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TIME-VARYING COEFFICIENT TAYLOR RULE AND CHINESE MONETARY POLICY: EVIDENCE FROM THE TIME-VARYING COINTEGRATION

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No consensus has been reached about whether the Taylor rule performs well in China. Most studies have either ignored the nonstationarity of the variables in the Taylor rule model or assumed a constant cointegrating vector. China is a transition economy, undergoing gradual reform. Consequently, the fixed coefficient cointegration approach is unable to capture the long-run relationship among interest rate, inflation gap, and output gap. Therefore, this paper develops a time-varying coefficient Taylor rule and estimates it using a smooth time-varying cointegrating approach. The results show a time-varying long-run relationship among the variables in the Taylor rule. The coefficient on the inflation gap is significantly less than 1, indicating that the nominal interest rate's response to inflation is inadequate. Moreover, the coefficient on the output gap is significantly greater than 0, implying that the response of the nominal interest rate to the output gap is sensitive. The People's Bank of China should adjust the short-term interest rate should be more flexible especially to changes in inflation.

Keywords: Chinese Monetary Policy, Time-varying Coefficient Taylor Rule, Time-varying Cointegration
JEL Classification: C14, E52, E58

1. INTRODUCTION

The Chinese economy, known as the "China miracle", has maintained steady and fast growth for three decades, and attracts much attention from scholars and practitioners. Unlike Eastern European countries, China undergoing a gradual market-oriented reform in which its economic structure and regime are changing slowly and smoothly. For this reason, it is of great importance to study whether existing economic theory can be

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applied to China. In macroeconomics, the "Taylor rule" proposed by Taylor (1993), is an important monetary policy that specifies how the US Federal Reserve should adjust its targeted interest rate to the inflation and output gaps. Studying the validity of the Taylor rule for China is theoretically and practically important.

There is a vast literature on the Taylor rule. For example, Taylor (1999) studied the validity of the Taylor rule using historical data covering 1897 to 1914 and 1955 to 1997, finding that the deviation of the actual interest rate from the targeted interest rate could help reflect the effectiveness of monetary policy. Kim and Nelson (2006) proposed a time-varying parameter forward-looking monetary policy rule and provided an efficient estimation using the Kalman filter. Yüksel, Metin-Ozcan, and Hatipoglu (2013) introduced an interest rate pass-through specification of the monetary transmission process in a general Taylor model. Xie and Luo (2002) were the first to check the validity of the Taylor rule for China, finding that it was a good measure for Chinese monetary policy and provided a reference for Chinese monetary policy implementation. However, Bian (2006) showed that the Taylor rule was unstable in China by using the GMM and cointegration test approach. Zheng and Liu (2010) developed a regime-switching Taylor rule with a time-varying inflation target, and showed that the Chinese monetary policy rule could be significantly divided into "passive" and "active" regimes.

As Österholm (2005) pointed out, however, previous studies ignored the nonstationarity of the variables in the Taylor rule model, despite the enormous body of literature. On one hand, the variables might not be stationary processes. Given the variable's unit root behavior, the cointegration relationships among them become essential for regression modeling. In the absence of cointegration, the model would be a spurious regression. On the other hand, the traditional fixed coefficient cointegration approach assumes a constant long-run equilibrium relationship among the variables, thus failing to capture the dynamic structure of the equilibrium relationship. China's gradual reform process is leading to a smooth structural change in the relevant economic variable and market, such as stock markets (Huang *et al*., 2000) and interest rate. For example, China is gradually carrying out interest rate liberalization. First, inter-bank lending and bond markets were deregulated in 1996; then, the ceiling on deposit rates and the floor on lending rates of commercial banks were relaxed; then, the Shanghai Interbank Offered Rate (Shibor) became China's benchmark rate in 2007; and then, the lending interest rate was completely decontrolled in 2013. Accordingly, this paper considers the smooth and gradual structural change occurring in China rather than abrupt structural breaks.

This paper develops a time-varying coefficient Taylor rule to study China's monetary policy. Given the nonstationarity of the model's variables, the paper employs the time-varying cointegration approach of Park and Hahn (1999). To the best of our knowledge, this paper is the first to examine the Taylor rule through the time-varying cointegration approach. Kim and Nelson (2006) also considered the time-varying coefficient Taylor rule, but failed to consider the nonstationarity of the variables. By using several unit root tests, we found that the interest rate, the inflation gap and the output gap are indeed nonstationary. Österholm (2005) also found that the three variables for the US, Australia and Sweden were near unit root processes. Lu and Zhong (2003) also tested the validity of the Taylor rule for China using the cointegration approach. However, neither Österholm (2005) nor Lu and Zhong (2003) considered time-varying cointegration. As mentioned, China is reforming gradually. Many significant events happened during the sample period, such as the Asian financial crisis in 1997 and the US subprime crisis in 2008. The fixed coefficient cointegration model is thus unable to capture monetary policy changes. Therefore, it is extremely theoretically and practically important to estimate the time-varying coefficient Taylor rule using the time-varying cointegration approach.

The rest of this paper is organized as follows. Section 2 presents the specification and estimation for the time-varying coefficient Taylor rule and the time-varying cointegration test. Section 3 summarizes the data. Section 4 presents the estimation results for the time-varying coefficient Taylor rule as well as the policy implication. Finally, Section 5 concludes the paper.

2. THE MODEL AND METHODOLOGY

2.1. Taylor Rule

Taylor (1993) claimed that the federal funds rate should be adjusted for the inflation gap (the deviation of current inflation from the inflation target) and the output gap (the deviation of current output from the potential output), and proposed a very simple monetary policy rule:

$$i_t = r^* + \pi_t + f_\pi(\pi_t - \pi^*) + f_y y_t + v_t, \tag{1}$$

where i_t, r^*, π_t and π^* representsthe central bank policy rate, the equilibrium real interest rate, the actual inflation rate and the inflation inflation gap, and y_t denoted the output gap - namely the percent deviation of actual real GDP from an estimate of its potential level. v_t is the error term, f_π and f_y are the response coefficients of the interest rate to the inflation gap and the output gap, respectively. According to Taylor (1993), when $r^* = 2$, $r^* = 2$, $f_\pi = 0.5$, $f_y = 0.5$, the Taylor rule fits the federal funds rates in effect between 1987 and 1992 quite well.

We define the economic meaning of the parameters and ease their estimation by transforming Equation (1) into Equation (2).

$$i_t = r + \beta(\pi_t - \pi^*) + \gamma y_t + v_t, \tag{2}$$

where $r = r^* + \pi^*$ represents the long-term equilibrium nominal interest rate,

$\beta = 1 + f_\pi$ and $\gamma = f_y$. For an economy in equilibrium, the actual inflation rate equals the target rate of inflation, and actual output equal potential output, thus, both the inflation gap and the output gap are zero. The central bank's policy rate is then long-term equilibrium nominal interest rate. According to Equation (1), if the inflation rate deviates from its target rate and/or the real output deviates from its potential value, the central bank should adjust the nominal interest rate to make the inflation rate and output return to their normal values. For example, a positive output gap indicates that total domestic demand is greater than total supply, a fortiori, inducing inflationary pressure. In this case, the central bank should raise interest rates to ease inflation and excess production capacity. The coefficient of an effective monetary policy should therefore satisfy $f_\pi > 0,\ f_v > 0$, namely, $\beta > 0,\ \gamma > 0$.

Many scholars have extended the original Taylor rule presented in Taylor (1993). For example, Orphanides (2003) and Molodtsova *et al.* (2008) used the inflation forecast instead of its current value to consider the forward-looking nature of monetary policy. Clarida *et al.* (1998) added lagged variable of interest rate to the Taylor rule to consider interest-smoothing behavior. These extensions have attracted much attention in the literature. As Österholm (2005) pointed out, however, using the forecast value might increase parameter estimation uncertainty since the forecast values are affected by many unobservable factors. Moreover, Rudebusch (2002) and Söderlind *et al.* (2005) argued that a Taylor rule with interest-smoothing made the predictability of the interest rates spurious. For these reasons, this paper does not consider forward-looking behavior or interest rate smoothing.

2.2. Time-varying Coefficient Taylor Rule and Estimation

Since smooth structural changes in an economy cannot be captured by the fixed-coefficients Taylor rule, we develop a time-varying coefficient Taylor rule:

$$i_t = r + \beta_t(\pi_t - \pi^*) + \gamma_t y_t + \varepsilon_t, \tag{3}$$

where β_t and γ_t are functions that vary smoothly over time, and ε_t is the error term.

Denoting $\alpha_t = (\beta_t, \gamma_t)'$, $x_t = \big((\pi_t - \pi^*), y_t\big)$, Equation (3) can be expressed by

$$i_t = r + \alpha_t' x_t + \varepsilon_t, \tag{4}$$

where α_t is assumed to be a smooth function. Thus let

$$\alpha_t = \alpha\left(\frac{t}{n}\right), \tag{5}$$

where n is the sample size and t is the order of observation in the total sample. Therefore, α_t is a smooth function defined in [0,1]. Equation (4) is a time-varying version of Equation (2), thus, the time-varying "Taylor rule" model.

Park and Hahn (1999) suggested approximating the smooth time-varying parameter α_t using the Fourier flexible form.

$$\alpha_t(\lambda) = \beta_{k,1} + \beta_{k,2}\lambda + \sum_{i=1}^{k}\big(\beta_{k,2i}, \beta_{k,2(i+1)}\big)\varphi_i(\lambda), \tag{6}$$

where $\beta_{k,j} \in \mathbb{R}^2$ is a column vector, $j = 1,2,\cdots,2(k+1)$. The smoothness of α_t is depends on the value of k. Moreover, if α_t is sufficiently smooth, k will be adequately small. In addition, $\lambda \in [0,1]$ and $\varphi_i(\lambda) = (\cos(2\pi i\lambda), \sin(2\pi i\lambda))'$. Therefore, variations of α_t are approximated by trigonometric polynomial functions with $2k + 2$ parameters.

The functions $\alpha_k(\lambda)$ in Equation (6) can be rewritten as

$$\alpha = (f_k' \otimes I_2)\beta_k, \tag{7}$$

where $f_k = \big(1, \lambda, \varphi_1'(\lambda), \cdots, \varphi_k'(\lambda)\big)'$, and $\beta_k = \big(\beta_{k,1}', \beta_{k,2}', \cdots, \beta_{k,2(k+2)}'\big)$, I_2 is an 2×2 identity matrix, and $\otimes$ denotes the kronecker product. Using these notations, Equation (4) can be represented as

$$i_t = r + \beta_k' x_{kt} + \varepsilon_{kt}, \tag{8}$$

where $x_{kt} = f_k(t/n) \otimes x_t$, and $\varepsilon_{kt} = \varepsilon_t[\alpha(t/n) - \alpha_k(t/n)]x_{kt}$.

Park and Hahn (1999) showed that the ordinary least square (OLS) estimators of Equation (8) were asymptotically inefficient and have non-standard limiting distribution, rendering the inference procedure invalid. To obtain efficient parameter estimators, Park and Hahn (1999) employed a canonical cointegrating regression (CCR) to estimate the model. Simply put, the CCR regression transforms the original independent and dependent variable by using the conditional and one-sided conditional long-run variances of the residuals. We can estimate those unknown parameters consistently using a nonparametric method (Andrews, 1991). The estimators of β_k in Equation (8) obtained, α_k can be recovered using Equation (7). Park and Hahn (1999) showed that the estimator of α_k in the CCR is consistent and follows a normal distribution asymptotically:

$$M_{nk}^{*-1/2} = \big(\Pi(\hat{\alpha}_k^*) - \Pi(\alpha)\big) \underset{d}{\rightarrow} N(0, \omega_*^2 I_{2d}), \qquad n \rightarrow \infty, \tag{9}$$

where, $\Pi(\alpha) = (\alpha(\lambda_1), \alpha(\lambda_2), \cdots, \alpha(\lambda_d))'$, and $\Pi(\hat{\alpha}_k^*) = (\alpha_k(\lambda_1), \alpha_k(\lambda_2), \cdots, \alpha_k(\lambda_d))'$ with $\lambda_i \in [0,1]$, $i = 1,2,\cdots,d$, I_{2d} is an $2d \times 2d$ identity matrix, M_{nk}^* is a $2d \times 2d$ matrix, and ω_*^2 is the conditional long-run variance of the ε_t in Equation (3).

Park and Hahn (1999) proposed two statistics based on the Wald test to test the adequacy of the time-varying coefficient cointegration. The first tests the time-varying coefficients model against the alternative that the time-varying coefficient model is a spurious regression. The statistic is given by

$$\tau^* = \frac{RSS_{TVC} - RSS_{TVC}^s}{\hat{\omega}_*^2},$$

where RSS_{TVC} and RSS_{TVC}^s are the sums of the squared residuals of Equation (4) and Equation (4) with some superfluous regressors, respectively. If the null hypothesis holds, the limiting distribution of τ^* is a chi-square distribution with s degree of freedom. Otherwise, the value of τ^* diverges.

The fixed coefficient model becomes a spurious regression when the true cointegration relation is time-varying. We can thus check the validity of the time-varying cointegration model by testing the adequacy of the fixed coefficient cointegration model. The null hypothesis of this test is that the fixed coefficient model is correct, and the alternative is that it is spurious. The statistic is given by

$$\tau_1^* = \frac{RSS_{FC} - RSS_{FC}^s}{\hat{\omega}_*^2},$$

where RSS_{FC} and RSS_{FC}^s are the sums of the squared residuals of Equation (2) and Equation (2) with some superfluous regressors, respectively. Under the null that the fixed coefficient model is correctly specified, τ_1^* will follow a chi-square distribution with s degree of freedom asymptotically. Otherwise, it diverges.

3. THE DATA

We use quarterly data covering the first quarter of 1992 to the fourth quarter of 2014 for a total of 92 observations, as described below.

3.1. The Nominal Interest Rate

When studying the Taylor rule, it is crucially important to choose a good proxy variable for the market interest rate. Taylor (1993) chose the federal funds rate as the target rate. However, the interest rate is not a good intermediate target for China since interest rate liberalization had not been completely realized in China during the sample period. We need a proxy variable for market interest rates that is fully market-oriented. Following the literature, we take the seven-day interbank lending and repo rate as the proxy variable for the nominal interest rate.

An inter-bank lending market was established in 1984. In 1996, a national unified interbank lending market was running successfully, and, a fortiori, the ceiling on interbank lending rates was removed in the middle of the year. Therefore, interbank lending rates constitute the proxy variable for interest rates for the 1996-2014 period, and the relevant data are downloaded from the People’s Bank of China website. During the 1992-1995 period, however, interbank lending transactions among Chinese financial institutions were disordered. Fortunately, Shanghai, the largest distribution and trading center of short-term funds in China, had a well-ordered interbank lending market. Therefore, we use the Shanghai Finance Center's interbank lending rate as the interest rate proxy for the 1992-1995 period, and the relevant data are downloaded from the Shanghai Finance Center website. Moreover, the seven-day national interbank rate is used as the proxy for the nominal interest rate from 1996 to 2014. Monthly interest rate and the quarterly data weighted by transactions are taken from the People's Bank of China website.

Figure 1 depicts the time series graph for the nominal interest rate. As shown in Figure 1, the interest rate was kept high between January 1992 and December 1996 to control the overheated Chinese economy. In 1996, interest rate growth began to slow when the Chinese economy landed softly. In 1997, however, the interest rate dropped abruptly to stimulate the economy out of the depression caused by the Asian financial crisis. It fell from 10.90% in the third quarter of 1997 to 2.71% in the fourth quarter of 1999. The interest rate then remained low for the rest of the sample period. A temporary increase occurred from the first half of 2006 to 2008. Subsequently, the interest rate hit its lowest level in the second half of 2008 due to the US subprime crisis.

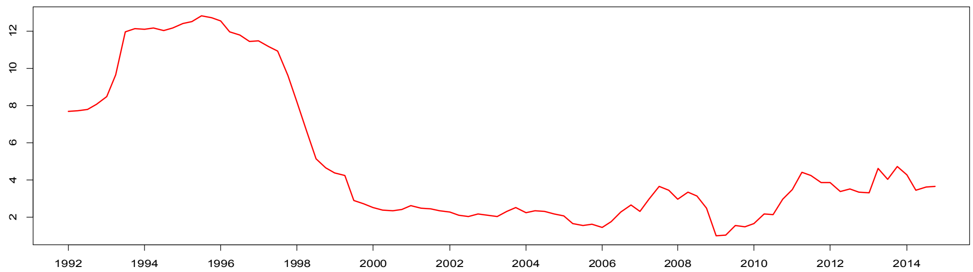

Figure 1. Time Series Graph for the Nominal Interest Rate

3.2. The Inflation Gap

Inflation is usually measured by four indexes: the consumer price index (CPI), the producer price index (PPI), the commodity retail price index (RPI), and the GDP deflator. Based on data availability and reliability, this paper uses the CPI as the proxy for inflation. The relevant monthly year-on-year data are downloaded from the Chinese National Bureau of Statistics website, and the quarterly CPI data are obtained by averaging the monthly data. Quarterly data are calculated using the formula $(CPI - 1) * 100\%$.

The literature offers various methods of computing the target inflation rate, such as the potential price level index, the average inflation rate, and the CPI anchor published by the government. Following the literature, we obtain the target inflation rate though historical analysis. From the first quarter of 1992 to the fourth quarter of 2014, the average inflation rate based on the CPI is 4.60%, and the median is 2.60%. Following Xie and Luo (2002), we set the target inflation rate at 4%, which is also the target inflation rate published by the Chinese government in its annual report.

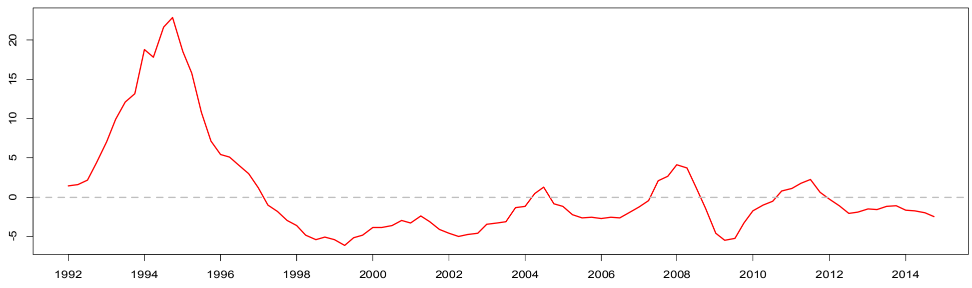

Figure 2. Time Series Graph for the Inflation Gap

Finally, the inflation gap is the difference between the inflation rate and the target inflation. Figure 2 shows a time series graph of the inflation gap. As shown, the inflation gap had an upward trend during 1992 and 1995, reaching a maximum of 22.90% in the fourth quarter of 1994, indicating a serious inflation. With the economic "soft landing" in 1996, the inflation gap decreased gradually to zero. Then, it dropped below zero due to the 1997 Asian financial crisis. By 1999, the inflation gap had reached its lowest point, -6.17%, when China experienced severe deflation. After wards, it remained stable for a long time. The inflation gap has increased from -1.27% in the first quarter of 2007 to 4.03% in the first quarter of 2008 because of the increasing food prices and strong economic growth (Shen *et al.*, 2016). In the second quarter of 2008, the Chinese economy fell into recession due to the US subprime mortgage crisis. The inflation gap quickly dropped to -5.53% and then returned to its normal state.

3.3. The Output Gap

The output gap is the difference between real output and potential output. Following Zheng *et al*. (2012), potential output is estimated as follows. First, to eliminate the effect of the price change, we calculate GDP by using the GDP growth rate. Specifically, we obtain the real quarterly GDP by using the cumulative quarterly GDP and GDP index (the year-earlier period=100). Second, we compute the seasonally adjusted GDP series using the X-11 seasonal adjustment method. Then, the real GDP is obtained by removing the seasonal component. Finally, potential output is estimated using the HP filter popularized by Hodrick and Prescott (1997). Generally speaking, the HP filter removes the cyclical component of a time series from the raw data. It is used to obtain a smoothed-curve representation of a time series, which is more sensitive to long-term than to short-term fluctuations.

Accordingly, let Y^T, Y_t^T,Y_t^c denote real GDP, potential GDP, and the output gap, respectively. Then,

$$Y^T = Y_t^T + Y_t^c, \qquad t = 1,2,\cdots,T.$$

The main role of the HP filter is to extract the Y_t^T from the Y^T. The unobservable part, Y_t^T, is usually defined as the minimizer in the minimization problem formulated by Equation (10):

$$\min \sum_{t=1}^{T}(Y_t - Y_t^T)^2 + \lambda[c(L)Y_t^T]^2, \tag{10}$$

where $c(L) = (L^{-1} - 1) - (1 - L)$ is a lag operator polynomial. Plugging $c(L)$ into Equation (10), allows Equation (10) to be written as

$$\min \sum_{t=1}^{T}(Y_t - Y_t^T)^2 + \lambda \sum_{t=2}^{T-1}[(Y_{t+1}^T - Y_t^T) - (Y_t^T - Y_{t-1}^T)]^2. \tag{11}$$

The trend's sensitivity adjusted to short-term fluctuations by modifying the multiplier, λ. The greater the value of λ, the greater the penalty. Hodrick and Prescott (1997) suggested 1,600 as a value for λ for quarterly data. Once the potential output Y^T and the output gap Y^c are obtained, the relative output can be computed as $100 \times (Y_t^c/Y_t^T)$.

Figure 3 presents the time series plot of the relative output gap. The output gap has high volatility. The relative output gap reached a maximum of 1.93 in the second half of 2007. From 2008 to 2009, the output gap fell sharply and dropped to its lowest value of -2.35, indicating the serious recession caused by the US subprime mortgage crisis in 2008.

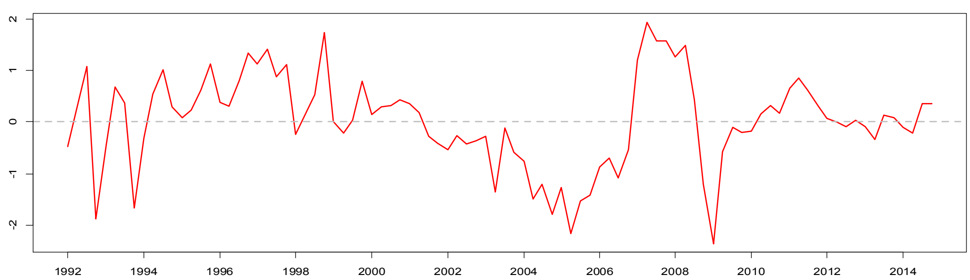

Figure 3. Time Series Graph for the Output Gap

4. EMPIRICAL ANALYSIS

4.1. The Unit Root Tests

Most of the literature on the Taylor rule has failed to check the stationarity of the nominal interest rate, the output gap, and the inflation gap. As Österholm (2005) pointed out, however, the traditional Taylor rule model might be a spurious regression in the absence of cointegration. It is thus extremely important to test the unit root properties of the related variables before implementing the regression for the Taylor rule.

We perform four unit root tests for all series: the Elliott, Rothenberg and Stock (1996, ERS) test, the Phillips and Perron (1988, PP) test, the Kwiatkowski *et al*. (1992, KPSS) test, and the Zivot and Andrews (1992, ZA) test. While the power of the standard Dickey-Fuller unit root test is known to be quite low, the ERS test has been shown to be approximately uniformly most powerful invariant. The null hypothesis of the ERS, PP, and ZA tests is that the series contains a unit root, whereas that of the KPSS test is that the series are stationary. The ZA test can check for a unit root under a structure break. For the ERS and ZA tests, we use the Akaike Information Criterion (AIC) with a maximum lag length of $\left[4 \cdot (T/100)^{1/4}\right]$ as the optimal lag length, where $[\cdot]$ denotes the integer part of a real number. For the PP and KPSS tests. $\left[4 \cdot (T/100)^{1/4}\right]$gives the value of the automatic bandwidth to compute the long-run variance.

Table 1 reports the results of the unit root tests for the nominal interest rate, inflation gap, and output gap. For the interest rate, the ERS and PP tests cannot reject the null hypothesis of a unit root at 10% significance level, the ZA test cannot reject the unit root at 1% significance level, and the KPSS test rejects the null hypothesis of stationarity at 1% significance level. For the inflation gap, the PP test cannot reject the null hypothesis of a unit root at 10% significance level, the ERS test cannot reject the unit root at 1% significance level, and the KPSS test rejects the null hypothesis that the series is stationary at 1% significance level. It follows that the nominal interest rate and the inflation gap can be regarded as unit root stationary. For the output gap, the ERS and ZA tests cannot reject the null of unit root at 5% significance level, and the KPSS test rejects stationarity at 5% significance level. Therefore, though the evidence for the unit root is weak, the output gap can be treated as the unit root process.

4.2. Cointegration Tests

Since the variables are nonstationary, we need to test cointegration to avoid the spurious regression. First, we test the fixed coefficient cointegration by using the Johansen cointegration test proposed by Johansen (1988, 1991). Table 2 provides the results for the Johansen cointegration test. The trace test λ_{trace} cannot reject the null hypothesis of $r = 0$ at 1% significance level and rejects the null of $r = 1$ at 1% significance level. The maximum eigenvalue test λ_{max} cannot reject the null hypothesis of $r = 0$ at 10% significance level and rejects the null of $r = 1$ at 5%

significance level. Therefore, no strong evidence to support cointegration is found among the nominal interest rate, inflation gap, and output gap using the Johansen cointegration test.

Table 1. Unit-root Tests

	PP	ERS	KPSS	ZA Intercept	ZA Trend
Nominal interest rate	-1.26	-1.8103	0.4019***	-5.035**	-4.6157**
Inflation gap	-2.12	-3.1303*	0.271***	-4.6648*	-4.8525**
Output gap	-4.24***	-2.2861	0.1413*	-4.9141**	-4.1151*
1% critical value	-4.06	-3.58	0.216	-5.34	-4.93
5% critical value	-3.46	-3.03	0.146	-4.8	-4.42
10% critical value	-3.16	-2.74	0.119	-4.58	-4.11

Notes: The null hypothesis of PP, ERS and ZA tests are that the series is nonstationary. While the null hypothesis of KPSS test is that the sequence is stationary. The "Intercept" and "Trend" in ZA test represent the structure breaks are allowed to appear in the intercept term and trend term, respectively. ***, **,* denote significance at 1%, 5%, and 10% levels, respectively.

Table 2. Johansen Cointegration Test

	H_0	λ_{trace}	λ_{max}
Values of teststatistic	$r = 0$	38.36**	18.89
	$r = 1$	39.47***	16.76**
1% critical value	$r = 0$	41.07	26.81
	$r = 1$	24.60	20.20
5% critical value	$r = 0$	34.91	22.00
	$r = 1$	19.96	15.67
10% critical value	$r = 0$	32.00	19.77
	$r = 1$	17.85	13.75

Notes: $r = 0$ denotes the null hypothesis of no cointegation. $r = 1$ of λ_{trace} and λ_{max} denotes the null hypothesis of at least one cointegration vector and one cointegration vector, respectively .***, **, and * denote significance at 1%, 5% and 10% levels, respectively.

Second, we check whether the time-varying cointegrating regression specification is appropriate by using the test statistics τ_1^* and τ^*. The null hypotheses of the two statistics are the fixed and time-varying coefficient cointegration, respectively. Table 3 shows the results for τ_1^* and τ^*. As shown, τ_1^* rejects the null hypothesis of the fixed coefficient cointegration in favor of the time-varying coefficient cointegration at 1% significance level. Moreover, τ^* rejects the null of time-varying coefficient cointegration at 5% significance level, but not at 1% significance level. The time-varying coefficient cointegration is thus supported by the tests. We analyze the variation on the cointegrating regression and its implication in Section 4.4.

Table 3. Model Specification Tests

	τ_1^*	τ^*
Values of teststatistic	103.3183***	16.6451**
1% critical value	16.8119	
5% critical value	12.5916	
10% critical value	10.6446	

Notes: The additional superfluous regressors are time polynomial terms, t, t^2, t^3, t^4, t^5, t^6. If the null hypothesis is true, the corresponding statistics converges to χ_4^2 in distribution. Otherwise, it will diverge as the sample size increases. ***, **,* denote significance at 1%, 5%, and 10% levels, respectively.

4.3. Robustness Tests

In the time-varying coefficient model, the coefficient is assumed to change smoothly and gradually. The cointegration with structural breaks proposed by Gregory and Hansen (1996) is also widely used in the literature, for example, by Narayan and Narayan (2010) and Sinha (2002). Gregory and Hansen (1996) developed three models to consider three forms of structural break. Model 1, denoted by C, is that there is a level shift in the cointergrating relationship. We call this the "level shift" model.

$$i_t = \alpha_1 + \alpha_2 E_{t\tau} + \alpha' x_t + \varepsilon_t, t = 1,2,\cdots,n. \tag{12}$$

where $E_{t\tau} = 0$ for $t \le [n\tau]$ and $E_{t\tau} = 1$ for $t > [n\tau]$. The unknown parameter $\tau \in (0,1)$ denotes the timing of the change point and $[\cdot]$ denotes integer part. α_1 is the intercept before the shift, and α_2 is the change in intercept due to the shift.

Model 2, denoted by C/T, introduces a time trend into the level shift model. We call this the "level shift with trend" model:

$$i_t = \alpha_1 + \alpha_2 E_t + bt + \alpha' x_t + \varepsilon_t, \qquad t = 1,2,\cdots,n, \tag{13}$$

Model 3, denoted by C/S, allows the slope vector equipped with possible structural change. We call this the "regime shift" model:

$$i_t = \alpha_1 + \alpha_2 E_t + bt + \alpha_1' x_t + \alpha_2' x_t E_{t\tau} + \varepsilon_t, \qquad t = 1,2,\cdots,n, \tag{14}$$

where α_1 and α_2 are as in the level shift model, α_1' denotes the cointegrating slope coefficients before the regime shift, and α_2' denotes the change in the slope coefficients.

To obtain the consistent estimates for the structural breaks, it is common practice in the literature to allow $\tau \in (0.15,0.85)$. If the residual ε_t is stationary, the i_t and $x_t = \left((\pi_t - \pi^*), y_t\right)'$ are cointegrated. Gregory and Hansen (1996) put forward three tests to test the null hypothesis of no cointegration. Specifically,

$$Z_\alpha^* = Z_\alpha(\tau),\ Z_t^* = Z_t(\tau),\ ADF^* = ADF(\tau).$$

The asymptotic distributions of Z_α^*, Z_t^* and ADF^* are functions of the Brownian motions; therefore, their critical values have to be obtained by simulation. The critical values depend on the number of regressors and the assumed models. Table 1 in Gregory and Hansen (1996) tabulated the critical values.

Table 4. Cointegration Tests with a Structural Break

		C	C/T	C/S
	ADF^*	-4.3323(0.2826)	-4.4501(0.2826)	-4.5697 (0.2826)
	Z_t^*	-4.3335(0.3043)	-4.4918 (0.3043)	-4.6163 (0.2934)
	Z_α^*	-32.0476(0.3043)	-34.0529(0.3043)	-35.3130(0.2934)
ADF^*,Z_t^*	1% critical value	-5.44	-5.80	-5.97
	5% critical value	-4.92	-5.29	-5.50
	10% critical value	-4.69	-5.03	-5.23
Z_α^*	1% critical value	-57.01	-64.77	-68.21
	5% critical value	-46.98	-53.92	-58.33
	10% critical value	-42.49	-48.94	-52.85

Notes: The symbols C, C/T, and C/S refer to Model (11), (12) and (13), respectively. The numbers in the parentheses are the estimated breakpoints. ***, **, and * denote significance at 1%, 5% and 10% levels, respectively.

Table 4 reports the test results. All three of our cointegration tests cannot reject the null hypothesis at 1% significance level. Therefore, it would be inappropriate to conclude that there is an abrupt structural break in the cointegration relationship. This implies that the structural change is smooth and gradual, which is consistent with the findings of the time-varying cointegration test.

4.4. Time-varying Cointegrating Regression and Policy Implication

To estimate the time-varying coefficient cointegration model, we use the BIC rule to determine the number of trigonometric function in Equation (6); the maximum number of trigonometric functions is $k = 10$.

Figures 4 and 5 depict the response coefficient of nominal interest rates to the inflation gap and the output gap, respectively. First, the coefficient on the inflation gap is significantly less than 1, indicating that the response of the nominal interest rate to inflation is inadequate; this is consistent with the literature (e.g., Zheng and Wang, 2011).

Second, the coefficient on the output gap is significantly greater than 0, implying that the response of the nominal interest rate to output gap is sensitive. The most direct reason for this is that Chinese government valued “achieving high economic growth” more than “maintaining price stability” (Ma, 2015). Therefore, Chinese monetary policy is stable which cannot be revealed by the fixed-coefficient model.

More importantly, the response of the central bank to several significant historical events can also be revealed by the time-varying coefficient variation. Specifically, the variation on the coefficients can be divided into four parts. First, in response to high inflation, the coefficient on the inflation gap from 1992 to 1994 is also large, and that on the output gap is small. The CPI year-on-year growth rate in 1994 attained the highest value, 27.70%. In this stage, there was a bubble in the Chinese market (Lehkonen, 2010). The high inflation is caused by overheating investment, inspired by Deng Xiaoping’s famous talks in South China in 1992 and the subsequent economic and social reform of the 1990s. To deal with the high inflation, the PBC doubled the benchmark lending rate in 1993. Though a series of macro-control means, such as rectifying financial order and deepening the financial reform, the Chinese economy achieved a soft landing in 1997.

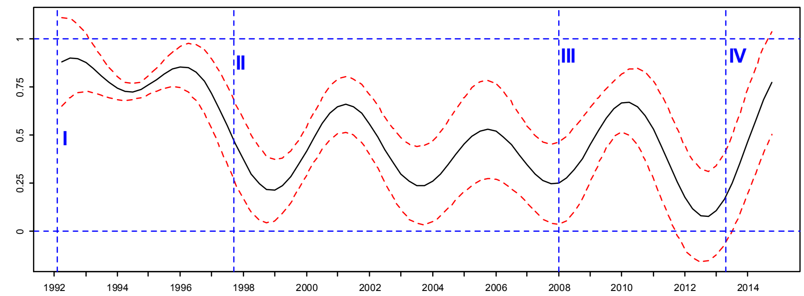

Figure 4. Time-varying Coefficient Graph for the Inflation Gap

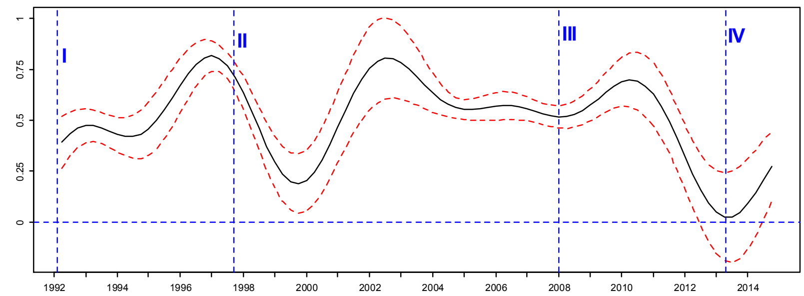

Figure 5. Time-varying Coefficient Graph for the Output Gap

Second, in the third quarter of 1997, the Chinese economy fell into deflation due to the Asian financial crisis. The benchmark lending rate dropped from 11.45% in the first quarter of 1997 to 2.70% in the fourth quarter of 1999. As shown in Figures 4 and 5, however, the coefficients on the inflation gap and the output gap decreased during this period. This implies that the PBC's response was insufficient, which is consistent with the literature (e.g., Chowdhry and Goyal, 2000). China announced "The Regulations on the Monetary Policy Committee of the People's Bank of China" in 1997, which clarified the rights and responsibilities of the monetary policy committee in the central bank. (Zhang, 2011). At the beginning, the monetary authorities managed inflation expectations and inflation target poorly. This is why China failed to get out of deflation and fell into a severe recession instead in 1999.

Third, in the second half of 2007, China's output gap reached its historical maximum value, and aggregate demand kept growing, which means that there were strong inflation pressures in China around 2007. In response, China adopted the so-called "double prevention" policy, to prevent overheating and inflation. The PBC raised benchmark lending rates seven times, and raised the bank reserve requirement ratio nine times, which reduced the seven-day interbank lending rate. As Figure 5 shows, the coefficient on the output gap stayed high during this period. This shows that the adjustment of the interest rate was effective and curbed inflation.

In the second half of 2008, shocked by the global financial crisis, the Chinese GDP year-on-year index dropped from 111 in the second quarter of 2008 to 106.6 in the first quarter of 2009, its lowest recorded value. As a result, the output gap reached an historical low in 2009, and economic growth fell to 6.60%. China fell into severe deflation directly from the inflation of the first half of 2008. The Chinese government implemented a proactive fiscal policy and prudent monetary policy in November 2008. Moreover, accompanying the stimulus of the central government's $4 trillion package, the PBC cut the benchmark interest rate five times. The seven-day interbank lending rates dropped from 3.34% in the second quarter of 2008 to 1.01% in the first quarter of 2009. As Figures 4 and 5 show, the coefficients on the inflation gap and the output gap first rose and then fell, indicating the proactive response of the PBC to the economic situation. This offset the negative effect on the Chinese economy of the global financial crisis, and the economy maintained a fast growth rate, which contributed to the global economic recovery.

Finally, the PBC decontrolled the lending rate of financial institutions on July 20, 2013; financial institutions could set the lending rate freely based on business principles. This initiative was a significant development and milestone in interest rate liberalization. Since the cap on the deposit rate is generally regarded as an effective restriction, the floor on lending rates was ineffective in the presence of restrictions on the loan rate (see Porter, 2009). For this reason, there are no obvious changes in the inflation gap or the output gap. As shown in Figures 4 and 5, the PBC implemented monetary policy more actively in order to stabilize the economy under the interest rate liberalization.

To sum up, the time-varying coefficients on the inflation gap are significantly smaller than 1 for the time period studied, indicating that the response of nominal interest rates to the inflation gap is inadequate, a kind of unstable "Taylor rule". In consequence, when the inflation gap is wide, monetary policy leads to greater volatility instead of a quick return to the target level. Therefore, it should be regarded with some caution by monetary authorities.

5. CONCLUSIONS

This paper captured the gradual structural changes among the Taylor rule's variables by using the time-varying coefficient cointegration approach proposed by Park and Hahn (1999). First, the interest rate, the output gap, and the inflation gap are found to be nonstationary. Second, while the fixed coefficient cointegration approach fails to detect the presence of the cointegration, the time-varying coefficient cointegration model captures the dynamic varying pattern for the response of the nominal interest rate to the inflation gap and the output gap. Finally, according to the estimated time-varying coefficient Taylor rule, we analyzed China's monetary policy and provided some policy advice to the Chinese monetary authorities. The PBC should adjust the short-term interest rate should be more flexible especially to changes in inflation.

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