



# Threshold cointegration and nonlinear adjustment between goods and services inflation in the United States

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## Abstract

In this paper, we model the long-run relationship between goods and services inflation for the United States over the period 1968:1–2003:3. Our empirical methodology makes use of recent developments on threshold cointegration that consider the possibility of a nonlinear relationship between the two inflation series. According to our results, the null hypothesis of linear cointegration would be rejected in favor of a two-regime threshold cointegration model. Consequently, we could expect a cointegrating relationship only when the divergence between services inflation and goods inflation is above the threshold point estimate. © 2006 Elsevier B.V. All rights reserved.

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## 1. Introduction

Over the past two decades, the existence of sectoral inflation differentials has attracted the attention of both economists and policy makers. Prices of services tend to increase faster than prices of goods. This dual inflation has been considered a cause of concern as far as the gap could influence the level of inflation in the long-run. Moreover, in last years, the difference in the

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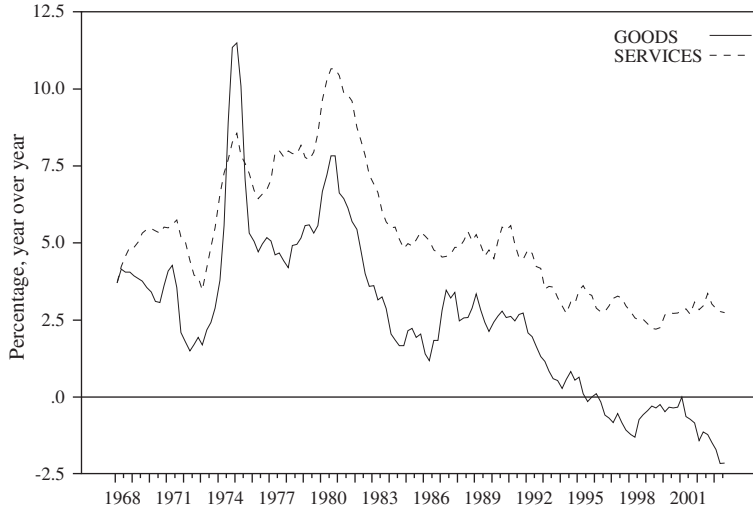


Fig. 1. Core PCE goods and core PCE services inflation, 1968:1–2003:3.

growth rates of prices between these two sectors has expanded considerably in most industrialized countries, reviving the concern about the dual inflation on the basis that a widening of the gap could affect the macroeconomic adjustment mechanism of the overall inflation rate. Only if we understand the process that generates periodical widening and shortening of the gap between both rates of inflation, we would be able to know whether the divergence in price movements could influence or not the trend in the development of the overall inflation.

Despite the significant implications of this issue for the implementation of monetary policy there is little empirical evidence on the long-run relationship between goods and services inflation rates. Peach et al., (2004), using quarterly data for the US economy over the period 1968:1–2002:4, find a linear cointegration relationship between both series of data. In other words, their results indicate that the difference between the two inflation rates shows a strong tendency to revert back to a constant equilibrium value in the long-run through a rise in goods inflation and a decrease in service inflation.

In this paper, we extend the work of Peach et al., (2004) to investigate the role of nonlinearities in the long-run relationship between goods and services inflation rates for the US economy.<sup>1</sup> Our empirical methodology makes use of recent developments on threshold cointegration allowing for the possibility of a nonlinear long-run relationship between goods and services inflation, so that a mean-reverting dynamic behavior of the “gap” between the two inflation rates (or a long-run equilibrium relationship) should be expected only once a certain threshold is reached.

We produce results based on the same data set as used in Peach et al., (2004) extending from 1968:1 to 2003:3. Fig. 1 plots the core services and core goods inflation rates for the United States. To preview the results, we find a two-regime threshold cointegration (non-linear cointegration) between goods and services inflation in which a value of the gap above 2.2 percentage points in one quarter will produce downward pressure on services inflation in the subsequent quarter in order to restore the equilibrium.

<sup>1</sup> The specific inflation series that we use is the quarterly change (at an annual rate) of the core personal consumption expenditure (PCE) goods deflator (excluding food and energy) and the core PCE services inflation (excluding energy services). See Peach et al., (2004) for more details.

The rest of the paper is organized as follows. The empirical methodology is outlined in Section 2, the empirical tests are performed in Section 3, and the main conclusions are summarized in Section 4.

## 2. Methodology

The concept of threshold cointegration was introduced by Balke and Fomby (1997) as a feasible way to combine nonlinearity and cointegration. It is well known, systems in which variables are cointegrated can be characterized by an error correction model (ECM), which describes how the variables respond to deviations from the equilibrium. In this way, the ECM can be characterized as the adjustment process through which the long-run equilibrium is maintained. The traditional approach, however, assumes that such a tendency to move towards the long-run equilibrium is present in every time period.

Balke and Fomby (1997) stress the possibility that this movement towards the long-run equilibrium might not occur in every time period, due to the presence of some adjustment costs on the side of economic agents. In other words, there could be a discontinuous adjustment to equilibrium so that, only when the deviation from the equilibrium exceeds a critical threshold, the benefits of adjustment are higher than the costs, and economic agents move the system back to equilibrium. Threshold cointegration characterizes this discrete adjustment as follows: the cointegrating relationship does not hold inside a certain range, but holds if the system gets ‘too far’ from the equilibrium; i.e., cointegration would hold only if the system exceeds a certain threshold.

In a recent contribution, Hansen and Seo (2002) provide an important new refinement into this literature, by examining the case of an unknown cointegration vector. In particular, these authors propose a vector error-correction model (VECM) with one cointegrating vector and a threshold effect based on the error-correction term, and develop a Lagrange multiplier (LM) test for the presence of a threshold effect. This will be the approach followed in this paper.

Hansen and Seo (2002) consider a two-regime threshold cointegration model, or a nonlinear VECM of order  $l+1$ , such as:

$$\Delta x_t = \begin{cases} A_1' X_{t-1}(\beta) + u_t & \text{if } w_{t-1}(\beta) \leq \gamma \\ A_2' X_{t-1}(\beta) + u_t & \text{if } w_{t-1}(\beta) > \gamma \end{cases} \quad (1)$$

with

$$X_{t-1}(\beta) = \begin{pmatrix} 1 \\ w_{t-1}(\beta) \\ \Delta x_{t-1} \\ \Delta x_{t-2} \\ \vdots \\ \Delta x_{t-l} \end{pmatrix}$$

where  $x_t$  is a  $p$ -dimensional  $I(1)$  time series which is cointegrated with one  $p \times 1$  cointegrating vector  $\beta$ ,  $w_t(\beta) = \beta' x_t$  is the  $I(0)$  error-correction term,  $u_t$  is an error term,  $A_1$  and  $A_2$  are coefficient matrices that describe the dynamics in each of the regimes, and  $\gamma$  is the threshold parameter.

As can be seen, the threshold model (1) has two regimes, defined by the value of the error-correction term. As long as deviations from the equilibrium are lower or equal than the threshold, there is no tendency for the variables  $x_t$  to revert to an equilibrium (i.e., the variables would not be cointegrated); on the contrary, if deviations from the equilibrium are greater than the threshold, there is a tendency for the variables  $x_t$  to move towards some equilibrium (i.e., the variables would be cointegrated).

Table 1  
Hansen–Seo tests of threshold cointegration

	sup LM <sup>0</sup> $\beta = 1$	sup LM $\hat{\beta}$ estimated
Test statistic value	25.76	19.19
Bootstrap <i>p</i> -values	0.002	0.008
Threshold parameter ( $\hat{\gamma}$ )	1.86	2.19
Cointegrating vector estimate ( $\hat{\beta}$ )	1.00	0.92

The sup LM<sup>0</sup> = sup <sub>$\gamma_L \leq \gamma \leq \gamma_U$</sub>  LM( $\beta_0, \gamma$ ) is a heteroskedastic-consistent LM tests statistic for the null hypothesis of linear cointegration (i.e., there is no threshold effect), against the alternative of threshold cointegration, where  $\beta_0$  is the known value of  $\beta$  (in the case analyzed below,  $\beta_0 = 1$ ), and  $[\gamma_L, \gamma_U]$  is the search region set so that  $\gamma_L$  is the  $\pi_0$  percentile of  $\tilde{w}_{t-1}$ , and  $\gamma_U$  is the  $(1 - \pi_0)$  percentile.

Moreover, Hansen and Seo (2002) propose two heteroskedastic-consistent LM tests statistics for the null hypothesis of linear cointegration (i.e., there is no threshold effect), against the alternative of threshold cointegration (i.e., model (1)). The first test would be used when the true cointegrating vector is known a priori, and is denoted as:

$$\text{sup LM}^0 = \sup_{\gamma_L \leq \gamma \leq \gamma_U} \text{LM}(\beta_0, \gamma) \tag{2}$$

where  $\beta_0$  is the known value of  $\beta$  (in the case analyzed below,  $\beta_0 = 1$ ); whereas the second test would be used when the true cointegrating vector is unknown, and is denoted as:

$$\text{sup LM} = \sup_{\gamma_L \leq \gamma \leq \gamma_U} \text{LM}(\tilde{\beta}, \gamma) \tag{3}$$

where  $\tilde{\beta}$  is the null estimate of  $\beta$ . In both tests,  $[\gamma_L, \gamma_U]$  is the search region set so that  $\gamma_L$  is the  $\pi_0$  percentile of  $\tilde{w}_{t-1}$ , and  $\gamma_U$  is the  $(1 - \pi_0)$  percentile; Andrews (1993) suggests setting  $\pi_0$  between 0.05 and 0.15. Finally, Hansen and Seo (2002) develop two bootstrap methods to calculate asymptotic critical values and *p*-values.

### 3. Results

We explore the possibility that threshold cointegration provides a better empirical description of the long-run relationship between goods and services inflation. To address this question, we may write the linear regression model as a bivariate linear cointegrating VAR model with one lag,  $l = 1$ , such as:

$$\begin{pmatrix} \Delta \pi_t^{\text{Services}} \\ \Delta \pi_t^{\text{Goods}} \end{pmatrix} = \mu + \delta w_{t-1} + \Gamma \begin{pmatrix} \Delta \pi_{t-1}^{\text{Services}} \\ \Delta \pi_{t-1}^{\text{Goods}} \end{pmatrix} + \varepsilon_t \tag{4}$$

where the long-run relationship is defined as  $w_{t-1} = \pi_{t-1}^{\text{Services}} - \beta \pi_{t-1}^{\text{Goods}}$  with cointegrating vector  $(1, -\beta)'$ .

We have applied the tests of threshold cointegration proposed by Hansen and Seo (2002), namely, sup LM<sup>0</sup> (for a given  $\beta = 1$ ) and sup LM (for an estimated  $\beta$ ). In both cases, the *p*-values are calculated using a parametric bootstrap method (with 5000 simulation replications), as proposed by Hansen and Seo (2002). To select the lag length of the VAR, we have used the AIC and BIC criteria,

Table 2  
Tests for multiple structural breaks in linear models: the Bai and Perron procedure

Test	$\pi_t^{\text{Goods}}$	$\pi_t^{\text{Services}}$
sup $F_T$ (1)	8.51	10.48
sup $F_T$ (2)	10.01	11.57
UD max	10.01	11.57
WD max	13.62	15.75
sup $F_T$ (2 1)	11.54	11.53
<i>Number of breaks:</i>		
SP	0	0
BIC	0	0
LWZ	0	0

The sup  $F_T(k)$  tests and the confidence intervals allow for the possibility of serial correlation in the disturbances. The heteroskedasticity and autocorrelation consistent covariance matrix is constructed following Andrews (1991) and Andrews and Monahan (1992) using a quadratic kernel with automatic bandwidth selection based on an AR(1) approximation. The residuals are pre-whitened using a VAR(1).

In the implementation of the procedure, we allowed up to two breaks ( $M=2$ ) and we used a trimming  $\epsilon=0.25$  which corresponds to each segment having at least 35 observations.

We apply the procedure with the dependent variable,  $y_t$ , a constant, a trend, and one lag of  $y_t$  as regressor [ $z_t = \{1, t, y_{t-1}\}$ ].

both of them leading to  $l=1$ . The results of the tests are reported in Table 1.<sup>2</sup> Threshold cointegration would appear at the 1% significance level when  $\beta$  is fixed at unity and when  $\beta$  is estimated rather than fixed, so that the null hypothesis of linear cointegration would be strongly rejected in both cases.

The results we report are for the case of estimated cointegrating vector, but the results are very similar if the unit coefficient is imposed. The estimated threshold is  $\hat{\gamma} = 2.2$ , with the error-correction term defined as  $w_t = \pi_t^{\text{Services}} - 0.92\pi_t^{\text{Goods}}$ . Hence, the first regime or the relatively unusual regime (including 20% of the observations) would occur when the services inflation are less than 2.2 percentage points above the goods inflation; in other words, when the gap is below 2.2%. In turn, the second regime or usual regime (with 80% of the observations) would occur when the gap is above 2.2% (Table 2).

The corresponding two-regime threshold VAR (with heteroskedasticity-consistent standard errors in parentheses) is given below:

$$\Delta\pi_t^{\text{Services}} = \begin{cases} -0.03_{(0.08)} - 0.08_{(0.05)} w_{t-1} + 0.09_{(0.18)} \Delta\pi_{t-1}^{\text{Services}} + 0.12_{(0.03)} \Delta\pi_{t-1}^{\text{Goods}} + u_{1t}, & w_{t-1} \leq 2.2, \\ 0.38_{(0.15)} - 0.12_{(0.04)} w_{t-1} + 0.40_{(0.07)} \Delta\pi_{t-1}^{\text{Services}} + 0.18_{(0.06)} \Delta\pi_{t-1}^{\text{Goods}} + u_{2t}, & w_{t-1} > 2.2, \end{cases} \quad (5)$$

$$\Delta\pi_t^{\text{Goods}} = \begin{cases} -0.77_{(0.11)} + 0.42_{(0.06)} w_{t-1} + 0.63_{(0.39)} \Delta\pi_{t-1}^{\text{Services}} + 0.72_{(0.14)} \Delta\pi_{t-1}^{\text{Goods}} + u_{1t}, & w_{t-1} \leq 2.2, \\ -0.09_{(0.19)} + 0.02_{(0.06)} w_{t-1} + 0.28_{(0.12)} \Delta\pi_{t-1}^{\text{Services}} + 0.26_{(0.09)} \Delta\pi_{t-1}^{\text{Goods}} + u_{2t}, & w_{t-1} > 2.2. \end{cases} \quad (6)$$

The estimation of the error-correction term in the VAR,  $w_{t-1}$ , allows for a straightforward investigation into the behavior of the gap between services and goods inflation in the US economy. We can also examine the sign and magnitude of these coefficients in order to analyze the adjustment process by which long-run equilibrium between the inflation series is restored. First, there is a strong and statistically significant error-correction term in the services inflation equation when  $\pi_t^{\text{Services}}$  is

<sup>2</sup> Peach et al., (2004) presents evidence that core goods inflation and core services inflation are nonstationary variables.

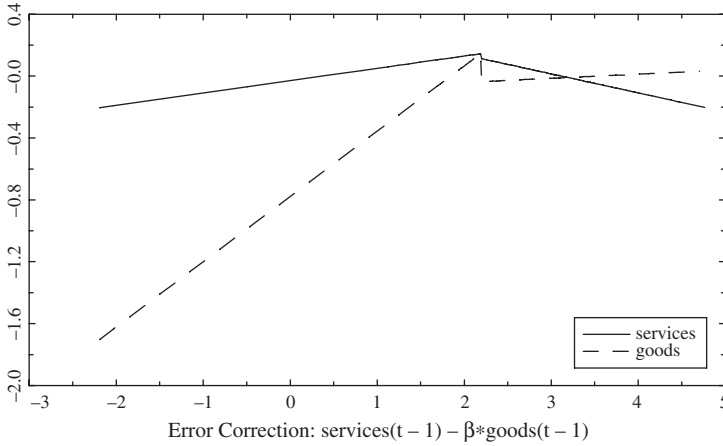


Fig. 2. Response of goods and services infalton to error correction quarterly data, 1968:1–2003:3.

above  $\pi_t^{\text{Goods}}$  (or the gap is relatively high) and in the goods inflation equation when  $\pi_t^{\text{Services}}$  is below  $\pi_t^{\text{Goods}}$  (or the gap is relatively low). Second, a value of the gap above 2.2% in one quarter will produce downward pressure on services inflation in the subsequent quarter. Third, a value of the gap below 2.2% in one quarter will produce upward pressure on goods inflation in the subsequent quarter. The coefficients on the error-correction term also indicate that the magnitude of the response for goods inflation is more than three times as big as the coefficient of the services inflation.

Fig. 2 plots the error-correction effect, i.e., the estimated response of  $\Delta\pi_t^{\text{Services}}$  and  $\Delta\pi_t^{\text{Goods}}$  as a function of  $w_{t-1}$ , holding the other variables of VAR constant. In the figure, it can be seen the strong positive error-correction effect for the goods inflation equation and the minimal error-correction effect (and on the borderline of statistical significance) for the services inflation equation on the left-hand side of the estimated threshold. In contrast, it can be seen the flat near-zero error-correction effect for the goods inflation and the minimal negative error-correction effect for the services inflation on the right-hand side of the estimated threshold.<sup>3</sup>

#### 4. Conclusions

In this paper, we model the long-run relationship between goods and services inflation for US economy over the period 1968:1–2003:3. Previously, Peach et al., (2004) using linear cointegration found that the “gap” between the two inflation rates exhibits a strong tendency to revert back to a

<sup>3</sup> Typically, tests for threshold effects are sensitive to structural breaks. Therefore, we present and use the Bai and Perron (1998, 2003a,b) methodology in order to detect these type of features in the data. The Bai and Perron sequential procedure for estimating breakpoints select zero breaks. Therefore, the evidence points strongly to reject the presence of any breakpoint in the inflation series. When implementing Bai and Perron’s procedure, we use a trend and one lag of the variable as regressors, and take into account any potential serial correlation via parametric adjustments; in particular, the covariance matrix is constructed, following Andrews (1991) and Andrews and Monahan (1992), using a quadratic kernel with automatic bandwidth selection based on an AR(1) approximation. We allowed up to 2 breaks, with a trimming equal to 0.25, so that each segment has at least 35 observations. The results are reported in Table 2, where the critical values are taken from Bai and Perron (1998, 2003b). The statistics UDmax and WDmax show that the null hypothesis of no structural break is not rejected for both variables. A similar conclusion is obtained when the statistics  $\sup F_T$  is used. In this case, the null hypothesis that there is no break in the model is not rejected. Thus, the  $\sup F_T(I+1|l)$  test is not significant. Finally, the three methods to determine the number of breaks selects zero breaks for both variables.

constant equilibrium value in the long-run through an increase in goods inflation and a decline in services inflation.

This paper attempts to contribute to the literature by modelling the mean-reverting behaviour of the “gap” and provides a better empirical description of the long-run relationship between goods and services inflation. Our empirical methodology makes use of recent developments on threshold cointegration that consider the possibility of a nonlinear relationship between goods and services inflation.

According to our results, the null hypothesis of linear cointegration would be rejected in favor of a two-regime threshold cointegration model. Consequently, a system of two regimes would seem to characterize the discontinuous or nonlinear adjustment of the services inflation rates towards a long-run equilibrium, with the threshold parameter estimated at 2.2 percentage points. Therefore, we could expect a cointegrating relationship only when the divergence between services inflation and the adjustment for goods inflation is above 2.2%.

Furthermore, when the gap is above the estimated threshold parameter, a decrease in services inflation ought to occur in order to restore the long-run equilibrium between the two inflation series. In contrast, when the gap is below the estimated threshold parameter, a rise in goods inflation would have to occur in order to restore the long-run equilibrium between the two inflation series. Finally, the magnitude of the response for goods inflation is much greater than the adjustment process for services inflation rate.

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