve provides a basis for monetary policy.

China has experienced high growth in the last three decades, as evidenced by the country's 9% average annual growth rate in real GDP. The economy of China has also exhibited a significant cyclical pattern, which has undergone a number of episodes of pronounced ups and downs in the inflation rate and output growth rate.

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The People's Bank of China, the national central bank, eased monetary policy during the low-output periods and tightened it when inflation was high. This approach raised a question regarding the existence of a Phillips curve trade-off in the policy decisions of China's monetary authority, which motivated researchers to examine the Phillips curve relationships in the Chinese economy using conventional or NKPC models.

Coe and McDermott (1997) find that the annual data in China do not fit the conventional Phillips curve model. However, this model works well in 13 Asian countries/regions. Using a similar sample period and a similar Phillips curve model, Oppers (1997) finds that the Phillips curve works well in China. These contrasting results are attributed to the different dynamic structures of the real output gap in the respective models [Zhang and Murasawa (2012)]. Gerlach and Peng (2006) find that the standard Phillips curve models do not fit the annual data from 1982 to 2003 for mainland China. However, when the Phillips curve models are modified by assuming an unobserved variable that follows an AR(2) process, they find that the modified model fits the data better.[1]

Some researchers [Ha et al. (2003); Kojima et al. (2005); Scheibe and Vines (2005)] claim that the NKPC model, rather than the conventional Phillips curve, is consistent with the underlying data-generating process of inflation in China. Mehrotra et al. (2010) use a hybrid NKPC to capture the inflation process at the provincial level in China. The results indicate that the NKPC provides a reasonable description of the inflation process only for coastal provinces. Zhang and Murasawa (2011, 2012) also use NKPC to model the inflation–output trade-off in China. The empirical results indicate that the inflation and output gap fit a new Phillips curve. The results also indicate the existence of some structural changes in the inflation–output relationship.

This literature has contributed to the understanding of the relationship between inflation and output in China during the postreform period. However, it seems simple and arbitrary to say that the data of China fit the Phillips curve model or that the data do not fit the model, because nearly all of the work was conducted under the assumption that the trade-off between output and inflation is linear, which can bias the results if the true model is nonlinear.

Figure 1 provides a depiction of the relationship between the inflation rate and the output growth rate, which is not typically linear and is more dispersed with a greater output growth rate.[2] The figure does not reflect the modern Phillips curve model, but it may indicate the existence of a more complicated story in China's Phillips curve. Therefore, a more careful test for the linearity of China's Phillips curve should be performed, which is the main aim of the current paper.

The form of a Phillips curve has important policy implications in conducting a monetary policy. Laxton et al. (1999) note that positive and negative shocks to demand will have equal effects on inflation if a Phillips curve is linear and there is little incentive to move early to combat inflationary pressures. In contrast, if a Phillips curve is nonlinear, the shocks to demand will have different effects on inflation, which depend on the specific form of a Phillips curve. If a Phillips curve

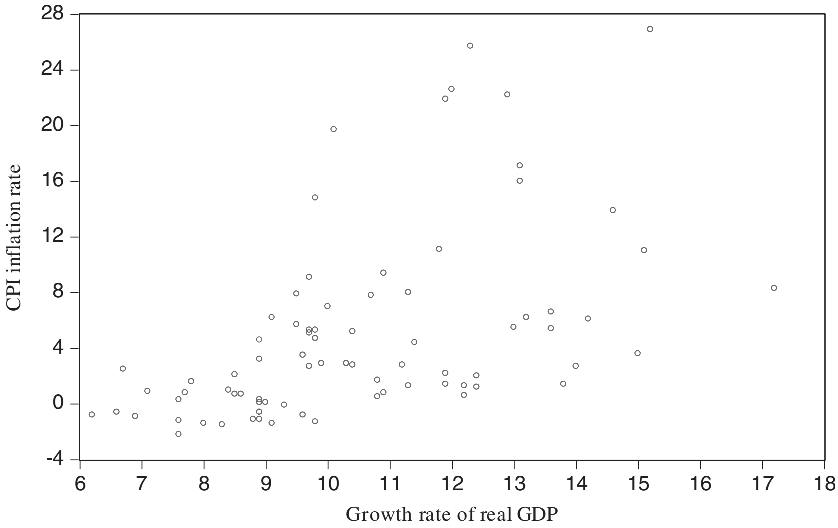

FIGURE 1. Scatterplot between output growth rate and inflation rate (1992Q1–2011Q4).

is convex, positive shocks to demand may raise inflation to a greater extent than negative shocks of the same magnitude lower it. However, a concave form is quite different. The slope of a Phillips curve will be flatter with the increase in output, and the reaction sensitivity of the inflation to the demand shocks will decrease, which suggests that greater output cost is necessary to control inflation in this period.

Laxton et al. (1999) reveal that if there is convexity in the Phillips curve and policy is based on the presumption of linearity, policy errors can lead to severe overheating, which will be costly to correct. If the case is reversed, the losses will be relatively minor. Corrado and Holly (2003) argue that a severe bias to inflation is imparted if the inflation–output trade-off exhibits nonlinearities, but a linear model is used. Through simulations, the results indicate that using the linear model in a nonlinear world would bias the estimate of the steady-state inflation rate, which is positive for the United States. The viewpoint of distribution indicates that U.S. distributions of output and inflation are more widely dispersed than those of the linear model. The distributions are skewed positively for inflation and negatively for output.

A growing number of studies turn to nonlinear Phillips curve models because of some of the potential biases. The current study investigates whether the relationship between inflation and output in China is nonlinear. However, the shape of a nonlinear Phillips curve poses a problem. Many existing studies on nonlinear Phillips curves offer a specific form of nonlinear Phillips curve. However, there is no consensus in the literature about the precise nonlinear form of the Phillips curve. The results in Debelle and Laxton (1997), Nobay and Peel (2000), and Schaling

(2004) favor a convex Phillips curve. Stiglitz (1997) suggests that the Phillips curve in the case of the United States is concave, whereas Filardo (1998) argues that the Phillips curve for the United States may be a combination of concave and convex shapes, where a convex shape is formed when the output gap is positive and a concave shape when the gap is negative. The present research overcomes this problem by using logistic smooth transition regression (STR) models as outlined by Teräsvirta (1994), which are sufficiently flexible to allow various nonlinear Phillips curve shapes without specification a priori.

The estimation of the Phillips curve is very sensitive to the measure of output gap [Schaling (2004); Zhang and Murasawa (2012)]. To avoid the risk of inconsistency, the current study does not rely on estimates of the output gap in the STR-type Phillips curve model, in contrast to existing literature.

This study suggests that the STR model is suitable for Chinese data for two reasons. First, China has conducted gradual reform policies since 1978, which have resulted in the transition characteristics of China's economy and a continuum of states between the regimes, which is consistent with slow adjustments and inertia in inflation. Second, China's inflation has dynamic characteristics of multiple equilibria; the dynamic multiple equilibria of China's inflation may be a consequence of the changes in the underlying monetary policy regime [Zhang (2013)]. The STR model can depict the characteristics of multiple equilibria dynamics [Pavlidis et al. (2013)]. The empirical results in the present study confirm that the STR models capture the nonlinear relationship between inflation and output in China. The use of this model provides more efficient information to Chinese monetary policy makers and contributes to the literature by analyzing the inflation dynamics of China more robustly.

This paper is organized as follows. Section 2 describes the stylized facts of the Chinese economy and monetary policies. Section 3 introduces the theoretical background of the nonlinear Phillips curve and determines the econometric model. Section 4 examines the linear nature of the Phillips curve and estimates the nonlinear Phillips curve. Section 5 analyzes the policy implication, and Section 6 concludes.

2. STYLIZED FACTS OF CHINA'S INFLATION, OUTPUT GROWTH RATE, AND MONETARY POLICIES

China started its economic reforms in 1978, which facilitated the process whereby administratively set prices were increasingly liberalized. Further liberalization and deregulation of prices were conducted after Deng Xiaoping's southern tour speech in 1992. Since then, China has set the target of establishing a market-oriented economy and developed statistics systems; thus, we can collect many data to analyze the Chinese economy. The data from the first quarter of 1992 to the last quarter of 2011 (1992Q1–2011Q4) can be used to describe stylized facts. Following the practices in the literature, the year-on-year consumer price index (CPI) growth rate is used as the proxy variable for inflation, and

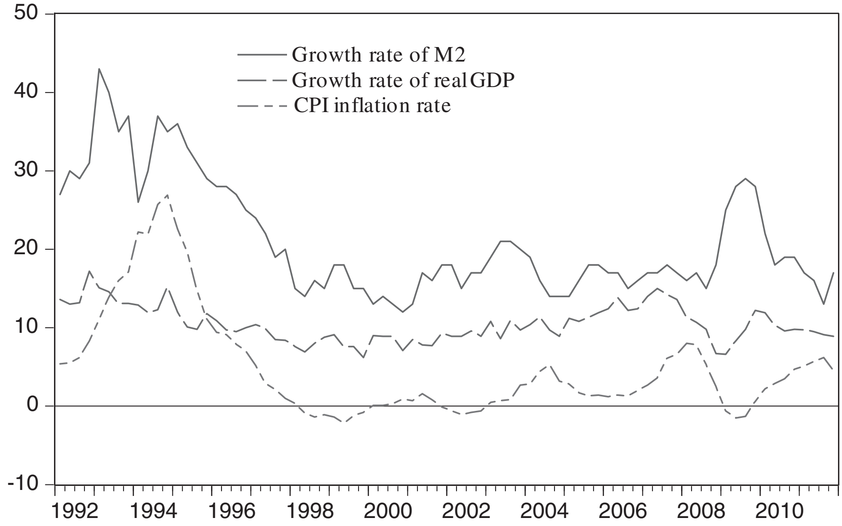

FIGURE 2. Growth rates of real GDP, M2, and the inflation rate in China (1992Q1–2011Q4).

we also investigate the data for the year-on-year economic growth rate and the year-on-year rate of monetary aggregate growth (M2). All data were obtained from the National Bureau of Statistics of China and the People's Bank of China.

Figure 2 plots the growth rates of real GDP, M2, and the inflation rate in China. These growth rates exhibit cyclical but different fluctuations.

In the early 1990s, the Chinese government gradually eliminated price controls in the industrial and retail sectors and encouraged investments by loosening credit control, associated with money supply growth of over 30% for a few years. These polices resulted in high inflation rates, which peaked at 27% in 1994. The growth rate of real GDP remains at a high level, averaging 13%. Monetary authorities in China conducted a number of tightening policy measures in 1994 to fight the high inflation. Inflation began to decelerate in 1995 and continued to decline sharply until the late 1990s.

Figure 2 indicates that China's inflation rate experienced three cyclical fluctuations from 1998 to 2008. A significant deflation occurred from 1998 to 2002, and a relatively low inflation level happened from 2005 to 2006. Similarly, the growth rate of real GDP remained at relatively high levels.

China experienced a transitory deflation and decline in output growth rate in 2009 because of the global financial crisis. To reinvigorate the economy, the Chinese government provided a stimulus package of RMB 4 trillion, which resulted in a sharp increase in the money supply (as shown in Figure 2), which enabled the country to achieve its goal of an 8% GDP growth rate.

Figure 2 also reflects the co-movement among inflation, economic growth, and monetary policy regime. However, these co-movements may not be contemporaneous. Zhang and Murasawa (2012) examine these co-movements by summarizing the respective correlations, namely, contemporaneous, lead, and lag, among CPI inflation, money supply growth rate, and GDP growth rate. Their results indicate a stronger correlation between inflation and lagged money growth and lagged GDP growth rate.

The following section focuses on the link between inflation and economic growth by examining the Phillips curve from a nonlinear perspective.

3. THEORETICAL BACKGROUND AND ECONOMETRIC MODEL SPECIFICATION

3.1. Microfoundations for a Nonlinear Phillips Curve Relationship

The slope of the Phillips curve is the function of the parameters of the price-setting model, which provide the micro-foundation for the construction of the nonlinear Phillips curve. Dupasquier and Rickets (1998) describe five theoretical models to depict the nonlinear relationship between output and inflation.[3]

Macklem (1997) expounds on the capacity constraint model and the momentary policy implications systematically. Under this model, the short-run Phillips curve would be convex.

Lucas (1972, 1973) proposes that output decisions of firms are based on changes in relative price. Firms are unable to distinguish precisely between aggregate and relative price shocks and only infer according to the changes in individual price, which results in the relationship between output and inflation. Such a relationship relies on the variance of the inflation rate. If aggregate prices are extremely volatile, little can be inferred about relative price shocks. Many variations in individual prices are attributed to aggregate price shocks. Under these conditions, output responds less to aggregate demand shocks when the volatility of prices is high than when the volatility is low (Dupasquier and Rickets (1998)].

Ball et al. (1988) and Ball and Mankiw (1994) believe that the relationship between output and inflation changes with inflation levels. Based on the existence of menu cost and long-run contracts, not all firms will change their prices when particular demand shocks confront the economy. However, the wages of workers will not be adjusted immediately. According to the model, a greater increase in the ranges of inflation leads to a greater adjustment range and frequency of price increases by firms. Therefore, the influence of the demand shock on inflation is greater than that on the output. Therefore, the Phillips curve is convex.

Stiglitz (1986) and Fisher (1989) present the nominal wage rigidity model systematically. Based on the money illusion and institutional factors, workers are not willing to accept decreases in the nominal wage. Therefore, under the economic conditions of low inflation, adjustment of the wage is relatively slow, which leads to ineffective allocation problems to some extent. Hence, the influence of oversupply on inflation in the low-inflation stage is smaller than that in the high-inflation stage. This behavior leads to an asymmetric effect between output and inflation. Correspondingly, nonlinear features characterize the Phillips curve.

Stiglitz (1984) notes that firms have pricing abilities in a monopolistically competitive market. As a result, firms are able and willing to influence the market share through strategic pricing behavior. To contain competitors, some firms may be unwilling to increase prices. Therefore, when excess demand confronts the economy, monopolistically competitive firms will enhance the output drastically and will adjust prices slightly. When oversupply confronts the economy, these firms will decrease prices to maintain their market share. This behavior implies that a concave feature characterizes the Phillips curve.

3.2. Specification of the Econometric Model

According to these theoretical models, the Phillips curve may be concave or convex. In practice, the presumptions of researchers on the formation of the Phillips curve according to different theories lead to different Phillips curves and policy implications. Filardo (1998) notes that such a practice would lead to systematic bias and that the Phillips curve may be a combination of concave and convex shapes. The Phillips curve alternates between concave and convex shapes according to changes in economic conditions. Filardo (1998) uses a three-regime model to estimate the Phillips curve for the United States as follows:

$$\pi_t = \pi_t^e + \beta_w g_{w,t-1} + \beta_b g_{b,t-1} + \beta_s g_{s,t-1} + \varepsilon_t, \tag{1}$$

where π_t, π_t^e denote the actual and expected inflation rates, respectively, g_t is the output gap, and ε_t is the supply shock. β_w, β_b, and β_s denote the reaction sensitivity of inflation to the output gap under a contractionary economy, a balanced economy, and an overheated economy, respectively. When $\beta_w = \beta_b = \beta_s$, equation (1) is the traditional linear Phillips curve. Filardo (1998) estimates that $\beta_w = 0.2$, $\beta_b = -0.02$, $\beta_s = 0.49$ by using the data for the United States from 1959 to 1997 and obtains the mixed convex and concave Phillips curve.

The model of Filardo (1998) is a three-regime threshold regression model (TR). However, the TR model is actually a special case of the STR, whose regime switches from one to another within a moment. This observation is too extreme. In contrast, the STR model is more realistic. In addition, there is no need for the STR model to make a priori assumptions about the shape of the nonlinear relationship. Therefore, an STR model will be adopted as the econometric model, in which the basic two-regime model is as follows:

$$\pi_t = [\pi_t^e + \phi_{11}(g_t - g^*)][1 - F(s_t, \gamma, c)] + [\pi_t^e + \phi_{21}(g_t - g^*)]F(s_t, \gamma, c) + \varepsilon_t, \tag{2}$$

where π_t, π_t^e denote the actual and expected inflation rates, respectively. g_t denotes the output growth rate, g^* is the potential output growth rate or natural rate,[4]

$F(s_t, \gamma, c)$ is the smooth transition function, and s_t, γ, c denote the transition variable, transition speed parameter, and threshold value, respectively. $F(s_t, \gamma, c)$ has two general forms, namely, the logistic and exponential functions:

$$F(s_t, \gamma, c) = (1 + \exp[-\gamma(s_t - c)])^{-1}, \quad \gamma > 0, \tag{3}$$

$$F(s_t, \gamma, c) = 1 - \exp[-\gamma(s_t - c)^2], \quad \gamma > 0. \tag{4}$$

Equations (3) and (4) correspond to the logistic smooth transition regression (LSTR) model and exponential smooth transition regression (ESTR) model, respectively.

Equation (2) describes the Phillips curve model using the output growth gap as Canova (2007) and Lacker and Weinberg (2007) did. In this paper we assume that the potential output growth rate g^* is fixed; therefore we actually analyze the Phillips-type relation between inflation and output growth.

An additional important issue is inflation expectation. Whether the inflation expectation is an adaptive or rational expectation is always a core problem in macroeconomic disputes. Chow (2011) claims statistical and econometrical evidence supporting the hypothesis indicating that the adaptive expectation is sufficient, but the evidence supporting rational expectations is insufficient. Therefore, this paper utilizes adaptive expectation, and higher-order lags of inflation are added to reflect the inertia characteristics of inflation [Gordon (1988); Zhang et al. (2008)].

From the discussion, equation (2) is rearranged as follows:

$$\pi_t = \left[\phi_{10} + \sum_{i=1}^{k} \theta_{1i}\pi_{t-i} + \phi_{11}g_t\right][1 - F(s_t, \gamma, c)] + \left[\phi_{20} + \sum_{j=1}^{l} \theta_{2j}\pi_{t-j} + \phi_{21}g_t)\right]F(s_t, \gamma, c) + \varepsilon_t. \tag{5}$$

When the corresponding parameter of each variable in the two regimes is equal or when $F(s_t, \gamma, c)$ is a constant, equation (5) degenerates into the linear Phillips curve, which is similar to the reduced Phillips curve model used by Gordon (2011). In equation (5), we do not necessarily restrict the parameters for adaptive inflation expectations in the two regimes to be equal. Technically, they may be equal, i.e., $\theta_{1i} = \theta_{2j}$ for all $i = j$, and only if $\phi_{11} \neq \phi_{21}$will the nonlinear equation hold. However, in practice, it is more reasonable that the parameters for adaptive inflation expectations in the two regimes are different because the agents have different inflation expectations in deflation and inflation regimes. Therefore, we do not impose any restriction on these parameters in equation (5). The baseline model of this paper is equation (5), which reflects the nonlinear relationship between inflation and output more explicitly.

TABLE 1. Unit root tests for the Chinese economic growth rate and inflation rate

	Unit root test					
Variable	ADF	PP	inf-t	t_N	t_{ESTAR}	W^{sup}
g_t	-2.863^{*}	-2.691^{*}	-3.427^{**}	-3.019^{**}	-2.453^{**}	42.121^{***}
π_t	-2.298	-1.815	-4.629^{***}	-3.775^{***}	-4.722^{***}	74.435^{***}

Notes: We follow Caner and Hansen (2001) and select the transition variable that minimizes the residual sum of squares of corresponding regressions. Lag lengths are selected using SIC. The 1%, 5%, and 10% critical values for the t_N test with an intercept are –3.48, –2.93, and –2.66, respectively. The 1%, 5%, and 10% critical values for the inf-t test with an intercept are –3.86, –3.30, and –3.03, respectively. The 1%, 5%, and 10% critical values for the W^{Sup} test are 18.28, 14.20, and 12.28, respectively. The 1%, 5%, and 10% critical values for the t_{ESTAR} test are –2.98, –2.37, and –2.05, respectively. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

4. MODELING THE NONLINEAR PHILLIPS CURVE WITH STR

4.1. Unit Root Test

We use the same data described in Section 2, in which the inflation rate and the economic growth rate are denoted by π_t and g_t, respectively.

Unit root tests for the inflation rate and the growth rate sequences are conducted to confirm whether the data are globally stationary. If the sequence is a unit root process, we should model the cointegration relationship or model in the first difference sequence.

Balke and Fomby (1997) and Taylor et al. (2001) indicate that the power of conventional unit root tests, such as the ADF and the PP, can be dramatically low against nonlinear alternatives. This lack of power motivates the development of new testing approaches that consider the nonlinear processes explicitly. Enders and Granger (1998), Caner and Hansen (2001), and Bec et al. (2008) conduct tests in the context of the threshold autoregressive model. Kapetanios et al. (2003), Park and Shintani (2005), Bec et al. (2010), and Kiliç (2011) propose a unit root test based on the STAR model.

To make the test results more robust, this paper applies traditional linear and nonlinear unit root tests proposed by Kapetanios et al. (2003), Park and Shintani (2005), Bec et al. (2010), and Kiliç (2011) (denoted by t_N, inf-t, W^{sup}, and t_{ESTAR}, respectively).[5] Table 1 displays the test results. With a significance level of 10%, all of the test results reject the unit root hypothesis for the economic growth rate sequence. The four nonlinear test methods are significant at the 5% level. For the inflation rate sequence, the ADF and PP tests cannot reject the unit root hypothesis, whereas the rest of the results indicate that the growth rate is globally stationary. Therefore, we believe that both the inflation rate and the growth rate are globally stationary processes, and we can model their relationship without further differencing.

4.2. Specification, Estimation, and Evaluation of the Smooth Transition Regression Model

A linear Phillips curve is estimated initially, and the residual sequence is fitted into a four-order autoregressive process according to the Box–Jenkins modeling procedure using the BIC criterion. The estimation results are displayed in the equation,

$$\begin{aligned} \pi_t &= -1.379 + 1.657\pi_{t-1} - 0.0.715\pi_{t-2} + 0.157 g_t + u_t \\ &\qquad (0.556) \quad (0.081) \qquad (0.076) \qquad (0.057) \\ u_t &= -0.344 u_{t-1} - 0.361 u_{t-4} + \varepsilon_t \\ &\qquad (0.107) \qquad (0.111) \end{aligned} \tag{6}$$

$$\begin{aligned} \hat{\sigma}_\varepsilon &= 1.154, \mathrm{LB}(4) = 4.134(0.126), \mathrm{LB}(8) = 7.692(0.262), \\ \mathrm{ARCH}(4) &= 13.821(0.001)\mathrm{ARCH}(8) = 14.310(0.026), \\ \mathrm{AIC} &= 3.202, \mathrm{SIC} = 3.389, \end{aligned}$$

where $\hat{\sigma}_\varepsilon$ is the standard deviation of the residual sequence. The figures in parentheses under the estimated coefficients represent the standard deviations of the estimated coefficients. LB (q) is the Ljung–Box Q statistic used to test whether a q-order autocorrelation exists in the residual sequence. ARCH (m) is the McLeod–Li Q statistic used to test whether an m-order ARCH effect exists in the residual sequence. All figures in parentheses are their corresponding p values. The results indicate no autocorrelation in the residual sequence, which is approximately a white noise process. However, an obvious ARCH effect lies in the residual sequence, which may be important evidence of neglected nonlinearity in the modeling process. Therefore, we should conduct a linear test based on the estimated results in equation (6).

Teräsvirta (1994) proposes an LM test for linearity against an STR model. Based on the basic STR model represented as equation (5), Teräsvirta (1994) employs the three-order Taylor expansion of the transition function around H_0 to form an auxiliary model that aims to overcome the unidentified problem of the parameter under the null hypothesis,

$$\pi_t = \boldsymbol{\beta}'_0 \boldsymbol{x}_t + \boldsymbol{\beta}'_1 \boldsymbol{x}_t s_t + \boldsymbol{\beta}'_2 \boldsymbol{x}_t s_t^2 + \boldsymbol{\beta}'_3 \boldsymbol{x}_t s_t^3 + u_t, \tag{7}$$

where $\boldsymbol{x}_t = (1, \pi_{t-1}, \pi_{t-2}, \cdots, \pi_{t-p}; y_t)'$ and $\boldsymbol{\beta}_i = (\beta_{i1}, \beta_{i2}, \cdots \beta_{im})', i = 0, 1, 2, 3, m = p + 2$. The null hypothesis of the linearity test is equivalent to $H_0 : \boldsymbol{\beta}_1 = \boldsymbol{\beta}_2 = \boldsymbol{\beta}_3 = 0$, and the LM-type test (under the small sample size, the F statistic is preferred) can be performed. Teräsvirta (1994) also constructs three

TABLE 2. LM-type tests for STAR nonlinearity

Transition variable s_t	Linearity test H_0	H_{03}	H_{02}	H_{01}
g_{t-1}	0.6025	0.4526	0.6971	0.4182
g_{t-2}	0.8369	0.3312	0.9280	0.7724
g_{t-3}	0.0040	0.0002	0.0934	0.4622
g_{t-4}	0.0072	0.0287	0.0198	0.2513
g_{t-5}	0.1633	0.0138	0.4662	0.9902
g_{t-6}	0.6949	0.3164	0.9540	0.5044
π_{t-1}	0.0349	0.0866	0.0089	0.8226
π_{t-2}	0.2846	0.2271	0.0813	0.8869
π_{t-3}	0.0006	0.0001	0.0959	0.8884
π_{t-4}	0.4761	0.1102	0.7418	0.8085
π_{t-5}	0.3593	0.2926	0.1137	0.9324
π_{t-6}	0.8255	0.6915	0.5941	0.6256

Note: The figures are p values of F statistics of the LM-type tests used in the specification procedures of Teräsvirta (1994).

sequential hypothesis tests to choose the proper transition function as follows:

$$H_{03} : \boldsymbol{\beta}_3 = 0,$$
$$H_{02} : \boldsymbol{\beta}_2 = 0 \big| \boldsymbol{\beta}_3 = 0,$$
$$H_{01} : \boldsymbol{\beta}_1 = 0 \big| \boldsymbol{\beta}_2 = \boldsymbol{\beta}_3 = 0.$$

Van Dijk et al. (2002) suggest that the ESTR model should be established if the p value of the H_{02} test is the smallest among the three tests and that the LSTR should be established if the test statistic H_{03} or H_{01} has the smallest p value. These tests provide important information for determining the transition variable as well. According to Teräsvirta (1994), the transition variable of the STR model is usually the lagged variable or lagged difference of the dependent variable. To determine the most appropriate transition variable in the STR model, Teräsvirta (1994) suggests that the practitioner use various variables as s_t in the test model (7) and choose the corresponding s_t of the smallest p value as the transition variable.

Using these tests, we conduct a linearity test based on the estimated result of equation (6). Table 2 displays the corresponding p values of the test statistics. When π_{t-3} is the transition variable, the p value is the smallest, which implies that the "inflation–output" Phillips curve of China has a notably nonlinear dynamic characteristic and can be described in the STR model. Moreover, in the three sequential tests, the p value of the H_{03} test is the smallest. Therefore, an LSTR model should be established.[6]

Maximum likelihood estimation is adopted to estimate the two-regime LSTR model, and the estimation result is indicated in the equations

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TABLE 3. Tests for remaining nonlinearity and the MRSTR model

Transition variable s_t	Test	d 1	2	3	4	5	6
g_{t-d}	LM_{MR}	0.0003	0.0862	0.0967	0.3287	0.0067	0.0725
	ET	0.0033	0.0042	0.0405	0.1650	0.0015	0.0115
Δg_{t-d}	LM_{MR}	0.0145	0.1172	0.1587	0.0029	0.0632	0.0211
	ET	0.0004	0.0026	0.0041	0.0018	0.0164	0.0127

Note: The figures are p values of F statistics of the remaining nonlinearity tests proposed by Eitrheim and Teräsvirta (1999) and van Dijk and Franses (1999).

$$\pi_t = \underset{(0.091)}{1.10}\pi_{t-1} - \underset{(0.092)}{0.354}\pi_{t-2} + (\underset{(2.400)}{-12.205} + \underset{(0.268)}{1.422}g_t) \times F(\pi_{t-3}) + \hat{\varepsilon}_t, \quad (8)$$

$$F(\pi_{t-3}) = (1 + \exp[-\underset{(0.108)}{0.315}(\pi_{t-3} - \underset{(1.819)}{6.365})])^{-1}, \quad (9)$$

$$\hat{\sigma}_{\varepsilon,(LSTR)} = 1.068,\ \hat{\sigma}_{\varepsilon,(LSTR)}\big/\hat{\sigma}_{\varepsilon,(AR)} = 0.92,$$
$$\text{ARCH}(4) = 28.723(0.000),$$
$$\text{ARCH}(8) = 28.951(0.000).$$

The results indicate that the standard deviation of the LSTR model is reduced to 92% of that of the linear model. When the three-order lagged inflation level is more than 6.365, the inflation rate starts to go toward the upper regime. However, the ARCH effect in the residual sequence exists, as the p values of the fourth- and eighth-order McLeod-Li Q statistics are small. This finding makes us doubt whether the LSTR model can adequately describe the nonlinear dynamic characteristic of the inflation rate.

To test for the remaining nonlinearity, we employ the LM-type test proposed by Eitrheim and Teräsvirta (1999; hereinafter, the ET test) and the LM_{MR} statistics used by van Dijk and Franses (1999) to test for the multiregime STR (MRSTR) model.[7] The test results in Table 3 indicate that the LSTR model with two regimes cannot adequately describe the nonlinear dynamic relation between the inflation and output of China and that nonlinearity still exists. By comparing the p values of the test statistics, we can determine when g_{t-1} becomes the transition variable, which occurs when the p value is the smallest. Therefore, g_{t-1} is selected as the second transition variable.

Based on the MRSTR model proposed by van Dijk and Franses (1999), we estimate a four-regime LSTR model using the maximum likelihood method to describe the inflation–output Phillips curve in China.[8] Following van Dijk et al. (2002), we eliminate the lagged variables for which the absolute value of the

t statistics is less than 1. The following equations display the estimation results:

$$\begin{aligned}
\pi_t = {} & [(\underset{(2.076)}{-2.779} + \underset{(0.126)}{0.771}\pi_{t-1} + \underset{(0.231)}{0.334}g_t) \times (1 - F_1(\pi_{t-3})) \\
& + (\underset{(0.364)}{1.66}\pi_{t-1} - \underset{(0.303)}{0.743}\pi_{t-2}) \times F_1(\pi_{t-3})] \times [1 - F_2(g_{t-1})] \\
& + [(\underset{(5.766)}{8.461} - \underset{(0.547)}{0.751}g_t) \times (1 - F_1(\pi_{t-3})) \\
& + (\underset{(10.934)}{-7.997} + \underset{(0.236)}{0.253}\pi_{t-1} + \underset{(0.804)}{2.097}g_t) \times F_1(\pi_{t-3})] \times F_2(g_{t-1}) + \varepsilon_t,
\end{aligned} \tag{10}$$

$$F_1(\pi_{t-3}) = (1 + \exp[-\underset{(0.089)}{0.307}(\pi_{t-3} - \underset{(0.993)}{5.77})])^{-1}, \tag{11}$$

$$F_2(g_{t-1}) = (1 + \exp[-\underset{(0.093)}{4.098}(g_{t-1} - \underset{(0.215)}{11.38})])^{-1}, \tag{12}$$

$$\hat{\sigma}_{\varepsilon,(MRSTR)} = 1.018,\ \hat{\sigma}_{\varepsilon,(MRSTR)}\big/\hat{\sigma}_{\varepsilon,(LSTR)} = 0.95,$$
$$ARCH(1) = 0.539(0.463),\ ARCH(4) = 6.441(0.169),$$
$$BDS = 1.163(0.245),\ BDS_{bootstrap} = 1.163(0.783).$$

Equation (10) represents the four-regime model, whereas equations (11) and (12) are the two smooth-transition functions. The results indicate that the estimated standard deviation is less than that of the two-regime LSTR model, which indicates an improvement of the goodness of fit despite the increase in the number of parameters. The test for nonautocorrelation and no ARCH effect cannot be rejected. The BDS approach is also applied to test for the independence of the residual. The BDS result is 1.163, for which the asymptotic p value is 0.245 and the 2,500 times bootstrap p value is 0.783. The results indicate that the residual sequence is approximately an independently distributed process. Thus, the four-regime LSTR model can adequately describe the dynamic structural relationship between the inflation rate and the output. From the estimated result of the MRSTR model, there exists an inflation–output Phillips curve effect in China's economy. The nonlinear adjustment features characterize the relationship of inflation and output. The reaction of the inflation rate to the output depends on the level of the inflation rate and the economic growth rate. Figure 3 indicates the actual inflation rate and the estimated inflation rate by the MRSTR Phillips curve, as we can see that the estimated Phillips curve tracks actual inflation fairly well.

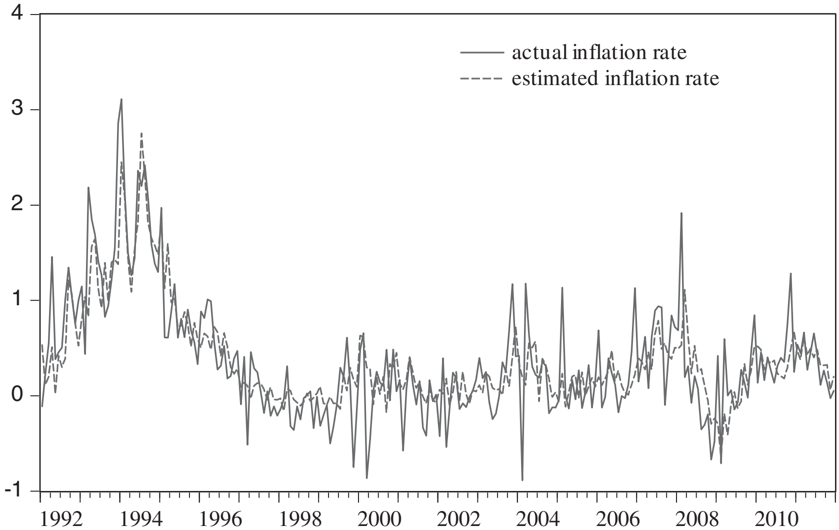

FIGURE 3. Actual inflation rate and inflation rate estimated by Phillips curve in China.

5. RESULTS ANALYSIS AND POLICY IMPLICATIONS

Equations (10)–(12) analyze the nonlinear relationship between the inflation rate and the economic growth rate in China and provide significant information for the partition of the business cycle. The following three findings may be valuable to policymakers based on the results of equations (10)–(12).

First, a nonlinear Phillips curve exists in China. The relationship between inflation and output in China is economic-state-dependent, which is more complicated than that in the linear world. Equations (10)–(12) indicate that the existence of an "inflation–output" trade-off depends on the past inflation rate and output growth rate, namely, π_{t-3} and g_{t-1}, which are chosen by empirical estimation. The equations reflect that China's inflation may be more related to the three-order lagged inflation rate and the one-order output growth rate. Therefore, policy makers must monitor these two transition variables because they may provide some forecasting information on inflation dynamics. On the other hand, the transition variables π_{t-3} and g_{t-1}, for which the delay parameters are 3 and 1, respectively, present the cyclical behavior and inertia characteristics of China's inflation. Much of the literature on China's inflation dynamics is descriptive in nature and confined to single inflation episodes. Brandt and Zhu (2000, 2001) focus on China's inflation cycles and offer detailed empirical evidence. Central to their story is the government's use of the monetary and financial system to support the state sector and the growing tension between a long-running commitment to this sector and economic decentralization. Their analysis suggests that the fundamental contradiction is between the state and nonstate sectors, and the inflation cycles are a product of the government's imperfect control over credit allocation and the costs of administrative credit control. However, their analysis overlooks the nonlinearities and asymmetries in China's economic cycles. The present paper fills this gap. In addition, Arghyrou et al. (2005) model the inflation dynamics in the United Kingdom, and Nobay et al. (2010) model the inflation dynamics in the United States using STAR models; however, both analyses focus more on the econometric results than on the economic meanings of the transition variables.

Second, regarding the Phillips curve of China as convex or concave would be naïve because it could be a kinked curve that included shapes that were convex in one region and concave in another region. This feature is similar to the curves of Dupasquier and Ricketts (1998), Filardo (1998), and Huh and Jang (2007), which reflect that more than one type of nonlinearity may be nested in a model. Therefore, policy makers should learn the exact regime of the economy and the smooth transition between regimes to conduct monetary policy.

Finally, unlike the three regimes of Filardo (1998) and the two regimes of Huh and Jang (2007) in the case of the United States, the nonlinear Phillips curve of China can be described by a four-regime STR model, which is more complicated than that of the United States. This finding corresponds to the multiple equilibria theory. A seminal contribution by Sargent and Wallace (1973) indicates that inflation is a nonlinear process that can exhibit two equilibria, for which stability depends on the process determining expectations. Marcet and Sargent (1989) indicate that when expectations are described by an adaptive rule, such as least-squares learning, the lower equilibrium is stable and the upper equilibrium is unstable. However, Evans et al. (2001) demonstrate that up to three equilibrium states can emerge in the context of an overlapping-generations model in which the government cannot use seigniorage to finance expenditures of more than a given fraction of gross national product. Furthermore, the dynamic multiple equilibria of China's inflation may be a consequence of changes in the underlying monetary policy regime, as indicated in the monetary policy literature [see, for example, Woodford (1994, 1995, 1996), Clarida et al. (2000), Schmitt-Grohé and Uribe (2000), and Benhabib et al. (2001)]. This issue is not pursued in the present paper but will be investigated in further research.

The traditional partition of the business cycle is based only on output fluctuations. However, the inflation rate also plays an important role in studying economic fluctuation. As a result, the partition of the business cycle should consider both output and inflation fluctuations. We will consider both according to the estimation results in this paper.

When π_{t-3} is lower than 2, F_1 is 0; when π_{t-3} is higher than 6.2, F_1 is 1; when g_{t-1} is lower than 7.6, F_2 is 0; when g_{t-1} is higher than 12.6, F_2 is 1. Therefore, based on the four different combinations of the two smooth-transition functions, for which the values are 0 and 1, the business cycle can be divided into four different extreme regimes that form the four stages of the business cycle:

Stage 1: When $g_{t-1} \leq 7.6$ and $\pi_{t-3} \leq 2$, the economy presents low inflation and low growth rates. We call this stage the contractionary stage.

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Stage 2: When $g_{t-1} \leq 7.6$ and $\pi_{t-3} \geq 6.2$, the economy presents low economic growth but has a high inflation rate. We call this stage recovery stage I.

Stage 3: When $g_{t-1} \geq 12.6$ and $\pi_{t-3} \leq 2$, the economy maintains a high output growth rate but has a low inflation rate. We call this stage recovery stage II.

Stage 4: When $g_{t-1} \geq 12.6$ and $\pi_{t-3} \geq 6.2$, the economy maintains high economic growth and high inflation rates. We call this stage the expansion stage.

Recovery stages I and II depict the middle state between the contractionary and the expansion stages. When the economy recovers from the contractionary state, the price recovers first and then enters recovery stage I, or the output growth recovers first and then enters recovery stage II.

The cases of $7.6 < g_{t-1} < 12.6$ and $2 < \pi_{t-3} < 6.2$ (namely, the central region, when both π_{t-3} and g_{t-1} are within the threshold values) are not ruled out, and lie in the smooth transition area rather than in the extreme stages. This observation implies that if the inflation rate is between 2% and 6.2% and the economic growth rate is between 7.6% and 12.6%, the economy of China will operate stably.

The partition of the business cycle reflects that the form of the Phillips curve depends on the business cycle phases.

When the economy is in the contractionary stage, a trade-off relationship occurs between the inflation rate and the economic growth rate (from 2008Q4–2009Q2). The coefficient of reaction of the inflation rate to the output growth rate is 0.334 in the contractionary stage, which is smaller than the value of 2.097 in the expansion stage (from 1992Q1 to 1995Q1). Hence, the Phillips curve in the contractionary stage is flatter. The results of the present study are different from those of the linear models. For instance, the estimates of the slope coefficients for the Phillips curve are 1.254, 0.896, and 1.028 in the models of Gerlach and Peng (2006), Narayan et al. (2009), and Zhang and Murasawa (2012), respectively. The findings of the current study confirm that the stylized Phillips curve trade-off is empirically valid, provided that the contractionary and expansion stages are known.

When the economy is in recovery stage I (from 1995Q3 to 1997Q4), the process of dynamic adjustment of the inflation rate is independent of the output growth. This finding suggests that under nonlinear conditions, even when the adaptive inflation expectation is adopted, there might be a short-term vertical Phillips curve in China's economy, which indicates that there is no trade-off between inflation and output in this stage. Therefore, if the economy is in this stage, monetary authorities may set monetary policies to fight inflation without losing any output growth. However, expansionary monetary policies cannot accelerate economic growth but can increase the inflation rate. This finding seems consistent with monetary neutrality but quite different from the long-run theory because the economy could switch stages in the short run. The form of the Phillips curve would then change, and a new trade-off would be obtained. Thus, monetarism will not explain the specific phenomenon in China. Unfortunately, the internal mechanism of its formation remains unclear, and may be discussed in future studies.

When the economy is in recovery stage II (from 2005Q4 to 2008Q1), a negative relationship exists between the inflation and output growth rates, which is in accordance with the theory stated by Gordon (2011). This theory claims that the short-term relationship between the inflation rate and the output may not be positive and may even be negative in different economic stages. Consequently, this theory mirrors the economic reality of China.

From 1998 to 2002, the economy at once developed rapidly and maintained a relatively low inflation rate. Economists call this phenomenon the "deflationary expansion puzzle." Many economists believe "deflationary expansion" originates from a positive supply impact, such as improvement in labor productivity [Gong and Lin (2008)].

Having significant policy implications, the sacrifice ratio plays a key role in studying the Phillips curve. As we know, the typical sacrifice ratio is defined as the percentage of output that must be forgone to reduce inflation by one percentage point. However, the robust estimation of the output gap is difficult and the current paper construct the Phillips curve using the output growth gap; therefore, we construct a *pseudo sacrifice ratio* between the change in the growth rate of output and inflation, namely, $\Delta g/\Delta\pi$.[9] This pseudo sacrifice ratio can describe how much output growth would be lost when policy makers decided to reduce inflation. This cost can then be compared with the benefits of lower inflation. Compared with the linear Phillips curve, the estimation of the sacrifice ratio in the nonlinear Phillips curve is more complicated because the sacrifice ratio of the nonlinear model depends on the specific stage of the business cycle and the inflation-control target.

To analyze the sacrifice ratio of the nonlinear model completely, we discuss the sacrifice ratio under two conditions, namely, estimation within stages and the estimation between stages. Under the former condition, the sacrifice ratio is actually the same as the estimation of the linear model. However, what is more realistic in economic operation occurs when an exogenous shock confronts the economic system, which could lead to the transfer from one stage to another. In this situation, we cannot obtain the estimate of the sacrifice ratio in the same way as that of the linear model. Instead, we apply random simulation to estimate the analog solution of the sacrifice ratio, for which the specific procedures are as follows:

(1) The expression for the output growth rate was solved with respect to the inflation rate and its lags according to equation (10). By doing this, a model can be derived with the output growth as dependent variable, making it convenient to compute the sacrifice ratio.
(2) The sample data of the output growth rate, inflation rate, and error term in various stages were derived according to the transition functions (11) and (12) to partition the data into different extreme stages and transition areas.
(3) Sample observations and the corresponding errors in the specific transition stage and transition areas were drawn and the growth rate calculated for when a decrease in the inflation and output growth rates in the initial inflation rate occurs. Therefore, the difference between the two output growth rates is the marginal effect of the decreasing inflation on output growth, which can be used to measure the sacrifice

TABLE 4. Estimation of sacrifice ratios along the nonlinear Phillips curve

	Output sacrifice ratio of decreasing inflation within stages					
	Within contractionary stage	Within recovery stage I		Within recovery stage II		Within expansion stage
	−3.0	—		1.3		−0.5
	Output sacrifice ratio of decreasing inflation between stages					
	1 to 2	1 to 3	1 to 4	2 to 3	2 to 4	3 to 4
Decreasing inflation by 1%	−0.77	0.37	−5.90	1.94	0.66	2.67
Decreasing inflation by 2%	−1.84	0.18	−6.81	−0.22	−2.96	0.24

Note: "1 to 2" denotes that the economy transfers from stage 1 to stage 2; others are similar.

ratio at a specific time. Because this is a bootstrap procedure, we should perform this step over and over again, and derive the mean. Hence, I performed the next step.

(4) Repeat step (3) for 10,000 replications and calculate the mean differences $\Delta g = \overline{g((\pi_t - \Delta\pi), \varepsilon_t)} - \overline{g(\pi_t, \varepsilon_t)}$ under the two simulations.

(5) Calculate the estimated value of the sacrifice ratio $\Delta g / \Delta\pi$.

Table 4 presents estimates of the sacrifice ratio in the two circumstances. When an economic system stays in the same stage, the sacrifice ratio is –3 in the contractionary stage and -0.5 in the expansion stage, which means that 1% disinflation costs 3% of output growth when the economy is in the contractionary stage without switching out and 0.5% of output growth when the economy is in the expansion stage. The results confirm the argument of this study that the stronger the economy is, the less the effect of a tighter monetary policy on output growth, which results in fewer output costs to achieve a given disinflation. In addition, this finding indicates that an obvious asymmetrical feature characterizes the output cost needed to control inflation. During an economic downturn, more output growth should be sacrificed to maintain a low inflation rate.

When the economic system transfers between different stages, the sacrifice ratio and its sign are dependent on the different stages of the business cycle and the inflation-control target.[10]

There are twelve transition cases between stages, because we have four extreme stages. Hence, we should compute the twelve sacrifice ratios when the economy transfers from one stage to another. However, in the sample data used in this paper, for some transition areas, the absence of sufficient observations resulted in the noncomputation of some sacrifice ratios. For example, no observation was found in the transition area from stage 4 to 1 and from stage 3 to 1. Only one observation was found in the transition area from stage 4 to 2, five observations in the transition area from stage 2 to 1, and seven observations in the transition area from stage 3 to 2. Therefore I only computed the sacrifice ratio for six other cases.

If the target is to decrease inflation by 1%, the sacrifice ratio may be negative when the economic system switches between stages 1 and 2 and/or stages 1 and 4, which means that a 1% disinflation costs 0.77% of output growth when the economy switches between stages 1 and 2 and costs 5.9% of the output growth when the economy switches between stages 1 and 4. The sacrifice ratio is high when the economy switches between stages 1 and 4. This result suggests that inflation control during sharp fluctuations in economic growth will lead to severe output losses. However, when the economy operates in other stages, such as between stages 1 and 3 and/or stage 3 and 4, inflation control may not lead to output losses and may even increase output. For example, the output growth will increase by 0.37% when inflation is decreased by 1% when the economy switches between stages 1 and 3; the output will increase by 2.67% if the economy switches between stages 3 and 4.

These results are special because the business cycle of China has a recovery II stage, where the relationship between inflation and output is negative. The implication behind these results is very important, because moderate inflation may benefit the economy to some extent, provided that monetary authorities know the business cycle stage exactly and employ a preemptive policy.

Furthermore, the sacrifice ratios with different disinflations include important implications because they may provide helpful information in choosing between gradualism and cold turkey.

If we aim to decrease the inflation rate by two percent, a decrease in the inflation rate will result in weak output yield only when the economic system transits between stages 1 and 3 or between stages 3 and 4. When it transits between other stages, inflation control will lead to output loss, and the sacrifice ratio will be higher than that of the control target of one percent. This finding implies that as far as macroeconomic regulation and control in China is concerned, a radical "cold turkey" policy is not applicable, and gradualism should be taken in the majority of cases.

6. CONCLUSIONS

This paper adopts the MRSTR model to study the relationship between inflation and output in China. Empirical results indicate that nonlinear features characterize the Phillips curve of the economy of China. A four-regime LSTR model depicts the structural relation between inflation and output. The major conclusions of this paper are as follows:

(1) There exists an "inflation–output" Phillips curve in the economy of China. Remarkable nonlinear features characterize the relationship between inflation and output.

The reaction of inflation to output relies not only on the inflation rate but also on the economic growth rate. Thus, the economic cycle in China can be divided into four stages, namely, contractionary, recovery I and II, and expansion. According to estimation results, a stable macroeconomic operation range occurs when the economic growth rate remains between 7.6% and 12.6%, and the inflation rate stays between 2% and 6.2%.

(2) When the economy is in the contractionary stage, a trade-off occurs between inflation and economic growth rates. The reaction coefficient of the inflation rate to the output growth rate is 0.334 in the contractionary stage, which is smaller than the 2.097 in the expansion stage. This result indicates that the Phillips curve in the contractionary stage is flatter. When the economy is in recovery stage I, the dynamic adjustment process of the inflation rate is independent from the output growth. This observation suggests the existence of a vertical Phillips curve in the Chinese economy in the short run. When the economy is in recovery stage II, there will be negative relationship between the inflation and output growth rates. This relationship is a new experience and a proof of the "deflationary expansion puzzle" phenomenon in the economy of China.

(3) When an economic system has no transition between the stages, the sacrifice ratio is –3 in the contractionary state and –0.5 in the expansion stage. When the economic system transits between different stages, the sacrifice ratios and their signs are dependent on the different stages of the business cycles and the inflation-control target.

According to the results, under certain economic conditions and specific business cycles, the economy can realize a stable price while maintaining rapid economic growth. Therefore, authorities should strengthen real-time monitoring of the macroeconomy and analyze the business cycle accurately in making and implementing monetary policies that are more appropriate and effective. When the economic growth and the inflation rates are in a harmonious interval, the momentary policy should keep continuity and stability as much as possible to avoid economic fluctuation caused by over adjustment. Therefore, a combination of rules and discretion should be followed. This paper also indicates that the radical "cold turkey" policy is not appropriate for macroeconomic regulation and control in China and that a milder but progressive policy should be adopted.

NOTES

1. Gerlach and Peng (2006) used only the AR (2) process to replace the driving variable in the model because they believed the driving variable can neither be observed nor measured by other proxy variables.

2. Figure 1 plots the scatter between quarterly data of the year-on-year growth rate of the Chinese consumer price index (CPI) and the growth rate in real GDP from the first quarter of 1992 to the fourth quarter of 2011 (1992Q1–2011Q4). The data are obtained from the National Bureau of Statistics of China.

3. Readers are directed to related references for details concerning the five models.

4. This paper assumes that the potential output growth rate is time-invariant, which is reasonable in the short run to some extent because China pursues an output growth rate of 7–9%.

5. Readers are directed to related references for details concerning the four tests.

6. We also conducted linearity tests using other transition variables, such as Δg_{t-I} and $\Delta \pi_{t-i}$; however, the test results refer to g_{t-i} and π_{t-i} as the transition variables.

7. Readers are directed to related references for the details concerning the two tests and the MRSTAR model.

8. The three-regime STR model was also estimated. Based on the nonlinear residual test, the residual still has nonlinear characteristics. Therefore, the three-regime model is not adequate.

9. We refer to this "pseudo sacrifice ratio" as "sacrifice ratio" hereafter for simplicity.

10. A positive sacrifice ratio indicates that a decrease in inflation will cause an increase in output.

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