Asymmetry in Inflation Rates under Inflation Targeting

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Abstract
A number of commentators and policy makers have argued that inflation targeting central banks are less aggressive in responding to shocks that push inflation below target than to shocks that push inflation above target (Thoma, 2012; Beckworth, 2016; Kashkar, 2017). Support for this claim is usually based on the observation that in a number of inflation targeting countries, recent inflation outcomes have been persistently below target, despite that fact that these countries have been experiencing growth rates below historical norms. For either a strict or flexible inflation targeting central bank, there is no trade-off in terms of real activity to prevent it from doing what is necessary to increase the rate of inflation.

In this paper we provide evidence of asymmetry in the time series process for inflation rates in five inflation targeting countries (Australia, New Zealand, Sweden, United States and the Euro-Area). Of the countries we examine, only Canadian inflation shows no evidence of asymmetry. Since it is relatively standard to model inflation as an autoregressive process, we use a threshold autoregressive (TAR) model to test for asymmetry in inflation persistence; above and below some estimated threshold. We find the threshold estimates are reasonable in light of a central bank’s announced inflation target.

JEL Classification Numbers: C22, E31

Key Words: Inflation Targeting, Threshold Autoregressive Model, Asymmetry, Inflation Persistence

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1. Introduction

The relatively prolonged period of low inflation experienced in many economies following the Global Financial Crisis – sometimes called “lowflation” – has led some commentators (Thoma, 2012; Beckworth, 2016) to argue that inflation targeting (IT) central banks are responding asymmetrically to deviations of inflation from target. The basic idea is that central banks tend to be relatively aggressive in responding to shocks that would push inflation above the upper bound of its target, but are less aggressive in responding to shocks that push inflation below the lower bound of the target. Recently Federal Reserve Bank of Minneapolis president Neel Kashkar (2017) dissented in a FOMC meeting and made the following statement:

“While the FOMC wants to avoid making forecast errors whenever possible, to the extent that we make them, I would think we’d want our errors to be equally too high and too low. Yet, over the past five years, 100 percent of the medium-term inflation forecasts (midpoints) in the FOMC’s Summary of Economic Projections have been too high: We keep predicting that inflation is around the corner. How can one explain the FOMC repeatedly making these one-sided errors? One-sided errors are indeed rational if the consequences are asymmetric. ... Based on our actions rather than our words, we are treating 2 percent as a ceiling rather than a target. I am not necessarily opposed to having an inflation ceiling. The European Central Bank has a 2 percent ceiling instead of a symmetric target. However, I am opposed to stating we have a target but then behaving as though it were a ceiling.”

The Federal Reserve Bank of Atlanta asked its Business Inflation Expectations Panel whether the Fed was more, less, or equally likely to tolerate inflation below or above its target. The responses are plotted in the following chart:

![Bar Chart: Firms' Perception of the Fed's Tolerance for Inflation above or below its Inflation Target](image)

One outcome of such behaviour is that we could observe below target inflation rates persisting for relatively long periods of time, in particular, for much longer periods than for episodes of above

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2 For central banks with a point target, as opposed to a band, the upper and lower bounds are equal.
target inflation. This question is important. Although inflation expectations can be well anchored there might be an increase in the persistence of inflation dynamics below the inflation target, which addresses issues of policy effectiveness.

Despite these claims about central bank behaviour there has been relatively little empirical work on whether, in fact, inflation rates in IT countries exhibit any type of asymmetric behaviour (Koirala, 2012; Akdoğan, 2015). In this paper we use data on inflation rates in four long-standing IT countries (Australia, Canada, New Zealand and Sweden), the Euro-Area (European Monetary Union) and in the United States (US) to test for evidence of asymmetric behaviour around their targets. Since it is relatively standard to model inflation as a low-order autoregressive process, we use a threshold autoregressive (TAR) model (Tong, 1983; Hansen, 1996; 1997).

Using quarterly inflation rates and the test for non-linearity due to Luukkonen, Saikkonen, and Terasvirta (1988) we find the data reject a linear autoregressive model for all of our countries, expect Canada. For the other five countries estimation of a two regime autoregressive model yields plausible results. Point estimates of the threshold are either close to or slightly above the upper bound of a country’s announced inflation target. In the estimated threshold models we find that point estimates of the autoregressive coefficient in the (relatively) high inflation regime are small in absolute magnitude and for most countries not significantly different to zero. In contrast in the (relatively) low inflation regime we find a positive and significant value for the autoregressive coefficient. Above the estimated thresholds quarterly inflation exhibits no (or in the case of the Euro-Area relatively less) evidence of persistence, while below the threshold there is positive persistence in inflation, although inflation rates are stationary. We carry out a series of robustness checks. Firstly, we check whether our results are driven by the global disinflationary period 2012-2015. Secondly, we consider a Phillips curve generalization of our model by including a measure of economic slack. In general we find our estimates change little. Finally, we argue the results are specific to the behaviour of inflation under IT by showing there is little asymmetry in the pre-IT period.

The rest of the paper is organized as follows: Section 2 provides a background analysis and literature review on modelling inflation persistence. In Section 3, we present our threshold model for inflation and the linearity test. Section 4 discusses the data, while Section 5 presents the main results including threshold estimates, linearity test and generalized impulse response analysis. Section 6 contains the robustness checks. Finally, in Section 7 we conclude.
2. Background

There is a large and varied literature on modelling the stochastic process for the inflation rate. Initially, studies were interested in whether there is a unit root in the inflation process (Rose, 1988; Henry and Shields, 2004). This research being influenced primarily by the persistent increase in inflation rates across many economies in the 1970s and 1980s and the hypothesis that inflation rates possessed a unit root was not commonly rejected. By the 1990s inflation rates had declined in most advanced countries and have subsequently remained low. Central banks in many countries have adopted formal inflation targets, which have helped to anchor inflation expectations and to maintain low inflation rates.

With the decline in inflation rates a number of studies have examined whether or not the degree of persistence of inflation rates has declined over the last 25 years in most advanced economies (Cogley and Sargent, 2002, 2005; Stock, 2002; Levin and Piger, 2002; O’Reilly and Whelan, 2005; Pivetta and Reis, 2007; Benati, 2008; Noriega and Ramos-Francia, 2009; Beechey and Österholm, 2012). We briefly review those studies that are relevant to our analysis.


A number of subsequent studies have reported stronger evidence of declining inflation persistence. Benati (2008) presents empirical evidence indicating the size of the sum of the autoregressive coefficients in an autoregressive model for inflation has declined in IT countries, but not for the non-IT countries of US and Japan. He attributes this finding to the fact that the indexation parameter in hybrid Phillips curve is not a “deep” structural parameter and it becomes smaller under IT as the degree of indexation of prices to past inflation becomes weaker. In addition to examining the evidence from an autoregressive model for inflation, Benati estimates the structural parameters of the hybrid New Keynesian model with a Taylor-rule, using Bayesian methods. For most IT countries he finds the estimate of the parameter for intrinsic persistence in the Phillips curve is close to zero for the IT sample period.

Noriega and Ramos-Francia (2009) use a test for multiple changes in the order of integration in a time series due to Leybourne, Kim and Taylor (2007) to identify periods of I(1) and I(0) behaviour in various measures of US inflation between 1947 and 2008. For the period since 1990 Noriega and Ramos-Francia find US inflation is stationary (i.e. I(0)) and that it has a relatively low degree of persistence.
Beechey and Österholm (2012) consider the process for inflation that is obtained from optimal monetary policy (under discretion) when the central bank has preferences of the form;

\[ L(\pi_t, y_t) = (\pi_t - \pi^T)^2 + \lambda_t y_t^2 \]

Where \( \pi_t - \pi^T \) is inflation relative to target inflation, \( y_t \) is the output gap and \( \lambda_t \) is a time-varying weight on the output gap. Given the standard hybrid New Keynesian model for the economy – with constant parameters – Beechey and Österholm show the reduced-form process for inflation is given by;

\[ \pi_t - \pi^T = \rho_t (\pi_{t-1} - \pi^T) + u_t \]

where \( \rho_t \) is a complicated function of the structural parameters of the model, including \( \lambda_t \).

Beechey and Österholm estimate versions of the above time-varying AR model using data on quarterly US inflation from 1955-2006. Their results suggest that the degree of persistence in inflation is time-varying and that \( \rho_t \) declines from around the 1990s.

A key element of the above studies is that they seek to examine the behaviour of inflation persistence across different regimes for monetary policy. Instead, in this paper we are interested in inflation persistence under a single monetary policy regime, viz. inflation targeting. In particular our focus is on whether there is any support for the view that inflation persistence is asymmetric around a central bank’s target for inflation. While it is apparent from Table 1 that the ECB has an inflation target that is explicitly asymmetric, most other inflation targeting central banks claim to be equally concerned about being 1 percent below target as being 1 percent above target.

Two recent studies have examined the issue of asymmetry in inflation rates in the IT era. Koirala (2012) estimates a TAR model for inflation in Nepal – not an inflation targeting country – using monthly data for the period 1998-2011. He finds evidence of asymmetry in the AR process for 12-month ended inflation, where the indicator variable is the inflation rate lagged one period and the threshold is estimated at 7.4 percent. When inflation is above the threshold, the estimate for the AR(1) coefficient is 0.78, whereas when inflation is below the threshold, the estimated AR(1) coefficient increases to 1.01. One interesting aspect of these estimates is the relatively high degree of persistence, particularly when inflation is below the threshold; although the large AR estimates may reflect the use of 12-month ended inflation.

Akdoğan (2015) examines the issue of asymmetry in inflation for a (large) sample of nineteen inflation targeting countries. The analysis focuses on the use of smooth transition autoregressive models (STAR) of the (exponential) ESTAR form (Kapetanios, Shin and Snell, 2003) and the (asymmetric) AESTAR form (Sollis, 2009). The AESTAR model allows for asymmetry in the (smooth) adjustment process towards the inflation target. In the empirical analysis Akdoğan uses monthly
inflation on a 12-month ended basis for each country, where the sample period covers a countries IT regime. Of the nineteen countries examined, eleven are found not to exhibit any evidence of non-linearity of the form implied by either the ESTAR or the AESTAR models. Estimates for the AESTAR model are reported for six counties: Canada, Norway, Sweden, Romania, Thailand and Turkey, though for Canada and Sweden the degree of asymmetry in adjustment speed appears to be relatively small.

In this paper we focus on estimating TAR models due to their relative parsimony in terms of the number of parameters to be estimated. Since we use quarterly inflation and data covering IT regimes we are limited in the degree of non-linearity that can be adequately modelled.

3. A Threshold Model for Inflation

Our basic strategy is to search for evidence of asymmetry in the process for the inflation rate under the IT regimes using a threshold autoregressive (TAR) model (Tong, 1983). We use a simple version of the two-regime TAR model (Hansen, 1996; 1997) given by:

\[ \pi_t = \mu + \theta_1 \pi_{t-1} I(z_{t-d} \leq \gamma) + \theta_2 \pi_{t-1} I(z_{t-d} > \gamma) + \epsilon_t \]  

where \( I(.) \) is an indicator function which takes the value 1 when the indicator variable \( z_{t-d} \) is less than or equal to the threshold \( \gamma \) and 0 otherwise. The indicator variable \( z_{t-d} = z(\pi_{t-d}, ..., \pi_{t-d-k}) \) is a known function of the data. In our model the autoregressive coefficient for the inflation process will switch between \( \theta_1 \) and \( \theta_2 \) whenever the indicator variable is below or above the threshold. The error process \( \epsilon_t \) is assumed to be serially uncorrelated, but may be conditionally heteroskedastic.

The TAR model has only one lag reflecting that fact that we choose to model the quarterly inflation rate. During periods when countries have adopted IT, it is typically the case that the quarterly inflation rate can be reasonably well approximated by a parsimonious, stationary linear AR model. For all of the countries that we consider it is possible to fit an AR(1) model to the quarterly inflation rate and find no evidence of serial correlation. In seeking to model the quarterly inflation rate we are aware that a possible alternative approach is to model the four-quarter-ended inflation rate:

\[ \pi_{4,t} = (log P_t - log P_{t-k}) \times 100 \]  

where \( P \) is a price index. The main disadvantage of modelling \( \pi_{4,t} \) as a TAR model is that it would almost certainly require a relatively high order AR process to capture all of the dynamics in the series and ensure a serially uncorrelated error term.

While our TAR model is of quarterly inflation, we do use a lagged value of \( \pi_{4,t} \) as the threshold variable. Central banks' inflation targets – be they point targets or bands – are stated in terms of an
annual rate of inflation, thus it seems appropriate to consider a lagged value of \( \pi_{4,t} \) as the threshold variable, instead of the lagged quarterly inflation rate. Note that we can write

\[
\pi_{4,t} = \pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}
\]

which shows the four-quarter-ended inflation is just the sum of current and the three previous lags of quarterly inflation. In estimating equation (1) we use \( z_{t-d} = \pi_{4,t-d} \) as the possible indicator variable and consider values of \( d = 1 \) to 4.

A final decision to be made concerns the choice of the value of the threshold at which switching occurs. For countries with a point target it seems natural to use the target as the threshold value. In the case of a target band, a reasonable choice might be the mid-point of the target band. Finally an alternative strategy is to estimate the threshold and see how it compares to the stated inflation targets. The latter is what we do.

The threshold model for inflation that we specify for IT countries takes the form:

\[
\pi_t = \mu + \theta_1 \pi_{t-1} I(\pi_{4,t-d} \leq \gamma) + \theta_2 \pi_{t-1} I(\pi_{4,t-d} > \gamma) + u_t
\]

Our interest is in whether the AR coefficients \( \theta_1 = \theta_2 \), in which case we would have a linear AR model and not find any support for the asymmetric target view. In the event that we reject the linear AR model, the relative magnitudes of the two AR coefficients are important. If central banks are relatively less aggressive at responding to shocks that push inflation below their targets, we expect to see a relatively more persistent process for inflation when the indicator variable \( \pi_{4,t-d} \) is below the threshold, than when it is above the threshold. In terms of model (4) this would mean that \( \theta_1 > \theta_2 \). Note the intercept term in the TAR model is assumed to be constant across the two possible regimes indicating that inflation expectations are well anchored.

4. Data

We estimate the TAR model for inflation (4) for Australia, Canada, New Zealand (NZ), Sweden, the United States (US) and the Euro Area (EA). The first four of these countries were all relatively early adopters of IT. Roger (2010) reports the effective adoption dates of IT are: New Zealand (1990:Q1), Canada (1991:M2), Sweden (1993:M1) and Australia (1993:Q4). The US Federal Reserve did not formally announce an inflation target until 2012:M1, although is widely thought to have been informally following a similar target rate for some period prior to that date. The European Central

\[\text{We do not allow for shifts in the constant (mean) inflation that would imply a de-anchoring of public perceptions of the central bank's inflation target from the officially announced target.}\]

\[\text{The United Kingdom (1992:M10) was also an early adopter of IT, however there have been a number of changes in the measure of inflation targeted by the Bank of England and we were not able to construct a sample of reasonable length.}\]
Bank (ECB) has had an IT since the formation of the Euro Area (1999:M1) and is the only central bank in our sample that has an explicitly asymmetric target of an annual inflation rate of less than 2 percent. In Table 1 we report the current inflation targets for each country.

**Table 1: Inflation Targets**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Frequency</th>
<th>Target Rate (% per-annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>CPI (quarterly)</td>
<td>2 – 3</td>
</tr>
<tr>
<td>New Zealand</td>
<td>CPI (quarterly)</td>
<td>1 – 3</td>
</tr>
<tr>
<td>Canada</td>
<td>CPI (monthly)</td>
<td>1 – 3</td>
</tr>
<tr>
<td>Sweden</td>
<td>CPI (monthly)</td>
<td>1 – 3</td>
</tr>
<tr>
<td>United States</td>
<td>CPI (monthly)</td>
<td>2</td>
</tr>
<tr>
<td>Euro Area</td>
<td>CPI (monthly)</td>
<td>≤ 2</td>
</tr>
</tbody>
</table>

Although the CPI inflation rate is available on a monthly frequency for four of the counties, we estimate the TAR model for all six countries using quarterly inflation rates. We do this for a number of reasons. First it allows for a direct comparison of the TAR results across all countries. Second monthly inflation rates tend to be relatively volatile and this makes it hard to fit a TAR model. Third most other studies that fit non-linear models to inflation rates have used quarterly inflation. In general we have used the headline CPI inflation rate in the TAR model. The exact definitions and sources of our data and any adjustments made to series are provided in the Data Appendix.

**5. Main Results**

**5.1 AR Models**

We begin by reporting in Table 2 estimates of linear AR models for each country during their IT regime. A maximum of four lags is allowed in the AR model. However as indicated by the (p-value) results of an F-test reported in the table, lags 2 to 4 are jointly insignificant for any of the countries. Quarterly inflation in all countries, except Canada, can be modelled with a linear AR(1) model, where the estimated AR coefficient ranges between 0.2 to 0.4. In the case of Canada even the AR(1) coefficient is not statistically significant. The relatively low values for the AR(1) coefficients suggest that during the IT regime, inflation shocks are not very persistent.

**Testing for Linearity**

The implication of the linear AR analysis is that the central bank views both overshooting and falling short of the inflation target as equally bad (symmetric inflation target). The second step of our analysis is to provide some evidence of non-linearity in quarterly inflation rates for the selected
counties. We use the non-linearity tests due to Luukkonen, Saikkonen, and Terasvirta (1988, LST). LST develop tests of a linear model versus a smooth transition autoregressive (STAR) model and show that these tests have power against TAR models. The LST test is simple to implement and has attracted a lot of attention in the literature. The test regression has the following general form:

\[ \pi_t = \mu + \theta \pi_{t-1} + c_1(\pi_{t-1} - \pi_{t-d}) + c_2(\pi_{t-1} - \pi_{t-2} + \pi_{t-2} - \pi_{t-d}) + u_t \]  

where \( d = 1 \) to 4 and the null hypothesis of linearity is tested by an F-test of \( H_0: c_1 = c_2 = c_3 = 0 \). Our findings are summarised using p-values in Table 3.

Of the six countries considered, Canada is the only one where the LST test does not provide any evidence against the null hypothesis of a linear AR(1) model for quarterly inflation. The test results do not point to any evidence of asymmetry in Canadian inflation. In contrast for the other five countries, there is at least one value of \( d \), that leads to the rejection of the linear AR(1) model for inflation at the 10 percent level of significance. Given our sample size, these rejections although not very strong seem reasonable. Thus for these IT countries we proceed with estimation of a TAR model.

5.2 TAR Estimates

Table 4 reports the estimated TAR models for inflation rates in Australia, New Zealand, Sweden, the United States and the Euro-Area. In all cases the point estimate of \( \theta_1 > \theta_2 \); i.e. the estimate of the autoregressive coefficient is larger when inflation is below the estimated threshold value than when it is above. We refer to the larger AR coefficient \( \theta_1 \) as coming from the increased persistence regime. The estimates of \( \theta_1 \) are all positive and statistically significant. When inflation is above the threshold – the decreased persistence regime – we obtain estimates of the AR coefficient \( \theta_2 \) that are not statistically different from zero in four of the five countries. The exception is for the Euro-Area where the point estimate of \( \theta_2 \) is positive and statistically significant, but smaller in magnitude than the estimate of \( \theta_1 \). For Australia, NZ and the US the very small point estimate for \( \theta_2 \) suggest the quarterly inflation rate is essentially a serially uncorrelated process when the indicator variable is above the threshold value.

For Australia and NZ the estimated value of the threshold is somewhat above the upper bound of their announced target bands. For the US the estimate of the threshold is 3.35, which is above the currently announced target of 2 percent. For Sweden and the Euro-Area the estimated threshold is close to the announced targets. In the case of Sweden the estimated value of the threshold lies within the central bank’s target bands of 1-3 percent. For the Euro-Area the estimated threshold is just slightly below the ECB’s upper limit for inflation of 2 percent.
The results in Table 4 point to asymmetry in the dynamics of quarterly inflation rates for all five countries. Moreover when lagged annualised inflation is below a particular value, quarterly inflation is relatively persistent. In contrast when annualised inflation is above a threshold value, it is not possible to reject zero persistence in quarterly inflation for all countries except the Euro-Area.

One interpretation of these results is that it reflects the behaviour of central banks. When inflation is relatively low a central bank is not particularly aggressive in its response to a shock to the quarterly inflation rate. Therefore shocks can have a reasonably persistent effect on quarterly inflation, provided the (historical) annualised rate of inflation is below a threshold value. On the other hand if the (historical) annualised rate of inflation is above the threshold value, then the central bank acts to eliminate any persistence in the inflation rate.

5.3 Generalized Impulse Response Functions

To investigate further the asymmetry in the inflation process we report some generalized impulse response functions (GIRFs) for the estimate TAR models. Rather than averaging across all initial conditions we report illustrative examples for each country for particular dates when the country was in a (relatively) high inflation and a (relatively) low inflation regime. A high inflation regime corresponds to a date when the indicator variable \( \pi_{4t-d} \) was above the estimated threshold, while a low inflation regime is a date when it was below the estimated threshold.

Figures 1 and 2 show the respective GIRFs for Australia. In Figure 1 the indicator variable places inflation in the increased persistence (low inflation) regime in 2009:1. In Figure 2 the indicator places inflation in the decreased persistence (high inflation) regime in 2006:3. It is evident that the GIRFs for the negative and positive shocks are broadly symmetric, but the persistent of inflation to the shocks is much higher in the low inflation regime compared to the high inflation regime.

The GIRFs for the four other economies (see Figures 3 to 10) confirm that the asymmetry in response to an inflation shock depends upon whether the economy is in an increased persistence (high) or increased persistence (low inflation) regime.

6. Robustness Analysis

In this section we report the results from a number of checks of the robustness of our basic finding.

6.1 Global Disinflationary Shocks Post-2012

Ciccarelli and Osbat (2017) report evidence that Euro-Area inflation was persistently below target after 2012 mainly due to global disinflationary shocks related to the fall of commodity prices. Therefore, we ask the obvious question: Are our TAR results driven by the global disinflationary period 2012-2015? To address this issue we re-estimated our models only using data up until 2011:4. The results are reported in Table 5. We find that generally TAR estimates change very little
over the restricted sample period. One exception is NZ where the estimate for $\theta_2$ is only slightly smaller in magnitude than the estimate for $\theta_1$, though not as highly significant as the latter. Our conclusion is that asymmetry seems to be a feature of the entire sample period of IT and not just driven by the global disinflationary period 2012-2015.

6.2 Generalization to Phillips Curve TAR

In this section, we consider the effect on our results of generalizing the TAR model to include a measure of economic slack (i.e. the output gap or unemployment). The specification is given by:

$$\pi_t = \mu + [\theta_1 \pi_{t-1} + \delta_1 x_{t-1}] I(\pi_{4,t-d} \leq \gamma) + [\theta_2 \pi_{t-1} + \delta_2 x_{t-1}] I(\pi_{4,t-d} > \gamma) + u_t$$

(5)

where $x_{t-1}$ is a measure of economic slack. For consistency with the baseline TAR model we use a lag of $\pi_{4,t-d}$ as the threshold variable. It is possible to give equation (5) a structural interpretation as a purely backward looking version of the Phillips curve.

The estimates of equation (5) based on a measure of the output gap are reported in Table 6a, while those based on the unemployment rate are in Table 6b. The inclusion of the output gap has relatively little effect on the estimates of $\theta_1$ and $\theta_2$. In the case where unemployment is used to measure economic slack, it appears to be marginally significant for NZ and Sweden but only in the low inflation regime (i.e. increased persistence). This result is in line with the view that the Phillips curve weakens in a low inflation environment due to nominal wage rigidities (Fortin and Akerlof, 2002; Krugman, 2012).

6.3 Inflation Rates in the Pre-IT Regime

In interpreting our findings it is helpful to know if they are specific to the behaviour of the inflation rate under IT or wherever there is asymmetry during the period 1970-1980. To address this issue we carried out the LST test for non-linearity using quarterly data for the period 1971-1991 (excluding the Euro-Area). The results are reported in Table 7. With the exception of Sweden, the evidence against linearity is much weaker during this pre-IT period.

7. Conclusion

In this paper we present some evidence of asymmetry in the persistence of inflation rates in three long-term IT countries, in the United States and in the Euro-area. Results for Canada – also an early adopter of IT – do not indicate any evidence of non-linearity in an autoregressive model for quarterly inflation. For quarterly inflation in Australia, New Zealand, Sweden, the United States and the Euro-Area we find evidence of a TAR model, with a single threshold and one lag for inflation. We use a lagged value of four-quarter-ended inflation as the indicator variable. In periods when four-quarter-ended inflation is above the estimated threshold, so that it is high in relation to the IT, we find close to zero persistence in the inflation process. Current shocks to inflation have no discernible effect on
future inflation rates. When four-quarter-ended inflation is below the estimated threshold, so that it is below the upper bound of the IT, we find positive persistence in the inflation process. However even in this relatively low inflation regime the point estimate of the AR coefficient is much less than unity, indicating a stationary process for inflation.
Data Appendix

Inflation Rates

Quarterly inflation rates are computed using the formula $\left(\frac{CPI}{CPI_{-1}} - 1\right) \times 100$, where CPI is a measure of the consumer price index.

Australia

CPI = All groups, quarterly, seasonally adjusted (Source: Australian Bureau of Statistics, Reference A3604506F).

An adjustment of (-3%) is made to the quarterly inflation rate in 2000:3 (3.85%) to remove the estimated one-time effect of the introduction a 10 percent Goods and Services Tax. The estimate is obtained from a Reserve Bank of Australia series for quarterly inflation that excludes interest and tax changes. (Source: Reserve Bank of Australia, Reference GCPIEITCQP)

New Zealand

CPI = All groups, quarterly, seasonally adjusted (Source: Statistics New Zealand, Reference CPI0226AA).

Canada

CPI = All items, monthly, seasonally adjusted (Source: Statistics Canada, Table 326-0022, Reference V41690914).

The quarterly inflation rate is computed as an average of monthly rates in the relevant quarter multiplied by three.

Sweden

CPI = All items, quarterly, not seasonally adjusted (Source: FRED, Reference SWECPIALLQINMEI)

The quarterly inflation rate is seasonally adjusted using seasonal dummies.

United States

CPI = All items, all urban consumers, monthly, seasonally adjusted (Source: FRED, Reference CPIAUCSL)

The quarterly inflation rate is computed as an average of monthly rates in the relevant quarter multiplied by three.

Euro Area

CPI = Harmonised index of consumer prices, all items for Euro Area (19 countries), quarterly, not seasonally adjusted (Source: FRED, Reference CP0000E219M086NEST)

The quarterly inflation rate is seasonally adjusted using the X11 filter in RATS.
**Unemployment Rates**

**Australia**

un = Unemployment rate, persons, monthly, seasonally adjusted (Source: Australian Bureau of Statistics, Reference A84423050A).

The quarterly unemployment rate is computed as an average of monthly rates in the relevant quarter.

**New Zealand**

un = Harmonised unemployment rate, all persons, quarterly, seasonally adjusted (Source: FRED, Reference NZLURHARMQDSMEI).

**Sweden**

un = Harmonised unemployment rate, all persons, quarterly, seasonally adjusted (Source: FRED, Reference SWEURHARMQDSMEI).

**United States**

un = Harmonised unemployment rate, all persons, quarterly, seasonally adjusted (Source: FRED, Reference LRHUTTTTUSQ156S).

**Euro Area**

un = Harmonised unemployment rate for Euro Area (19 countries), persons, monthly, seasonally adjusted (Source: Eurostat).

The quarterly unemployment rate is computed as an average of monthly rates in the relevant quarter.

**Gross Domestic Product**

**Australia**


**New Zealand**

GDP = Average of production-based and expenditure-based measures of real gross domestic product, quarterly, seasonally adjusted (Source: Reserve Bank of New Zealand, ).

**Sweden**

GDP = Real gross domestic product, 2015 prices, quarterly not seasonally adjusted (Source: ***)

The series for GDP seasonally adjusted using the X11 filter in RATS.

**United States**

GDP = Real gross domestic product, chained 2000 dollars, quarterly, seasonally adjusted (Source: FRED, Reference GDPC1)
Euro Area

GDP = Real GDP for European Union (15 countries), millions of chained 2010 Euros, quarterly, seasonally adjusted (Source: FRED, Reference CLUMNACSCABIGQUEU15).

Output Gaps

Estimates of output gaps for each country are based on the Beveridge-Nelson (BN) filter method proposed by Kamber, Morley and Wong (2016). For the US and EA we estimate AR(12) models for the log-difference of real GDP, where the AR coefficients are restricted to sum to unity. A BN decomposition is then applied to this model, with the output gap being defined as the log of real GDP less the BN stochastic trend. The same procedure is applied to Australian, New Zealand and Sweden, except the uses a AR(6) model for these countries. Figure A1 shows the estimated output gaps for Australia and the US for the period 1984:1 to 2015:4.

Figure A1: Output gap Estimates for Australia and US
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<table>
<thead>
<tr>
<th>Indicators</th>
<th>Australia</th>
<th>Canada</th>
<th>New Zealand</th>
<th>Sweden</th>
<th>United States</th>
<th>Euro-Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>1.495 (0.28) ***</td>
<td>1.981 (0.28) ***</td>
<td>1.353 (0.27) ***</td>
<td>0.891 (0.25) ***</td>
<td>1.762 (0.31) ***</td>
<td>0.955 (0.25) ***</td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>0.388 (0.10) ***</td>
<td>-0.112 (0.10) **</td>
<td>0.308 (0.10) ***</td>
<td>0.292 (0.10) ***</td>
<td>0.217 (0.10) **</td>
<td>0.434 (0.11) ***</td>
</tr>
<tr>
<td>$\theta_2=\theta_3=\theta_4=0$</td>
<td>0.95</td>
<td>0.11</td>
<td>0.84</td>
<td>0.87</td>
<td>0.42</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Notes: The final row reports p-values for the F-test for the exclusion of lags 2, 3 and 4 from the AR model. For Australia, Canada and Sweden the data sample is 1993:1 – 2015:4, for New Zealand and the United States it is 1991:1 – 2015:4, while for the Euro-area the data sample is 2001:1 – 2016:3.

Standard errors are in (.).***, ** and * indicate significance at 1%, 5% and 10%, respectively.

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**Table 3: Test for Linearity against Two Regime TAR Model for Quarterly Inflation Rate**

<table>
<thead>
<tr>
<th>Indicator Variable</th>
<th>Australia</th>
<th>Canada</th>
<th>New Zealand</th>
<th>Sweden</th>
<th>United States</th>
<th>Euro-Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_{4,\tau-1}$</td>
<td>0.803</td>
<td>0.182</td>
<td>0.065</td>
<td><strong>0.009</strong></td>
<td>0.093</td>
<td>0.396</td>
</tr>
<tr>
<td>$\pi_{4,\tau-2}$</td>
<td>0.204</td>
<td>0.474</td>
<td><strong>0.039</strong></td>
<td>0.593</td>
<td>0.474</td>
<td><strong>0.076</strong></td>
</tr>
<tr>
<td>$\pi_{4,\tau-3}$</td>
<td><strong>0.053</strong></td>
<td>0.874</td>
<td>0.471</td>
<td>0.723</td>
<td>0.319</td>
<td>0.131</td>
</tr>
<tr>
<td>$\pi_{4,\tau-4}$</td>
<td>0.107</td>
<td>0.720</td>
<td>0.482</td>
<td>0.882</td>
<td><strong>0.046</strong></td>
<td>0.305</td>
</tr>
</tbody>
</table>


---

**Table 4: TAR Model Estimates**

<table>
<thead>
<tr>
<th>Indicator Variable</th>
<th>Australia</th>
<th>New Zealand</th>
<th>Sweden</th>
<th>United States</th>
<th>Euro-Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.455 (0.30) ***</td>
<td>1.364 (0.21) ***</td>
<td>0.708 (0.16) ***</td>
<td>1.393 (0.45) ***</td>
<td>0.839 (0.25) ***</td>
</tr>
<tr>
<td>$\theta_1$: Increased Persistence</td>
<td>0.475 (0.10) ***</td>
<td>0.372 (0.08) ***</td>
<td>0.741 (0.16) ***</td>
<td>0.436 (0.16) ***</td>
<td>0.701 (0.17) ***</td>
</tr>
<tr>
<td>$\theta_2$: Decreased Persistence</td>
<td>0.017 (0.14)</td>
<td>-0.269 (0.16)</td>
<td>0.078 (0.08)</td>
<td>-0.009 (0.19)</td>
<td>0.425 (0.10) ***</td>
</tr>
<tr>
<td>$\gamma$: Threshold</td>
<td>3.17</td>
<td>3.47</td>
<td>2.67</td>
<td>3.35</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Notes: HAC standard errors are in (.). See also notes Table 2.
### Table 5: TAR Estimates Excluding Disinflationary Period Post-2012

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Australia</th>
<th>New Zealand</th>
<th>Sweden</th>
<th>United States</th>
<th>Euro-area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$\pi_{4,t-3}$</td>
<td>$\pi_{4,t-2}$</td>
<td>$\pi_{4,t-1}$</td>
<td>$\pi_{4,t-4}$</td>
<td>$\pi_{4,t-2}$</td>
</tr>
<tr>
<td></td>
<td>1.481 (0.36) ***</td>
<td>1.575 (0.25) ***</td>
<td>0.886 (0.18) ***</td>
<td>1.546 (0.62) **</td>
<td>1.243 (0.42)***</td>
</tr>
<tr>
<td>$\theta_1$ : Increased Persistence</td>
<td>0.499 (0.11) ***</td>
<td>0.357 (0.08) ***</td>
<td>0.734 (0.17) ***</td>
<td>0.435 (0.21) **</td>
<td>0.633 (0.24)**</td>
</tr>
<tr>
<td>$\theta_2$ : Decreased Persistence</td>
<td>0.019 (0.15)</td>
<td>-0.315 (0.16) *</td>
<td>0.050 (0.08)</td>
<td>-0.024 (0.19)</td>
<td>0.339 (0.14)**</td>
</tr>
<tr>
<td>$\tau$ Threshold</td>
<td>3.17</td>
<td>3.49</td>
<td>2.67</td>
<td>3.35</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Notes: HAC standard errors are in (.). See also notes Table 2.

### Table 6a: Phillips Curve TAR Estimates with Output Gap

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Australia</th>
<th>New Zealand</th>
<th>Sweden</th>
<th>United States</th>
<th>Euro-Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$\pi_{4,t-3}$</td>
<td>$\pi_{4,t-2}$</td>
<td>$\pi_{4,t-1}$</td>
<td>$\pi_{4,t-4}$</td>
<td>$\pi_{4,t-2}$</td>
</tr>
<tr>
<td></td>
<td>1.490 (0.32) ***</td>
<td>1.363 (0.21) ***</td>
<td>0.676 (0.17) ***</td>
<td>1.610 (0.38) ***</td>
<td>0.917 (0.28)***</td>
</tr>
<tr>
<td>$\theta_1$ : Increased Persistence</td>
<td>0.465 (0.11) ***</td>
<td>0.340 (0.07) ***</td>
<td>0.824 (0.26) ***</td>
<td>0.361 (0.13) ***</td>
<td>0.681 (0.16)***</td>
</tr>
<tr>
<td>$\theta_2$ : Decreased Persistence</td>
<td>0.013 (0.12)</td>
<td>-0.270 (0.14) *</td>
<td>0.090 (0.10)</td>
<td>-0.043 (0.23)</td>
<td>0.387 (0.10)***</td>
</tr>
<tr>
<td>$\gamma_1$ : Increased Persistence</td>
<td>0.004 (0.40)</td>
<td>0.459 (0.22) **</td>
<td>-0.266 (0.38)</td>
<td>0.159 (0.21)</td>
<td>0.090 (0.08)</td>
</tr>
<tr>
<td>$\gamma_2$ : Decreased Persistence</td>
<td>1.170 (0.81)</td>
<td>0.003 (0.45)</td>
<td>0.068 (0.31)</td>
<td>0.455 (0.64)</td>
<td>0.202 (0.16)</td>
</tr>
<tr>
<td>$\tau$ Threshold</td>
<td>3.17</td>
<td>3.47</td>
<td>2.67</td>
<td>3.35</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Notes: HAC standard errors are in (.). See also notes Table 2.

### Table 6b: Phillips Curve TAR Estimates with Unemployment

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Australia</th>
<th>New Zealand</th>
<th>Sweden</th>
<th>United States</th>
<th>Euro-Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$\pi_{4,t-3}$</td>
<td>$\pi_{4,t-2}$</td>
<td>$\pi_{4,t-1}$</td>
<td>$\pi_{4,t-4}$</td>
<td>$\pi_{4,t-2}$</td>
</tr>
<tr>
<td></td>
<td>1.807 (0.95) **</td>
<td>2.457 (0.56) ***</td>
<td>2.984 (1.13) **</td>
<td>1.870 (0.77) **</td>
<td>2.505 (1.73)</td>
</tr>
<tr>
<td>$\theta_1$ : Increased Persistence</td>
<td>0.494 (0.12) ***</td>
<td>0.342 (0.09) ***</td>
<td>0.762 (0.17) ***</td>
<td>0.422 (0.14) ***</td>
<td>0.743 (0.18)***</td>
</tr>
<tr>
<td>$\theta_2$ : Decreased Persistence</td>
<td>-0.094 (0.13)</td>
<td>-0.381 (0.16) **</td>
<td>-0.164 (0.05) ***</td>
<td>-0.014 (0.18)</td>
<td>0.217 (0.18)</td>
</tr>
<tr>
<td>$\gamma_1$ : Increased Persistence</td>
<td>-0.068 (0.13)</td>
<td>-0.172 (0.07) **</td>
<td>-0.312 (0.14) **</td>
<td>-0.072 (0.09)</td>
<td>-0.196 (0.16)</td>
</tr>
<tr>
<td>$\gamma_2$ : Decreased Persistence</td>
<td>0.008 (0.14)</td>
<td>-0.098 (0.08)</td>
<td>-0.097 (0.14)</td>
<td>-0.076 (0.14)</td>
<td>-0.112 (0.15)</td>
</tr>
<tr>
<td>$\tau$ Threshold</td>
<td>3.17</td>
<td>3.47</td>
<td>2.67</td>
<td>3.35</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Notes: HAC standard errors are in (.). See also notes Table 2.
Table 7: Test for Linearity against Two Regime TAR for Quarterly Inflation Rate, 1971-1991

<table>
<thead>
<tr>
<th>Indicator Variable</th>
<th>Australia</th>
<th>Canada</th>
<th>New Zealand</th>
<th>Sweden</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_{4,t-1}$</td>
<td>0.402</td>
<td>0.304</td>
<td>0.275</td>
<td><strong>0.032</strong></td>
<td>0.076</td>
</tr>
<tr>
<td>$\pi_{4,t-2}$</td>
<td>0.639</td>
<td>0.289</td>
<td>0.778</td>
<td>0.271</td>
<td>0.404</td>
</tr>
<tr>
<td>$\pi_{4,t-3}$</td>
<td>0.749</td>
<td>0.126</td>
<td>0.653</td>
<td>0.407</td>
<td>0.612</td>
</tr>
<tr>
<td>$\pi_{4,t-4}$</td>
<td>0.936</td>
<td>0.150</td>
<td>0.772</td>
<td>0.284</td>
<td>0.336</td>
</tr>
</tbody>
</table>

Figure 1: GIRFs for Australia in Increased Persistence Inflation Regime ($\pi_{t-1} = 2.31$ in 2009:1)

Figure 2: GIRFs for Australia in Decreased Persistence Inflation Regime ($\pi_{t-1} = 3.79$ in 2006:3)

Figure 3: GIRFs for New Zealand in Increased Persistence Inflation Regime ($\pi_{t-1} = 2.04$ in 2010:1)

Figure 4: GIRFs for New Zealand in Decreased Persistence Inflation Regime ($\pi_{t-1} = 3.9$ in 2006:2)
Figure 5: GIRFs for Sweden in Increased Persistence Inflation Regime ($\pi_{4,t-1}=0.77$ in 2006:1)

Figure 6: GIRFs for Sweden in Decreased Persistence Inflation Regime ($\pi_{4,t-1}=3.19$ in 2008:1)

Figure 7: GIRFs for United States in Increased Persistence Inflation Regime ($\pi_{4,t-4}=-0.14$ in 2009:1)

Figure 8: GIRFs for United States in Decreased Persistence Inflation Regime ($\pi_{4,t-4}=3.64$ in 2006:1)
Figure 9: GIRFs for Euro Area in Increased Persistence Inflation Regime ($\pi_{t-2}=0.58$ in 2009:1)

Figure 10: GIRFs for Euro Area in Decreased Persistence Inflation Regime ($\pi_{t-2}=3.08$ in 2007:4)