# Inflation Targeting and the Stationarity of Inflation: New Results from an ESTAR Unit Root Test

Andros Gregoriou [a]*, Alexandros Kontonikas [b]

[a] *Brunel Business School, Economics and Finance Section, Brunel University, Uxbridge, UB8 3PH, UK*

[b] *Department of Economics, University of Glasgow, Adam Smith Building, Glasgow, G12 8RT, UK*

---

**Abstract**

In this paper we examine the time series properties of inflation in seven countries that have adopted inflation targeting. Unlike previous studies we utilize a non-linear mean reverting adjustment mechanism for inflation and we discover that although deviations of inflation from the target can exhibit a region of non-stationary behavior, overall they are stationary indicating successful targeting implementation.

*JEL classification*: E31; C22.
*Keywords*: Inflation; Unit root tests; ESTAR models.

---

October 2005

* Corresponding author. Tel: +44 (0) 1895 816282; Fax. +44 (0) 1895 269770; E-Mail: andros.gregoriou@brunel.ac.uk

We would like to thank Virginie Boinet, George Bagdatoglou and Chris Martin for valuable comments and suggestions. The usual disclaimer applies.

## 1. Introduction

In the 1990s a number of countries adopted explicit inflation targeting (IT) monetary policy frameworks. Over the same time period, their inflation rates became lower, less persistent and less variable (see among others, Kontonikas, 2004), which are all taken as indications of successful IT implementation. In the context of these targeting regimes, the stationarity of inflation becomes fundamental for policy analysis, given the great attention paid to empirical estimates of inflation forecasts from either structural or atheoretical time series models. As Svensson (1997) argues, IT implies 'base drift' of the price level, suggesting that the price level has a unit root and inflation is stationary. Taking this argument a step further, we claim that successful implementation of IT implies that deviations of inflation from the target should follow a stationary process. If this is not the case, the resulting excess volatility in inflation relative to the target could generate excess interest rate and output volatility. This is because IT central banks typically respond with positive interest rate-weights to inflation pressures and demand pressures (Taylor, 1993). Hence, finding that inflation deviations from the target are non-stationary should be considered a puzzle, indicating either non-successful IT, or inadequate testing procedures.

Previous empirical studies test for stationarity of the level of inflation by employing linear unit root tests[1]. Unlike previous studies, we examine whether inflation is stationary relative to its pre-determined target. A further contribution to the previous literature is that we present new empirical evidence, which explicitly allows for the possibility that inflation can be characterised by a non-linear mean-reverting process. This process may exhibit near unit root behaviour in specific range, so inflation deviations from the target can appear non-stationary from the

[1] See among others, Culver and Papell (1997) for sequential break and panel unit root tests, Hassler and Wolters (1995) for fractional unit root tests using international inflation data.

perspective of test procedures, which specify a linear non-stationary process as the null hypothesis. In this paper, we propose an alternative hypothesis where the speed of adjustment increases, the greater the deviation of inflation from the target. This is consistent with non-linear monetary policy reaction functions, where there is a stronger response to inflation when it is further from the target (Orphanides and Wieland, 2000; Martin and Milas, 2004). In particular, due to the volatility costs associated with adjusting interest rates to control inflationary pressures, monetary authorities may not react when inflation is close to the target. Consequently, inflation may follow a random walk close to the target. Conversely, the more distant inflation is from the target, the greater the probability that the Central Bank will take remedial action.

The remainder of the paper is structured as follows. The next section describes the data. Section 3 presents the econometric methodology and results. Section 4 concludes.

## 2. Data

Our dataset comprises of five OECD countries, United Kingdom, Canada, Sweden, Australia, New Zealand, and two highly inflationary non-OECD countries, Chile, Israel, that have announced a quantitative inflation target[2]. Since inflation targeting regimes typically monitor the evolution of annual inflation, we measure inflation, $\pi_t$, as the annual difference of the natural log of the price index, *P*, that is relevant for monetary policy decisions. Hence, $\pi_t$ is defined as $\pi_t = 100 * (\ln P_t - \ln P_{t-12})$ in United Kingdom, Canada, Sweden, Chile and Israel, which provide monthly price series; $\pi_t = 100 * (\ln P_t - \ln P_{t-4})$ in Australia and New Zealand, which provide quarterly price series.

[2] See Appendix A for a description of the IT implementation.

### 3.1 Linear unit root tests

The standard linear Augmented Dickey-Fuller (ADF) test uses the following regression model to test whether the deviations of inflation from the target are stationary:

$$\Delta(\pi_t - \pi_t^*) = \gamma_0 + \gamma(\pi_{t-1} - \pi_{t-1}^*) + \sum_{i=1}^{n} \gamma_i \Delta(\pi_{t-i} - \pi_{t-i}^*) + \varepsilon_t \qquad (1)$$

where $\pi_t$ is the inflation rate at time period *t*, $\pi_t^*$ is the inflation target at time period *t*, the $\gamma's$ are constants and $\varepsilon_t$ is a random disturbance term. The terms in $\Delta(\pi_{t-i} - \pi_{t-i}^*)$ are included to remove any serial correlation in $\varepsilon_t$. Rejecting the null of non-stationarity requires the estimates of $\gamma$ to be negative and significantly different from zero. The linear ADF results can be seen in columns two and three of Table 1.

The evidence in Table 1 indicates that, with the exception of Chile, the null-unit root cannot be rejected in all other countries. When, in addition to the constant, $\gamma_0$, we incorporate a linear trend the puzzling unit root evidence remains prevalent. Overall, the linear ADF tests provide strong evidence of unit root in the deviations of inflation from the target.

**[INSERT TABLE 1 HERE]**

### 3.2 Non-linear unit root tests

Possible explanations for the failure to reject non-stationarity are that linear unit root tests are not very powerful when short data spans are considered, and when the true adjustment process is non-linear. Hence, in this section we employ an Exponential Smooth Transition

Autoregressive model (ESTAR), which assumes that the adjustment of inflation towards the predetermined target is characterized by a symmetric non-linear process[3]:

$$\pi_t = \pi_t^* + \beta\left(\pi_{t-1} - \pi_{t-1}^*\right) + \delta\left(\pi_{t-1} - \pi_{t-1}^*\right)\left[1 - e^{-\alpha\left(\pi_{t-1} - \pi_{t-1}^*\right)^2}\right] + u_t \qquad (2)$$

where $u_t$ is the error term and the other variables are as previously defined. Under the null-non stationarity, $\beta = 1$ and $a = 0$, inflation follows a random walk around $\pi_t^*$. In the case of stationarity ($a > 0$), inflation reverses to $\pi_t^*$. Computing a first-order Taylor series approximation to (2) under the null and allowing for serial correlation in $u_t$, we obtain the following auxiliary regression model (Kapetanios et al., 2003):

$$\Delta(\pi_t - \pi_t^*) = \gamma_0 + \gamma(\pi_{t-1} - \pi_{t-1}^*)^3 + \sum_{i=1}^{n} \gamma_i \Delta(\pi_{t-i} - \pi_{t-i}^*) + v_t \qquad (3)$$

where $v_t$ is the error term and the other variables are defined as previously. Equation (3) follows a non-standard distribution; therefore critical values of the *t*-statistic for the significance of $\gamma$ are calculated from 1000 bootstrapped re-samples for each of our seven countries. The non-linear unit root test results are presented in columns four and five of Table 1.

The non-linear ADF tests show that the deviations of inflation from the target are stationary at all significance levels. The decisive rejection of the null-unit root appears to be the result of the significant increase in the magnitude of the estimated ADF coefficient, $\gamma$. This finding holds across all sample countries and is not affected by the inclusion of a linear trend in

[3] See, among others, Granger and Terasvirta (1993) for other applications of the ESTAR model. A symmetric non linear adjustment model is chosen because of the relatively small number of data points available in our empirical analysis (Ioannidis et al, 2003).

the regressions[4]. Hence, the puzzling unit root evidence of linear tests disappears when we allow for non-linear adjustment in inflation.

## 4. Conclusions

In this paper, we examine the time series properties of inflation relative to its target within a sample of seven countries that adopted IT over the 1990s. Using standard linear unit root tests we discover that, with the exception of Chile, inflation deviations from the target follow a non-stationary process. A possible explanation for these findings, could be that the rate of adjustment of inflation to its target is increasing in the deviation from the target, as opposed to assumed being constant in the linear unit root tests. This process is captured with the use of the ESTAR unit root test. Once we apply the ESTAR unit root test to the data, we find that inflation relative to its target follows a stationary process, implying successful IT implementation. Given the relatively low power of standard unit root tests this appears to be an important empirical result.

[4] For UK, Canada and Australia that target the underlying inflation rate, we inspect the robustness of our results using the broad CPI-based inflation. The non-linear ADF results, available upon request, indicate stationarity in all alternative specifications. In addition, we also experiment using a measure of short-run inflation for all countries: $\pi_t = 100 * (\ln P_t - \ln P_{t-1})$. The results do not change and are available upon request.

## References


Culver, S. and D. Papell, 1997. Is there a unit root in the inflation rate? Evidence from sequential break and panel data models, Journal of Applied Econometrics 12, 435-444.

Granger, C.W.J. and T. Terasvirta, 1993. Modelling nonlinear economic relationships, Oxford: Oxford University Press.

Hassler, U. and J. Wolters, 1995. Long memory in inflation rates: international evidence, Journal of Business and Economic Statistics 13, 37-45.

Ioannidis, C, D. A. Peel and M. J. Peel, 2003. The Time Series Properties of Financial Ratios, Journal of Business Finance and Accounting 30, 699-714.

Kapetanios, G., Shin, Y. and A. Snell, 2003. Testing for a unit root in the non-linear STAR framework, Journal of Econometrics 112, 359-379.

Kontonikas, A., 2004. Inflation and inflation uncertainty in the United Kingdom, evidence from GARCH modeling. Economic Modelling 21, 525-543.

Martin, C. and C. Millas, 2004. Modelling monetary policy: inflation targets in practice, Economica 71, 209-221.

Orphanides, A. and V. Wieland, 2000. Inflation zone targeting, European Economic Review 44, 1351-1387.

Svensson, L., 1997. Monetary policy and inflation targeting, NBER Reporter Winter 1997/98, 5-8.

Taylor, J. B., 1993. Discretion versus policy rules in practice" Carnegie-Rochester Conference Series on Public Policy 39, 195-214.

**Table 1: Unit root test results**

| Countries | Linear ADF test statistic | | Non-Linear ADF test statistic | |
|---|---|---|---|---|
| | Constant | Constant and Trend | Constant | Constant and Trend |
| United Kingdom | -2.27 | -2.96 | -8.02 ** | -9.65 ** |
| Canada | -2.07 | -1.73 | -3.12 ** | -4.95 ** |
| Sweden | -1.48 | -2.06 | -9.19 ** | -11.64 ** |
| Australia | -2.54 | -2.48 | -7.33 ** | -8.69 ** |
| New Zealand | -2.91 | -3.07 | -4.22 ** | -6.21 ** |
| Chile | -4.23 ** | -4.83 ** | -8.06 ** | -10.95 ** |
| Israel | -2.13 | -2.15 | -5.76 ** | -6.12 ** |

Note:

(a) ) The number of lagged difference terms in the regressions was chosen by the reduction criterion. We set an upper bound of lagged difference terms corresponding to two years and tested down by sequentially removing the last lag until a significant (at 5% level) lag was reached.
(b) The reported *t*-statistics test the null hypothesis that inflation contains a unit root. **, * indicate rejection of the null-unit root hypothesis at 1, 5% level of significance.

## Appendix A: Inflation targeting implementation in the sample countries

| Countries | Targeting Variable [a] | Date of Adoption or Modification | Target Range or Value | Average Annual Inflation |
|---|---|---|---|---|
| United Kingdom | Retail Price Index Excluding Mortgage Interest Payments | October 1992<br>May 1997 | 1 - 4 %<br>2.5 % | 2.5 % |
| | Harmonized Index of Consumer Prices | January 2004 | 2 % | |
| Canada | Consumer Price Index excluding Food, Energy and Indirect Taxes | February 1991<br>January 1992<br>June 1994<br>January 1995 | 3 - 5 %<br>2 - 4 %<br>1.5 - 3.5 %<br>1 - 3 % | 1.7 % |
| Sweden | Consumer Price Index | January 1995 | 2% | 1.2 % |
| Australia | Treasury Underlying Consumer Price Index | September 1994 | 2 - 3 % | 2.7 % |
| New Zealand | Consumer Price Index | January 1990<br>January 1991<br>January 1992<br>January 1993<br>January 1997 | 3 - 5 %<br>2.5 - 4.5 %<br>1.5 - 3.5 %<br>0 - 2 %<br>0 - 3 % | 1.9 % |
| Chile | Consumer Price Index | January 1991<br>January 1992<br>January 1993<br>January 1994<br>January 1995<br>January 1996<br>January 1997<br>January 1998<br>January 1999<br>January 2000<br>January 2001 | 15 - 20 %<br>13 - 16 %<br>10 - 12 %<br>9 - 11 %<br>8 %<br>6.5 %<br>5.5 %<br>4.5 %<br>4.3 %<br>3.5 %<br>2 - 4 % | 6.5 % |
| Israel | Consumer Price Index | January 1992<br>January 1993<br>January 1994<br>January 1995<br>January 1996<br>January 1997<br>January 1999<br>January 2000<br>January 2002 | 14 - 15 %<br>10 %<br>8 %<br>8 - 11 %<br>8 - 10 %<br>7 - 10 %<br>4 %<br>3 - 4 %<br>1 - 3 % | 6.3 % |

Note: The inflation target in all sample countries is expressed in terms of the annual growth rate of the relevant price index