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Inflation Targeting and the Unemployment-Inflation Trade-off

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Abstract

This paper examines the impact of the introduction of inflation targeting on the unemployment-inflation trade-off in OECD countries. Theoretical models suggest that the credibility-enhancing effects of the adoption of inflation targeting should cause an improvement in the unemployment-inflation trade-off, i.e., that reducing inflation by a given amount should occur with a smaller rise in unemployment. The empirical evidence examined for OECD countries adopting inflation targeting supports this hypothesis. Using a smooth transition regression model, it is shown that the improvement in this trade-off does not take place immediately after the adoption of inflation targeting; rather, it improves over time as the credibility of the central bank is established.

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"Nor does the recent experience of OECD countries suggest that central banks that posted inflation targets were able to disinflate at lower cost than central banks without such targets."

Alan S. Blinder (1998)

I. Introduction

Over the past few years a large number of industrial countries have adopted inflation targeting (IT) as their framework for monetary policy and now an increasing number of emerging market countries are also adopting IT (see Bernanke and others (1999), Clifton (1999), and Mishkin and others (2001)). Notwithstanding the above statement by Alan Blinder, the widespread adoption of IT has been partly due to the perception that the IT countries have been successful at reducing inflation with a relatively lower cost of forgone output compared to non-IT countries (see Haldane (1996)). However, with the exception of Bernanke and others (1999) and Corbo and others (2000), little empirical research has been done to examine systematically how the adoption of IT affects the output-inflation trade-off or, as it is often phrased in empirical work, the unemployment-inflation trade-off. This paper examines this issue by estimating Phillips curves for seven Organization for Economic Cooperation and Development (OECD) countries that adopted IT, comparing their experiences with those of nine OECD countries that did not do so.

Discussions about IT emphasize that IT improves the transparency and credibility of monetary policy. In general, countries adopting IT regularly provide the public with substantial and frequent information about the goals and conduct of monetary policy (Debelle (1997)). Haldane (1997) notes that transparency is arguably *the* feature distinguishing IT from other monetary frameworks. The transparency of IT is thought to reduce the inflationary bias of monetary policy since financial markets should quickly spot any inflationary opportunism. In this way, improved transparency enhances the credibility of monetary policy. Moreover, establishing the primacy of the inflation target over any other monetary policy objectives, such as an exchange rate commitment or output stabilization, is usually considered a necessary condition for the successful adoption of IT (Masson and others (1997)). IT thus strengthens the *de facto* instrument independence of the central bank, improving the ability of the central bank to achieve its targets (see Fischer (1994) and Persson and Tabellini (1993) for discussions of credibility and transparency as desirable aspects of a monetary policy framework). A recent empirical study of the relationship between inflation targeting and credibility by Kuttner and Posen (1999) finds that the bulk of the evidence supports what they call the "trust-building" interpretation of IT. In this interpretation, by providing greater information about inflation forecasts and policy actions for meeting those forecasts, the central bank convinces the public that it can accommodate one-time inflationary shocks without raising doubts about its underlying counter-inflationary resolve.

Strengthening the credibility of monetary policy is generally seen in the literature as a development that should improve the unemployment-inflation trade-off since a given change in inflation would be associated with a smaller change in unemployment. In other words, the

Phillips curve would become steeper (see, for example, Posen (1998) and Baltensperger and Jordan (1998)). A very large literature exists on the subject of the credibility of monetary policy and a recent paper by Clarida and others (1999) nicely summarizes the issues using a simple dynamic general equilibrium model. These authors show that, if price-setting behavior depends on forward-looking expectations, then a central bank that can credibly commit to an inflation-fighting rule faces an improved short-run trade-off between inflation and unemployment. They note that inflation targeting can be viewed as a transparent way for a central bank to put relatively greater weight on fighting inflation in their policy loss function. The simple explanation for this result is that a central bank that agents believe will be an inflation hawk in the future will not have to contract output by as much today to achieve a given disinflation.

However, there are two problems with this result. First, as Clarida and others acknowledge, it is difficult to generalize the result they find in their simple model to a more general model where monetary policy reacts to the entire history of cost-push shocks rather than only to contemporaneous shocks. Second, if higher credibility also leads to increased nominal rigidities (e.g., lengthening of labor contracts), the effect on the unemployment-inflation trade-off is unclear (see, for example, Ball and others (1988), Walsh (1995), and Hutchison and Walsh (1998) for discussions of these issues). For example, when a credible monetary policy regime produces a climate of low inflation, firms change their prices less frequently because they have low inflation expectations and thus are less afraid of having to catch up if costs increase. At the same time, as the central bank becomes more inflation averse, labor unions may choose less wage indexation and lengthen their wage contracts. The greater nominal wage-price rigidity implies a flatter Phillips curve and suggests that the increased nominal rigidities could offset some or all of the direct effects of the improved credibility.

Hutchinson and Walsh (1998) illustrate the offsetting effects of a monetary policy change on the unemployment-inflation trade-off using a Phillips curve augmented by past expectations of current inflation and forward-looking expectations of future inflation. They show that as credibility improves, the trade-off between unemployment and inflation improves because policy changes can affect expected inflation as well as actual inflation. On the other hand, lower average inflation can increase nominal rigidities and worsen the trade-off. In the extreme case where the decline in inflation is fully anticipated, the disinflation has no effect on output. Thus, if the adoption of inflation targeting improved credibility but also lowered average inflation, the sign of the net impact on the unemployment-inflation trade-off would be ambiguous.

Empirical studies of the effect of adoption of IT on the output-inflation trade-off have been done by Bernanke and others (1999) and Corbo and others (2000).[2] The first group of authors

[2] In addition, Andersen and Wascher's (1999) study of monetary policy and sacrifice ratios in 19 industrial countries found that the increases in the "sacrifice ratios" tend to be smaller in countries that had adopted inflation targeting.

examines the effect of the adoption of IT using sacrifice ratios and parameter instability tests from out-of-sample forecasts generated from Phillips curves. They find "essentially no evidence that the adoption of inflation targets has reduced the real output and employment costs of disinflation, at least not during the early stages of the new approach." In the first part of their empirical work on sacrifice ratios, the authors' study covers only the inflation targeting period of Canada, New Zealand, and the United Kingdom.[3] For each of these countries, three disinflations are examined. In addition to the methodological issues reviewed in their paper, it is important to note that in all three cases only one of the disinflations was partly in the period during which the country could be considered an inflation targeter. In the second part of their empirical study, Bernanke and others estimate Phillips curves for Canada, New Zealand, Sweden, and the United Kingdom before and after inflation targeting and also for a control group. For three of the four IT countries they find that stability of the output-inflation parameter is not rejected at the 5 percent level comparing pre- and post-inflation targeting periods. They interpret this as evidence that the output-inflation trade-off was not materially shifted by the introduction of inflation targeting. However, given the date that this study was completed,[4] there was very limited use of inflation targeting in the three countries where no evidence of parameter instability was found. Thus, as their paper notes, the lack of evidence regarding the impact of inflation targeting refers only to its early stages. If it took some time to establish the credibility of the new approach, this result would not seem too surprising.

Corbo and others (2000), in an examination of 9 IT countries and 16 other countries, find some preliminary evidence that the adoption of inflation targeting may have contributed to lowering the output costs of inflation stabilization. However, their study is based only on before and after point examinations of sacrifice ratios and they find different results depending on their output measure. In addition, they make no attempt, as in Ball (1994), to determine what has changed the sacrifice ratios, i.e., the adoption of IT or something else. Finally, their industrial output results depend on outliers in their sample (i.e., Israel, Spain and Finland, the first two of which mixed inflation targeting with exchange rate targeting). The opposite conclusion holds if only Australia, Canada, Chile, New Zealand, Sweden and the United Kingdom are included in their sample set.

Similar empirical studies have been done to investigate the impact of central bank independence (CBI) on economic performance including effects on the unemployment-inflation trade-off. Given that an independent central bank is often seen as a prerequisite for the successful adoption of inflation targeting, the empirical issue examined by this paper is closely related to the CBI studies (Masson and others (1997)). Contrary to most observers'

[3] Australia and Sweden are included in the study but in the period before they became full-fledged inflation targeters.

[4] The data end in 1991 Q4 for New Zealand; 1992 Q4 for Canada; 1994 Q3 for the United Kingdom; and 1994 Q4 for Sweden.

expectations, the empirical literature generally suggests that CBI is associated with a flatter Phillips curve (see, for example, Andersen and Wascher (1999), Posen (1998), and Walsh (1995)). An important methodological problem with studies of the relationship between CBI and economic performance is that the definition and measurement of CBI—the explanatory variable—is subjective, which creates problems for statistical inference (see, for example, Pollard (1993)). For example, the independence of a central bank is determined by many factors, including the legal framework and political representation on governing bodies. Further, the weights used to combine the various factors into an overall index of CBI are arbitrary. Also, there may be differences between *de facto* and *de jure* independence. As Pollard (1993) and Walsh (1995) show, these definitional problems can generate significant differences in country rankings among the various indices. This study suffers much less from the definitional problems associated with the CBI studies, as it is easier to specify which countries are inflation targeters than to measure the degree of CBI.[5]

This paper is intended to show empirically that the unemployment-inflation trade-off has improved in OECD countries adopting inflation targeting, i.e., reducing inflation by a given amount should occur with a smaller rise in unemployment. A model with linear parameters is first developed which allows for a structural break at the time of the adoption of IT. In this case, it is found that inflation expectations are largely based on lagged inflation in the pre-IT period and on official inflation targets in the post-IT period. With this model, the unemployment-inflation trade-off improves significantly with the adoption of IT. A comparison of IT and non-IT countries indicates that there was also an improvement in the unemployment-inflation trade-off in non-IT countries in the early 1990's but the improvement was not significant. Finally, the model with linear parameters suggests that there was some transition period between pre- and post-IT regimes when the inflation targets may not have been fully credible. For this reason, a smooth transition regression (STR) model is estimated, which shows that the improvement in the unemployment-inflation trade-off does not take place immediately after the adoption of IT; rather, it improves over time as the credibility of the central bank is established.

While the results of this study suggest that the adoption of inflation targeting may indeed help to improve the unemployment-inflation trade-off, there is nothing to suggest that inflation targeting is unique in this regard. Other steps to improve the inflation-fighting credentials of central bankers, such as appointing a "Rogoff" conservative central banker, may have similar effects (Rogoff (1985)).

The next section of the paper examines data on the unemployment and inflation experiences of 16 OECD countries. The third section develops a simple Phillips curve model that allows the empirical issues to be examined more formally. The fourth section describes the results of

[5] It is debatable whether some of the countries should be truly considered as inflation targeters. For example, during the period under investigation Spain was a self-declared inflation targeter but also had important exchange rate commitments.

the analysis and the final section discusses the results and examines how they relate to previous findings.

II. Data

Seven OECD inflation targeting countries are included in this study: Australia, Canada, Finland, New Zealand, Spain, Sweden, and the United Kingdom.[6] The experiences of these countries are compared with a control group of nine OECD countries that have not adopted IT: Belgium, Denmark, France, Germany, Italy, Japan, Netherlands, Norway, and the United States. As explained by Haque and Khan (1998), there are several different methods that can be used to construct a counterfactual for testing the effects of policy implementation. In this paper, two of the techniques they describe are used: the before-after approach and the with-without approach which uses a control group. For the control group to provide a reasonable comparison, the two groups should not differ systematically. For this reason, we have confined this study to OECD countries with inflation histories relatively close to the typical OECD experience.[7] In addition, as discussed in section V below, the monetary transmission mechanism is likely to be different in high and low inflation countries which suggests that it would be best to examine these groups of countries separately. Since most of the early adopters of IT were industrial countries, we have examined this group.

Quarterly consumer prices for all countries are taken from the International Monetary Fund's *International Financial Statistics (IFS)* database. Inflation is measured as the change in the price level from the same quarter one year earlier. The timing of the adoption of inflation targeting is taken from Schaechter and others (2000): Australia in 1993:Q2; Canada in 1991:Q1; Finland in 1993:Q1; New Zealand in 1989:Q3; Spain in 1994:Q4; Sweden in 1993:Q1; and United Kingdom in 1992:Q4.

Seasonally adjusted quarterly unemployment rates are OECD data collected from *Datastream*.[8] Data on labor productivity are constructed using seasonally adjusted GDP data from *IFS* and employment data from the OECD.

Figure 1 displays data on average inflation and unemployment in the IT countries, adjusting the sample so that inflation targeting in each of the countries starts at time "T".[9] The top

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[6] Spain and Finland abandoned IT in January 1999, when they joined the European Monetary Union.

[7] The decision to adopt IT is endogenous and part of the optimization problem facing monetary authorities. Countries that self-select IT are more likely to have larger potential gains from reducing inflation. In this paper we do not model the adoption decision and our results should be interpreted as conditional on IT having been adopted.

[8] Due to unavailable data, Belgium's 2000 unemployment rate was derived by applying the actual monthly year-to-year change for 2000 to the 1999 data.

panel shows the sequence of inflation and unemployment outcomes and the lower panel shows the same data but in unemployment-inflation space. The start of inflation targeting is done according to the official adoption of IT. Of course, in some countries the authorities may have started *de facto* inflation targeting prior to this date.[10] Alternatively, it could be argued that any effect on expectations and behavior would not take place immediately but rather only after the public has had an opportunity to become familiar with the new monetary policy regime. Particularly for the early IT countries, this time could have been significant. Thus, for any individual country, the best date to use for examining the pre- and post-IT experience could differ somewhat from the dividing line chosen in this study. Figure 2 shows the data for the IT countries indicating the chronological sequence.

Figures 1 and 2 suggest that, on average in the IT countries, the unemployment-inflation trade-off changed in the post-IT period compared to the pre-IT period. It appears that immediately after the adoption of inflation targeting, a significant reduction in inflation was achieved even while unemployment was decreasing. Subsequently, it appears that the trade-off worsened.

Data for the non-IT countries are shown in Figures 3 and 4.[11] For these countries there is no obvious counterpart to the date of the adoption of IT. For comparison purposes, the first quarter of 1993 is chosen since this was the median date on which the IT countries adopted their new monetary frameworks. Figure 3 suggests that the non-IT countries experienced a worsening of the unemployment-inflation trade-off; the expected inverse relationship seems to be non-existent or even positive. As discussed below, a major drawback of graphical Phillips curve analysis is that it is bivariate. In section IV, it is shown that once a multivariate approach is used, the unemployment-inflation trade-off has the correct sign before and after 1993.

Figure 5 shows the trends in inflation and unemployment for the 16 countries being examined. The individual country charts show that in all the countries (IT and non-IT) the unemployment-inflation relationship changed over time, after the adoption of inflation targeting for the IT countries and during the 1990s for the non-IT countries. Looking at individual countries indicates that the picture shown by the average inflation and unemployment rates are also evident in most of the individual countries.

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[9] This construction of "IT time" is similar to that used in Fischer and Sahay (2000) to construct "transition time" in a study of the transition economies.

[10] Schaechter and others (2000) discuss the timing of transition periods to full-fledged inflation targeting. In some of the emerging market countries they examine, this period lasted many years (e.g., Chile and Israel).

[11] Figures 3 and 4 look broadly similar if Germany, Japan, and the United States are excluded.

In summary, a preliminary look at the data suggests that on average the unemployment-inflation trade-off shifted in the OECD countries adopting IT. In addition, a similar development appears to be evident in the other OECD countries under examination. This graphical examination is consistent with the findings of empirical studies on the effects of CBI, as well as those in Bernanke and others (1999), in that it does not appear that there was an improvement in the unemployment-inflation trade-off. However, a major drawback to this graphical analysis is that it is bivariate and does not account for changes in other variables that may affect inflation. For example, Figures 6a and 6b illustrate two hypothetical shifts in a Phillips curve. In Figure 6a, the shift is a worsening of the trade-off with a small one-time shift down of the constant in the inflation-inverse unemployment relationship that could, for example, be brought about by a small impact effect of the adoption of IT on the inflation rate.[12] Figure 6b has an improvement in the trade-off but with a larger one-time shift down of the constant. Visually, it would seem that either one of these figures could characterize a scatter plot of the data points in Figure 1. The following sections therefore examine the shift in the Phillips curve more formally using multivariate analysis.

III. Model

In the literature on inflation, the three most commonly used approaches to modeling inflation are: the expectations augmented Phillips curve, the mark-up model, and the indicators model. In this paper, a Phillips curve model is estimated to formally test: (a) whether the trade-off between inflation and unemployment has changed significantly in countries that have adopted inflation targeting; and (b) whether the change in the trade-off in the IT countries is significantly different from that in the non-IT countries.

The version of the Phillips curve estimated is augmented by inflation expectations and the rate of growth in labor productivity:

$$\pi_t = \pi_t^e + \alpha_0 + \alpha_1 Invump_t + \alpha_2 Dlprod_{t-1} + u_t \qquad (1)$$

where π_t : actual rate of inflation;

π_t^e : expected rate of inflation;[13]

[12] In both figures, the equation used is inflation equals a constant plus a trade-off coefficient times the inverse of the unemployment rate. The trade-off coefficient starts at 20 and goes to 30 in the case of the improvement and 4 in the case of the worsening. The constant goes from 5 to 1 in the case of the improving trade-off and to 4½ with the worsening trade-off.

[13] In the empirical literature, the expected inflation variable sometimes has a coefficient different from unity. See, for example, DiNardo and Moore (1999) and Hutchinson and Walsh (1998).

Invump$_t$: the inverse of the unemployment rate; and
Dlprod$_{t-1}$: the lagged four-quarter difference in the log of average labor productivity.

For given inflation expectations and labor productivity, the trade-off between inflation and unemployment is governed by the parameter α_l, which is expected to be positive. This specification implies that the trade-off relationship is nonlinear. The nonlinearity is based on imperfections in both labor and product markets. As Phillips (1958) put it:

> "When the demand for labor is high and there are very few unemployed, we should expect employers to bid wage rates up quite rapidly, each firm and each industry being continually tempted to offer a little above the prevailing rates to attract the most suitable labor from other firms and industries. On the other hand, it appears that workers are reluctant to offer their services at less than the prevailing rates when the demand for labor is low and unemployment is high so that wage rates fall only very slowly."

The trade-off between unemployment and inflation can be inferred from the nonlinear relationship between unemployment and the rate of change of wage rates.[14]

A change in monetary policy regimes is expected to change the magnitude of α_l. As explained above, in the case where monetary policy lacks credibility, i.e., not perceived as devoted to fighting inflation, inflation inertia may persist, making the trade-off less favorable, as any inflation not eliminated today would potentially require more output contraction in the future. A credible monetary policy with a clear commitment to controlling inflation may improve the trade-off, to the extent that price and wage setting/adjustment depends on beliefs about future economic conditions and becomes more rapid.

In some Phillips curve models, the discrepancy between the actual unemployment rate and the natural unemployment rate, rather than the actual unemployment rate itself, is used as an explanatory variable. The difference between the two approaches is that the former implies a time-varying natural rate, whereas the latter, as specified in equation (1), assumes that the natural rate is a constant and hence will be reflected in the constant term of the equation. While the assumption of a constant natural rate of unemployment may be restrictive, the formulation in equation (1) avoids the explicit identification and estimation of this variable. This assumption, however, is relaxed in the application of the STR model in Section IV, although we do not explicitly calculate the natural rate of unemployment.

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[14] As mentioned, alternative explanations of the nonlinearity can be found in Ball and others (1988) and Hutchison and Walsh (1998). Debelle and Laxton (1997) provide evidence of convexity in the Phillips curves for Canada, the United Kingdom, and the United States for the period 1972–94.

Policy changes are also likely to affect expected inflation. In part, the impact effect of a disinflation on unemployment will depend on how inflation expectations are formed and how expected inflation adjusts. A central bank that has established its credibility will be able to pursue a disinflation policy with a smaller decline in output or a smaller increase in unemployment because the expected rate of inflation will be lowered if disinflation is expected. In other words, a disinflation policy widely believed by the public will cause a downward shift in the Phillips curve. This "credibility bonus" is likely to occur sometime after the introduction of inflation targeting.

In estimating equation (1), we consider three alternative specifications of inflation expectations. First, the expected inflation rate may be approximated by a weighted average of past inflation rates, or the expected inflation rate in each period is adjusted by a portion of the discrepancy between actual and expected inflation rate in the previous period:

$$\begin{aligned}\pi_t^e &= \pi_{t-1}^e + \gamma(\pi_{t-1} - \pi_{t-1}^e) \\ &= \gamma\pi_{t-1} + \gamma(1-\gamma)\pi_{t-2} + \gamma(1-\gamma)^2\pi_{t-3} + \cdots \end{aligned} \tag{2}$$

where $0 < \gamma \leq 1$ is the speed of adjustment. This specification may be appropriate for the non-IT countries for the entire estimation period. It may also apply to IT countries, with the speed of adjustment parameter, γ, not necessarily being the same before and after the introduction of IT. An unrestricted version of this equation is:

$$\pi_t^e = (A(L)\pi_t)'\beta = \sum_{j=1}^{p} \beta_j \pi_{t-j} \tag{2a}$$

where $A(L)$ is a lag polynomial. In the unrestricted specification, expectations are still backward-looking, reflecting the inertia in the inflation process, but are not restricted to follow an exponentially declining pattern.

Second, for inflation targeting countries where the central bank has established its credibility, the expected rate of inflation could be equal to the inflation target, π_t^*, announced by the central bank. Therefore,

$$\pi_t^e = \pi_t^* \tag{3}$$

Third, for inflation targeting countries where the central bank is still in the process of establishing its credibility, inflation expectations could be influenced by past inflation rates and by the reaction to the inflation target. A possible form of this mixture of backward-looking and forward-looking inflation expectations would be a weighted average of (2) and (3):

$$\pi_t^e = (1-\phi)[\pi_{t-1}^e + \gamma(\pi_{t-1} - \pi_{t-1}^e)] + \phi\pi_t^* \tag{4}$$

where $0 \leq \phi \leq 1$. As the inflation targeting central bank becomes more credible, ϕ would be expected to move towards one. An unrestricted version of this equation can be formulated by replacing the expression of (2) by 2(a):

$$\pi_t^e = (1-\phi)\sum_{j=1}^{p} \beta_j \pi_{t-j} + \phi \pi_t^* \tag{4a}$$

In equation (1), we hypothesize also that productivity could influence inflation, with α_2 measuring the effect of the rate of change of productivity. A higher rate of increase in labor productivity may increase the rate of change of money wage rates, with a lag, because employers may be more willing to grant wage increases and workers are in a better position to bargain for wage increases. The rate of increase in labor productivity, therefore, captures part of the increase in the rate of change of money wage rates that is not explained by labor market tightness or aggregate demand pressures. Of course, the increase in the rate of change of money wage rates has a positive impact on inflation in the short run. In the long run, however, a higher rate of increase in labor productivity, in excess of the rate of change of money wage rates, lowers unit labor costs and therefore will likely have a negative impact on inflation.[15]

The Phillips curve model, as presented in this section, has the advantage of being useful for forecasting inflation and for providing a framework for policy. In particular, it shows the short-run trade-off between unemployment (output) and inflation that could serve as a basis on which monetary policy could respond to output fluctuations while adopting inflation targeting. This approach omits variables which are considered explicitly in the other two approaches, such as unit labor costs, import prices, the exchange rate, commodity price indices, interest rate spreads, and monetary growth. These variables, however, assist inflation forecasts over different horizons. Of course, depending on the purposes, two or all approaches could be combined in a multi-equation model, from which a reduced-form equation for inflation could be derived. The main purpose of this paper, however, is not to establish an ideal inflation equation, but rather to test how the unemployment-inflation relationship is affected by inflation targeting.

[15] Ball and Moffitt (2001) use the difference between productivity growth and an average of past real wage growth as an explanatory variable in the Phillips curve equation to explain the shift in the unemployment-inflation relationship in the U.S. since 1995. They argue that workers' "wage aspirations" adjust slowly to shifts in productivity growth, and that a rise in productivity growth relative to wage aspirations has a negative effect on inflation.

IV. EMPIRICAL RESULTS

1. Estimation of equation (1) and tests for structural breaks

We use equation (1) to estimate the relationship between average inflation and average unemployment. The data are the averages for the countries in each group and measure the average inflation and unemployment rates at quarter t = 1, 2, … prior to and post introduction of inflation targeting.[16] The estimation spans the symmetric period {T-24,…,T,…T+24} around the introduction of IT for each individual country. For the non-IT countries, 1993:Q1 is used for T.[17] In the empirical tests, we add a trend variable (*Trend*) to equation (1). This variable is intended to capture the drift in inflation over the sample period, accounting for any nonstationarity in the data.[18]

1(a) IT Countries: Pre- and Post-IT

In Table 1, we present estimates of the unemployment-inflation relationship for the IT countries. An interaction variable, defined as a dummy variable multiplied by the variable of

[16] The data used are seasonally adjusted. It is well known that the properties of seasonally adjusted series may differ from those of the original data, generating different dynamic responses and possibly nonlinear behavior in an otherwise linear process. Further, if seasonal patterns are changing over time, seasonally adjusted data may mask the inherent dynamics of the data generation process. On the other hand, estimation results based on unadjusted data may be distorted if the seasonal dynamics are not modeled adequately. Given the averaging transform employed and the greater availability of seasonally adjusted data, modeling the dynamics of "average" seasonality seemed less attractive than focusing on average trend-cycle dynamics from seasonally adjusted data. The modeling of seasonal dynamics would more than likely be necessary if individual country estimations were undertaken.

[17] Given the point made above that the transition to full-fledged inflation targeting took a considerable period of time in some countries, the data were examined to test whether an earlier choice of T could be justified. Equation (1) was estimated for T equal to 4 and 8 quarters prior to the introduction of IT. A comparison of the three regressions supported the choice of the quarter in which IT was introduced as the most appropriate break between the pre- and post-IT regimes.

[18] Initial analysis of the variables suggests that all inflation variables, except for the United Kingdom and the United States, are integrated of order one, I(1). This would suggest modeling the unemployment-inflation relationship in first differences as opposed to levels. However, the short span of the data and the structural changes that took place could suggest low power against linear alternatives. Specifically, nonlinear models may look like integrated processes when subject to structural shifts or outliers. We therefore assume that the data are globally stationary but possibly nonlinear and locally nonstationary (see, for example, Skalin and Terasvirta (2001)).

interest, is used to test for the significance of structural breaks between the pre- and post-IT periods in the trend and in the effect of unemployment on inflation. These breaks can be interpreted as occurring when the coefficients on the interaction terms are significant.

In Table 1, Model 1A restricted, post-IT expectations are modeled as in equation (3) and as in equation (2) for the pre-IT period, with the coefficient on the inflation targets variable restricted to equal one.[19] The imposed restriction implies that the inflation targets were fully credible immediately after the introduction of inflation targeting. We examine that restriction below by assuming, as an alternative, that inflation targets were not fully credible; in addition, we examine the relationship for evidence of constant parameters, alternatives being abrupt shifts and a smooth transition after the introduction of inflation targeting.
In Model 1B restricted, expectations are modeled as in equation (2) in the pre-IT period and as equation (4) in the post-IT period. While the results are very similar, Model 1B restricted performs better than Model 1A restricted, based on the log likelihood statistic. However, both equations display evidence of serial correlation and heteroscedasticity (ARCH) in the residuals.

Looking at Model 1B restricted, there is a significant downward shift of the trend term (by –0.20) indicating that the average rate of inflation fell significantly in the post-IT period. There was a significant change in the inflation-inverse unemployment relation (by 0.68) supporting the contention that the credibility enhancing effects of IT improve the unemployment-inflation trade-off.[20] The value of the coefficient on the inflation target, 0.61, which is ϕ in equation (4), indicates that after the adoption of IT the inflation targets played a very significant role in the formation of inflation expectations. It also indicates that the inflation targets were not fully credible. Finally, the coefficient on the productivity term is positive indicating that, at least for the short run, improving productively did not lower inflation on average in these countries. It should be noted, of course, that the results for Models 1A and 1B restricted in Table 1 relate to the specific expectations formation variables used and do not necessarily represent the exact relationship for individual countries.

A problem with Models 1A and 1B restricted is that they are corner solutions of a grid search used to define the lag structure.[21] With one lag, economic agents are assumed to be very myopic and we have no way of distinguishing whether the model was obtained from an

[19] An unrestricted estimation yields a coefficient of 0.9, which was not significantly different from unity.

[20] Evaluated at the sub-sample means, the inflation unemployment trade-off improves from –0.5 in the pre-IT period to –0.8 in the post-IT period.

[21] Starting from a maximum of 12 lags, a grid search was used to define the lag structure of the expectations variable; the minimum Akaike Information Criterion (AIC) was used to choose among alternatives. The results show that inflation lagged for one period fit the equation best.

exponentially declining lag or from a first order autoregressive process. Further, these models exhibit residual serial correlation. We examine the impact of the corner solution on our results by estimating Models 1A and 1B unrestricted, replacing equation 2 by equation 2a and equation 4 by 4a. In these models, we replace the exponentially declining lag structure by an unrestricted autoregressive polynomial, with a maximum of twelve lags, and choose the model that minimizes the AIC. The results (Models 1A and 1B unrestricted) show significant improvements over their restricted counterparts. More importantly, the results—significant downward shift of the trend term and improvement in the unemployment-inflation trade-off—obtained in the restricted models are maintained.[22]

1(b) Comparison between IT and non-IT countries

As shown in Figures 1 and 3, thc experiences of the IT countries and the non-IT countries appear to have been different over the period under examination. Thus it would be interesting to compare the estimates in Table 1 with similar estimates for the non-IT countries. However, the specifications used in Table 1, with inflation expectations modeled using the inflation targets, are not applicable to the non-IT countries. For the non-IT countries, the specification of equation (2) is relevant for the entire period. To establish a basis for comparison, an estimate of equation (1), using inflation expectations as in equation (2), is given for both groups of countries in Table 2. Model 2A shows the results for the IT countries. As in Table 1, "restricted" refers to the exponentially declining model and "unrestricted" to an autoregressive polynomial. While Models 1A and 1B in Table 1 perform significantly better than the models in Table 2, based on the log likelihood statistics, the estimates for Models 1A and 2A are not very different qualitatively. There is still a significant improvement in the unemployment-inflation trade-off in the post-IT period. Only the sign of the effect of the trend switches and this coefficient is very near zero and not significant, in any case.

Estimates of equation (1) using inflation expectations as in equation (2) are given for the non-IT countries in Model 2B. It is clear that in the case of the non-IT countries, the estimated equation performs less well than for the IT countries. However, the primary purpose of this paper is to examine the unemployment-inflation relationship in the IT countries. The estimates for the non-IT countries are meant only for comparison purposes. Nevertheless, it is interesting that there are several differences between the country groups. For example, the improvement in the unemployment-inflation trade-off is maintained for the IT countries; for the non-IT countries, inverse unemployment is not significant and the coefficient for that variable does not increase significantly in the post-IT period. Also, the lag polynomial for the non-IT countries is much shorter and the sum of coefficients for lagged inflation higher than that for the IT countries. This suggests that for a given change of inflation expectations based on lagged inflation in the two groups, the impact on current inflation would be stronger in the non-IT countries. The productivity term is very close to

[22] For Model 1B, the unemployment-inflation trade-off improves from –0.3 in the pre-IT period to –0.6 in the post-IT period.

zero for the non-IT countries and of marginal significance; in contrast, it is positive and significant for the IT countries.

The estimates of Table 1 suggest that inflation expectations in the IT countries are significantly based on lagged inflation in the pre-IT period and on the inflation targets in the post-IT period.[23] Corbo and others (2000) find similar results. This finding could be interpreted as suggesting that IT is successful at providing a nominal anchor for these countries. The results further indicate that there may have been some transition period when the inflation targets were not fully credible. Figure 1 also suggests that there was some transition period between the pre- and post-IT regimes. In the next subsection, a STR model is developed for the IT countries, which includes the single structural shift as a special case.

2. Smooth Transition Regression Models

The models in the previous section for the IT countries assume that the inflation process can be modeled as two linear trends with a switch occurring at the exact introduction of inflation targeting. It is more likely that the aggregate reaction of economic agents to inflation targeting will be more smooth, leading to a less than abrupt change in their underlying behavioral parameters. This type of process is better modeled by assuming that the parameters of the underlying process evolve continuously, allowing a smooth transition between regimes.

STR models are a general class of state-dependent nonlinear time series models that can account for deterministic changes in parameters over time, in conjunction with regime switching behavior (see survey in van Dijk and others (2001)). The STR model can be viewed as a weighted average of two linear models, with weights determined by the value of a transition function, typically defined as either a logistic or an exponential function.[24]

The STR model of order r, for variable z, is: $y_t = \beta_t'\tilde{x}_t + \theta'\tilde{x}_t F(z_t;\gamma,c) + \mu_t$, where $\tilde{x}_t$ is a vector of exogenous variables; z_t is the transition variable and may include a linear combination of several variables; F is the transition function; γ measures the speed of

[23] The coefficient on the inflation targets remains significant when this variable replaces the weighted average of lagged inflation and inflation targets in the post-IT period.

[24] The logistic smooth transition regression (LSTR) is $F(z_{t-d};\gamma,c) = \left[\left(1+\exp\left\{-\gamma\left(z_{t-d}-c\right)\right\}\right)^{-1} - \frac{1}{2}\right]$ and the exponential smooth transition regression (ESTR) is $F(z_{t-d};\gamma,c) = \left[1-\exp\left\{-\gamma\left(z_{t-d}-c\right)^2\right\}\right]$.

transition from one regime to the next; and c is the location variable (threshold) for the transition function. As γ becomes very large, the change of $F(z_t;\gamma,c)$ from 0 to 1 becomes almost instantaneous at $z_t = c$, and the transition function approaches the indicator function $I[z_t > c]$. Thus, the STR model includes threshold as well as intercept and coefficient shift models as special cases, for suitably defined transition functions or parameter restrictions. For example, consider the single variable version of the interaction model of Table 1:

$$\begin{aligned} y_t &= \alpha + \gamma D_t + \beta x_t + \delta x_t D_t + \varepsilon_t \\ &= (\alpha + \beta x_t) + (\gamma + \delta x_t) D_t + \varepsilon_t \end{aligned} \tag{5}$$

This model can be interpreted as an STR formulation with $F(\cdot) = D_t$ a dummy variable reflecting a discontinuous jump; in equation (5), $\gamma = \delta = 0$ defines the constant coefficient linear model.

We follow the specific-to-general modeling strategy of Lundbergh and others (2000) in estimating the smooth transition model. The modeling cycle has the following features. First, test linearity of a tentative model against smooth transition alternatives. If the test does not reject, accept the linear model. If the test rejects, estimate the model for which the rejection is the strongest. Evaluate the estimated model for misspecification. If the model fails the misspecification tests, an extended model may need to be estimated and evaluated.[25]

The details of the results of the modeling procedure are reported in the Appendix. In summary, the model presented in Table 3 is chosen. This model appears to be an adequate characterization of the inflation process: the coefficients are interpretable and significant, and the residual diagnostics do not reject any of the standard tests for model misspecification.

Relative to the linear and segmented regression model (Model 1B) for the IT-countries, the STR in Table 3 reduces the estimated standard error by 42 percent.[26] The trend coefficient in Table 3, evaluated at the pre-IT mean of the transition functions, has the same sign and size as in Model 1B unrestricted; for the post-IT period, both models show a significant change in magnitude and sign of the trend coefficient, although the magnitude effect is larger for Model 1B. In contrast, the STR model exhibits a larger inflation response for both productivity and inflation target variables. We also observe that the impact of the inflation

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[25] The modeling methodology can be found in Terasvirta (1994) and Lundbergh and others (2000); misspecification tests are described in Terasvirta (1998).

[26] As an alternative benchmark, we estimated Model 1B as an STR, with *Trend* as the transition variable. The STR model reduced the standard error by 15 percent; the speed of transition was estimated at 11.5 and the threshold parameter at 0.54, about one quarter after the adoption of IT.

targets variable on inflation is full (approximately unity) only when both inflation and productivity transition functions are in their upper regimes. Evaluated at the post-IT mean of the transition functions, the coefficient on the inflation targets in Table 3 is the same (0.37) as for Model 1B. Conversely, when inflation is approximately equal to its expected or threshold value and productivity is at "normal" levels, the impact of inflation targets on inflation is minimal. This, in part, helps explain the sharp fall in inflation after the adoption of IT and the flattening of the inflation response as inflation is lowered.

As regards the unemployment-inflation trade-off, the results in Table 3 show that the impact of unemployment on inflation varies in magnitude from zero to 0.6, depending on whether we are in the lower or upper regimes of the transition functions. In contrast to Model 1B where the slope coefficient in the post-IT period increases relative to the pre-IT period, the unemployment variable does not enter the linear part of the inflation function; instead, it interacts nonlinearly with the productivity and inflation transition functions. This implies that the maximum response will occur when the forcing variables are far from their threshold levels (in their outer regimes). As the forcing variables revert to their normal levels, the trade-off reduces and the unemployment-inflation relationship flattens. Research findings of a breakdown in the Phillips curve may well be due to a time-varying or nonlinear relationship that is dependent on a set of forcing variables, in our case, lagged inflation and productivity.

To illustrate the effect on the unemployment-inflation trade-off, Figure 7 shows the unemployment-inflation elasticities (trade-off) for both the STR model (Figure 7(a)) and Model 1B (Figure 7(b)). Both figures show an improvement in the trade-off in the post-IT period, indicating lower unemployment (output) costs to disinflation. However, the STR model indicates that the improvement in the trade-off is not immediate, occurring about 8 quarters after the adoption of inflation targeting. Similarly, Bernanke and others (1999) find that inflation expectations are slow to fall to ranges established for official inflation targets.

V. Discussion

This paper examined the impact of the adoption of inflation targeting on the unemployment-inflation trade-off in seven OECD countries. This examination was conducted by estimating Phillips curve models for combined country averages, explicitly modeling the change in the formation of inflation expectations before and after the adoption of inflation targeting.[27] For the pre-inflation targeting period, the empirical results supported the modeling of inflation expectations as backward looking, depending on lagged inflation. For the period

[27] The modeling of deseasonalized average country data smoothens out some of the individual country variation both with respect to underlying behavioral relationships and to potentially different and changing seasonal patterns. Our results can be viewed as representative of the experience of OECD countries that have adopted inflation targeting, based on trend-cycle data, and as a benchmark for individual country studies.

after the adoption of inflation targeting, the results supported a model of inflation expectations as both forward and backward looking, depending on official inflation targets as well as lagged inflation. These results suggest that the adoption of inflation targeting has indeed enhanced the credibility of the adopting central banks since inflation expectations became at least partially forward looking, based on official targets.

The empirical results also indicated that on average the unemployment-inflation trade-off improved in OECD countries subsequent to the adoption of inflation targeting. In other words, disinflations subsequent to the adoption of inflation targeting on average were associated with smaller increases in unemployment. This result confirms the implications of theoretical models where a central bank that credibly commits to an inflation-fighting rule faces an improved trade-off between unemployment and inflation. The findings of this paper are consistent with Corbo and others (2000) who found preliminary evidence that the adoption of inflation targeting may have contributed to lowering the output costs of inflation stabilization.

At first glance, the results in this paper appear to be in contrast to those of Bernanke and others (1999) who did not find that inflation targeting had a significant impact on the output-inflation trade-off. However, a smooth transition model was used in this paper to examine the dynamics of the adoption of inflation targeting. It was found that immediately after inflation targeting is adopted, the trend in the unemployment-inflation trade-off is maintained, but it begins to flatten. However, the trade-off then improves significantly over time as the credibility of the new policy is established. From this perspective, the results in this paper do not contradict those of Bernanke and others (1999) since their study examined only a relatively short period after the adoption of inflation targeting while this paper looked at a period of six years after IT adoption.

As noted in Bernanke and others (1999), achieving disinflation is hard work. The results in this paper do not deny this inescapable fact. However, part of the work is the fight to establish credibility. The results here suggest that the adoption of inflation targeting may make some parts of the job easier if central bankers are able to convince markets of their commitment to the fight against inflation. Of course, establishing credibility takes time.

An unanswered question is whether inflation targeting would be a successful strategy for countries starting with inflation significantly above OECD levels, even if it is correct that inflation targeting improved the unemployment-inflation trade-off in a group of OECD countries that already had relatively low inflation by emerging market standards. As explored by Khan and Senhadji (2000), the relationship between growth and inflation may be substantially different in developing and industrial countries, i.e., negative effects of inflation on growth may set in at a substantially higher inflation threshold in developing countries. In addition, at higher levels of inflation the monetary transmission mechanism is likely to react to changes in inflation with shorter lags than at low inflation rates. This suggests that in future research it may be useful to study the effects of credibility and monetary policy separately in the emerging market countries now adopting inflation targeting.

Table 1: Regression Results for the Restricted and Unrestricted Models: Inflation Targeting Countries

	Model 1A		Model 1B	
Independent Variable	**Restricted (Eqns. 1, 2, and 3)**	**Unrestricted Eqns. 1, 2(a), and 3**	**Restricted (Eqns. 1, 2 and 4)**	**Unrestricted (Eqns. 1, 2, and 4(a)**
Constant	**-2.74**	**-2.67**	**-1.99**	**-0.72**
	(-7.63)	(-6.94)	(-4.46)	(-1.22)
π_{t-1}	**0.49**	**1.13**	**0.56**	**1.29**
	(5.97)	(4.76)	(7.67)	(8.89)
π_{t-2}	-	**-0.62**		**-0.75**
	-	(-1.45)		(-3.16)
π_{t-3}	-	**-0.19**		**0.33**
	-	(-0.45)		(1.32)
π_{t-4}	-	**0.31**		**-0.67**
	-	(1.57)		(-2.62)
π_{t-5}	-	-		**0.75**
	-	-		(2.97)
π_{t-6}	-	-		**-0.31**
	-	-		(-1.97)
Trend	**0.02**	**0.02**	**0.01**	**0.01**
	(2.03)	(2.07)	(0.87)	(1.54)
*Trend*Dum*	**-0.22**	**-0.22**	**-0.20**	**-0.15**
	(-8.99)	(-9.79)	(-6.70)	(-6.03)
$Invump_t$	**0.40**	**0.33**	**0.32**	**0.19**
	(8.65)	(7.30)	(6.74)	(4.89)
$Invump_t$*Dum*	**0.70**	**0.75**	**0.68**	**0.49**
	(8.01)	(8.68)	(7.52)	(5.70)
$Dlprod_{t-1}$	**0.04**	**0.03**	**0.04**	**0.03**
	(2.17)	(1.93)	(2.52)	(2.31)
π^*	**1.0**	**1.0**	**0.61**	**0.37**
			(3.50)	(3.01)
Diagnostic Statistics				
Std. Error	0.293	0.262	0.281	0.209
Log-Likelihood	-5.52	1.624	-2.952	14.803
AIC	0.511	0.342	0.447	-0.074
DW	1.06	1.39	1.08	1.82
L-BQ(4)	36.18 (p=0.00)	14.80 (p=0.05)	35.64 (p=0.00)	7.58 (p=0.11)
L-BQ²(4)	13.55 (p=0.01)	7.69 (p=0.10)	11.16 (p=0.025)	1.93 (p=0.75)
Skewness	-0.67	-0.99	-0.44	0.07
Kurtosis	3.46	3.76	3.67	3.65
JB	4.06 (p=0.13)	9.22 (p=0.01)	2.49	0.91
FLMSC(4)	8.00 (p=0.00)	3.42 (p=0.02)	7.69 (p=0.00)	3.23 (p=0.02)
FARCH(4)	9.11 (p=0.00)	2.60 (p=0.05)	3.93 (p=0.01)	0.39 (p=0.81)
$\sum \pi_{t-j}$	0.50	0.63	0.56	0.64

Note: AIC is the Akaike Information Criterion, L-B(Q4) and L-B($Q^2$4) are the Lung-Box tests for the residuals and squared residuals, JB is the Jarque-Bera test for normality, FLMSC(4) is the F-version of the Lagrange multiplier test for serial correlation, and FARCH is the F-version of the for autoregressive conditional heteroscedasticity. $\Sigma\pi$ is the sum of the lagged inflation terms.

Table 2: Regression Results for the Restricted and Unrestricted Models: Inflation Targeting and Non-Targeting Countries

	Model 2A (IT countries)		Model 2B (non-IT countries)	
Independent Variable	**Restricted**	**Unrestricted**	**Restricted**	**Unrestricted**
Constant	**-0.97**	**0.31**	**0.03**	**0.24**
	(-2.74)	(0.56)	(0.04)	(0.34)
π_{t-1}	**0.62**	**1.29**	**0.71**	**0.72**
	(9.61)	(9.20)	(6.29)	(4.88)
π_{t-2}		**-0.72**		**-0.12**
		(-3.47)		(-0.62)
π_{t-3}		**0.34**		**0.31**
		(1.62)		(1.63)
π_{t-4}		**-0.69**		**-0.15**
		(-3.30)		(-1.03)
π_{t-5}		**0.85**		-
		(4.00)		-
π_{t-6}		**-0.42**		-
		(-3.11)		-
Trend	**-0.01**	**0.003**	-0.01	**-0.01**
	(-0.65)	(0.34)	(-1.81)	(-1.39)
Trend*Dum	**-0.14**	**-0.11**	**-0.02**	**-0.01**
	(-4.19)	(-4.08)	(-1.21)	(-0.36)
Invump$_t$	**0.22**	**0.12**	**0.08**	**0.06**
	(6.20)	(3.53)	(1.55)	(0.87)
Invump$_t$*Dum	**0.56**	**0.37**	**0.05**	**0.03**
	(4.69)	(3.93)	(1.55)	(0.61)
Dlprod$_{t-1}$	**0.05**	**0.04**	**-0.01**	**-0.01**
	(3.04)	(2.97)	(-1.51)	(-1.21)
Diagnostic Statistics				
Std. Error	0.314	0.235	0.194	0.194
Log-Likelihood	-9.027	8.324	14.69	16.42
AIC	0.654	0.150	-0.314	-0.262
DW	0.96	1.75	2.04	1.86
L-BQ(4)	22.37	2.42 (p=0.65)	11.25 (p=0.02)	6.09 (p=0.19)
L-B Q^2(4)	4.63 (p=0.33)	3.17 (p=0.53)	5.83 (p=0.21)	5.00 (p=0.29)
Skewness	-0.36	0.51	0.17	0.16
Kurtosis	3.78	4.05	3.35	3.05
JB	2.29	4.34 (p=0.11)	0.48 (p=0.79)	0.22
FLMSC(4)	5.45 (p=0.001)	1.53 (p=0.22)	3.23 (0.02)	1.92 (p=0.13)
FARCH(4)	1.26 (p=0.30)	0.75 (p=0.57)	1.28 (p=0.29)	1.15 (p=0.35)
$\sum \pi_{t-j}$	0.62	0.63	0.71	0.77

Note: AIC is the Akaike Information Criterion, L-B(Q4) and L-B($Q^2$4) are the Lung-Box tests for the residuals and squared residuals, JB is the Jarque-Bera test for normality, FLMSC(4) is the F-version of the Lagrange multiplier test for serial correlation, and FARCH is the F-version of the for autoregressive conditional heteroscedasticity. $\Sigma\pi$ is the sum of the lagged inflation terms.

Table 3: Transition Functions – Lagged Inflation and Productivity

$$\pi_t = \underset{(6.54)}{6.58} + \underset{(3.96)}{0.38}\pi_{t-1} + \underset{(3.02)}{0.39}\pi_{t-3} - \underset{(3.22)}{0.57}\pi_{t-4} + \underset{(1.47)}{0.15}\pi_{t-5} - \underset{(7.47)}{0.17}\,Trend + \underset{(4.86)}{0.06}\,Dlprod_{t-1}$$

$$+\left(-\underset{(7.79)}{7.22} - \underset{(5.60)}{0.72}\pi_{t-2} + \underset{(4.71)}{0.61}\pi_{t-4} + \underset{(8.02)}{0.13}\,Trend + \underset{(12.51)}{0.30}\,Invump_t + \underset{(6.81)}{0.53}\pi_t^*\right) * F(\pi_{t-6})$$

$$+\left(-\underset{(8.99)}{9.86} + \underset{(1.79)}{0.25}\pi_{t-2} - \underset{(1.96)}{0.32}\pi_{t-4} + \underset{(6.59)}{0.90}\pi_{t-6} + \underset{(5.44)}{0.10}\,Trend + \underset{(12.51)}{0.30}\,Invump_t + \underset{(6.81)}{0.53}\pi_t^*\right) * F(Dlprod_{t-1})$$

$$F(\pi_{t-6}) = \left[1 - \exp\left\{-\underset{(7.24)}{0.69}.\sigma_{\pi_{t-6}}^{-1}(\pi_{t-6} - \underset{(34.77)}{3.65})^2\right\}\right]$$

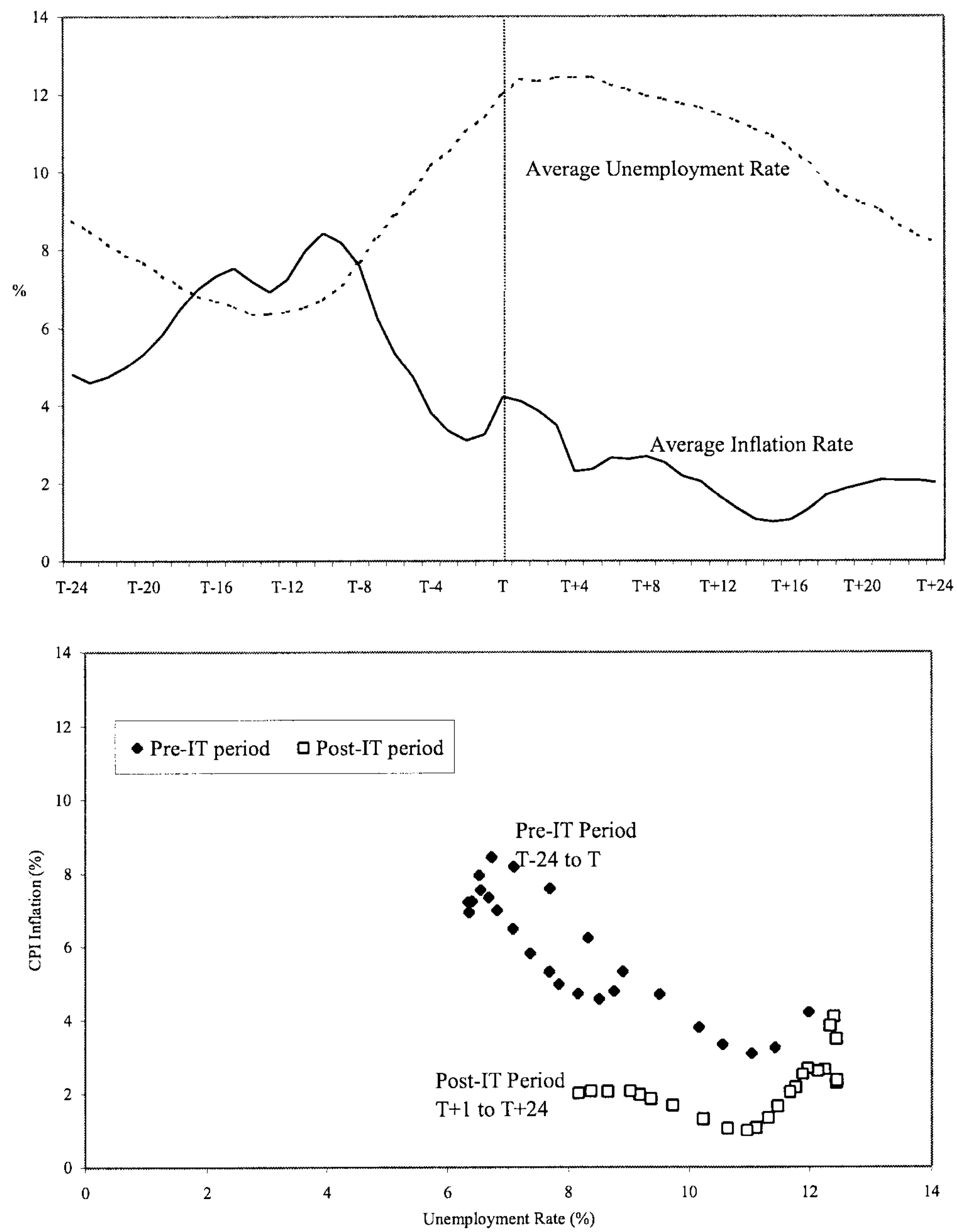
$$F(Dlprod_{t-1}) = \left[1 - \exp\left\{-\underset{(4.53)}{0.37}.\sigma_{Dlprod_{t-1}}^{-1}(Dlprod_{t-1} - \underset{(7.07)}{1.44})^2\right\}\right]$$

Log-likelihood = 48.35; Std. Error =0.1215; Q(5)=2.69 (0.75); $Q^2(5)$*=3.31 (0.65);*
SK = -0.23; KT =2.0; JB =2.52 (0.28); FLMSC(2) =0.86 (0.44); FLMSC(5) =0.32 (0.89);
FARCH(2) =0.08 (0.92); FARCH(5) = 0.51 (0.77); PCALL = 0.64 (0.76); BDS = 0.01 (0.37)
RNL(Invump)= 0.55 (0.83); RNL (π_{t-4}) *= 2.42 (0.05);* σ_{NL}/σ_L *= 0.58*

Note: *Q(k)* and $Q^2(k)$ are the Lung-Box statistics for *k* autocorrelations of the residuals and the squared residuals, respectively; *JB* is the Jarque-Bera test for normality, with *SK* and *KT* denoting skewness and kurtosis; *FLMSC(p)* and *FARCH(p)* test for serial correlation and autoregressive conditional heteroscedasticity up to *p* lags, respectively; *PCALL* is the test for constant parameters (all estimated parameters with first-order trend term); *RNL(z)* tests for remaining nonlinearity in variable *z*. *BDS* is a test for residual independence – p-value is based on the bootstrap estimate at embedding dimension of 3; and σ_{NL}/σ_L is the ratio of the standard error of the nonlinear and linear models.[28] Numbers in parentheses in the equation are t-statistics and numbers in parentheses in the diagnostics section refer to p-values.

[28] The tests for parameter constancy and remaining nonlinearity are based on $\varepsilon_t = \left(\partial y/\partial\alpha\right)'\varphi + \beta_1 x_t z_t + \beta_2 x_t z_t^2 + \eta_t$, where $\partial y/\partial\alpha$ are the derivatives of the mean function with respect to the parameters and z_t is either trend (parameter constancy) or other variable in the mean function (remaining nonlinearity). Higher powers of z_t were not included because of limited degrees of freedom. The null hypotheses are: $H_{02}: \beta2=0$ and $H_{01}: \beta1=0|\beta2=0$. We report statistics for H_{01}.

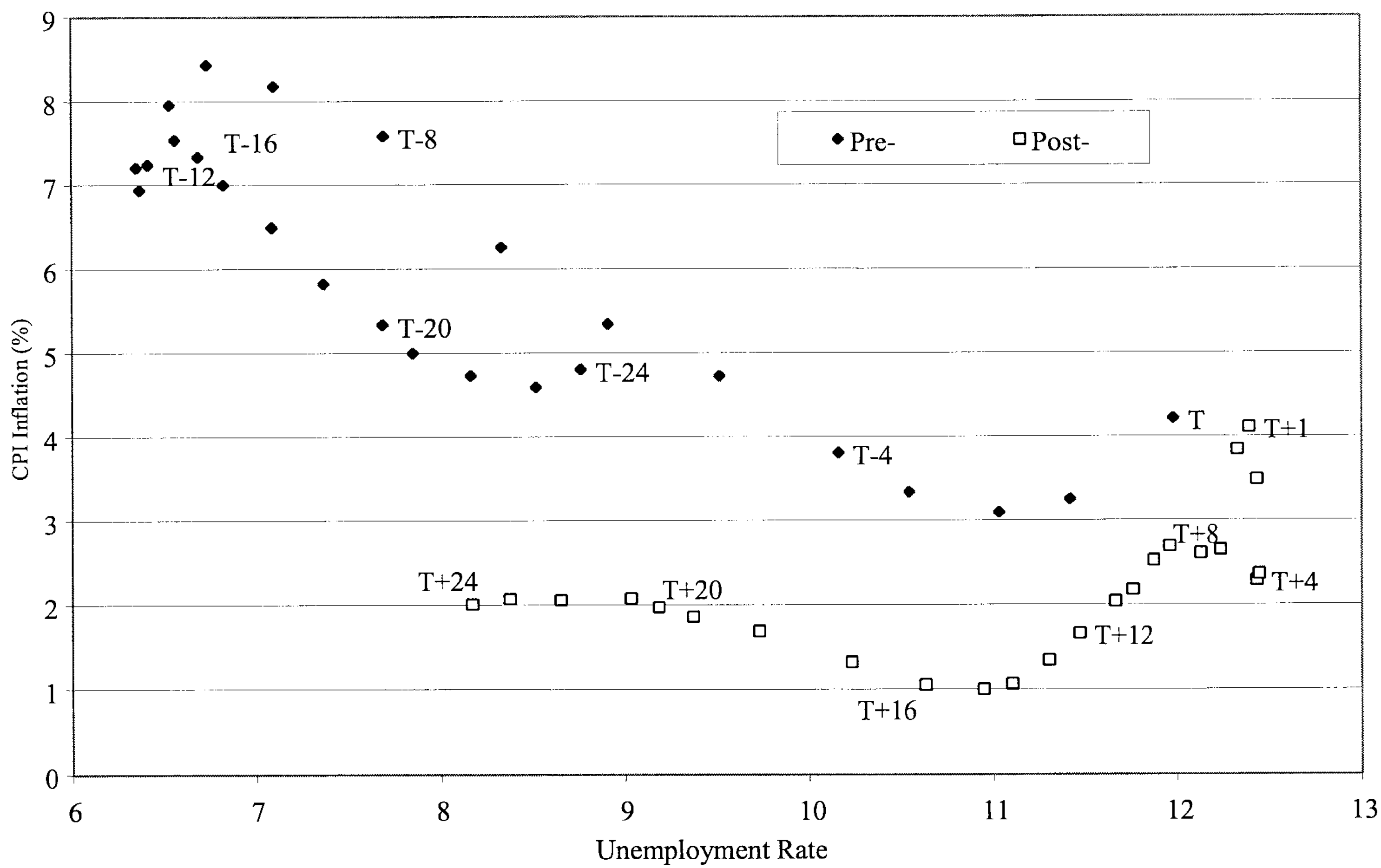
Figure 1. Inflation Targeting Countries: Unemployment and Inflation Averages Pre- and Post-IT



Source: Datastream, International Monetary Fund and Organization for Cooperation and Development. Inflation-targeting countries include Australia, Canada, Finland, New Zealand, Spain, Sweden and United Kingdom.

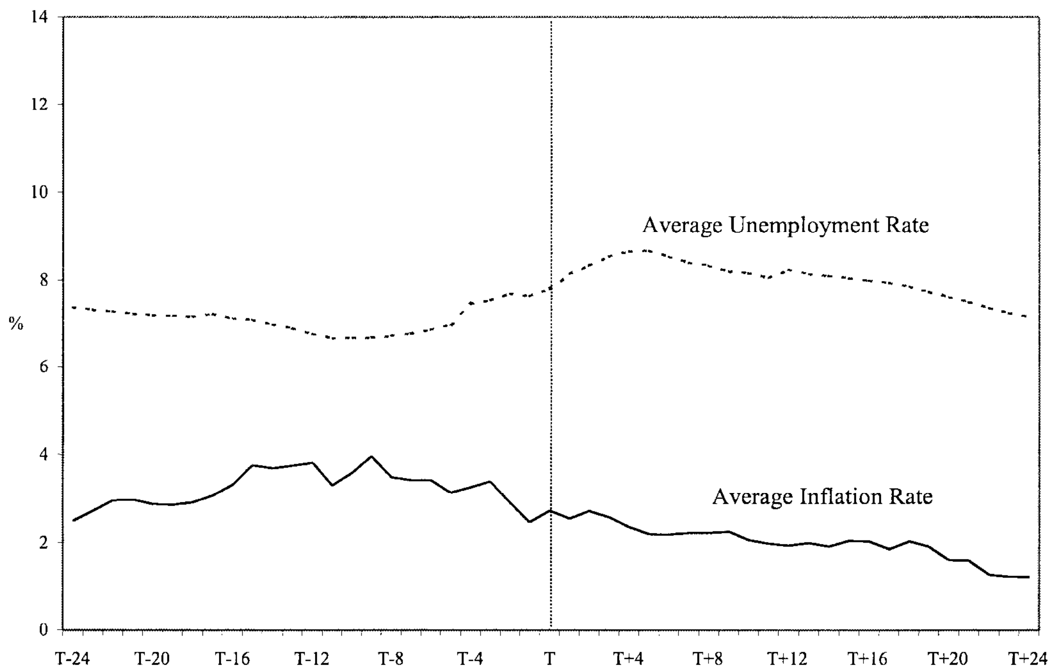
T is defined as the quarter in which inflation targeting was adopted.

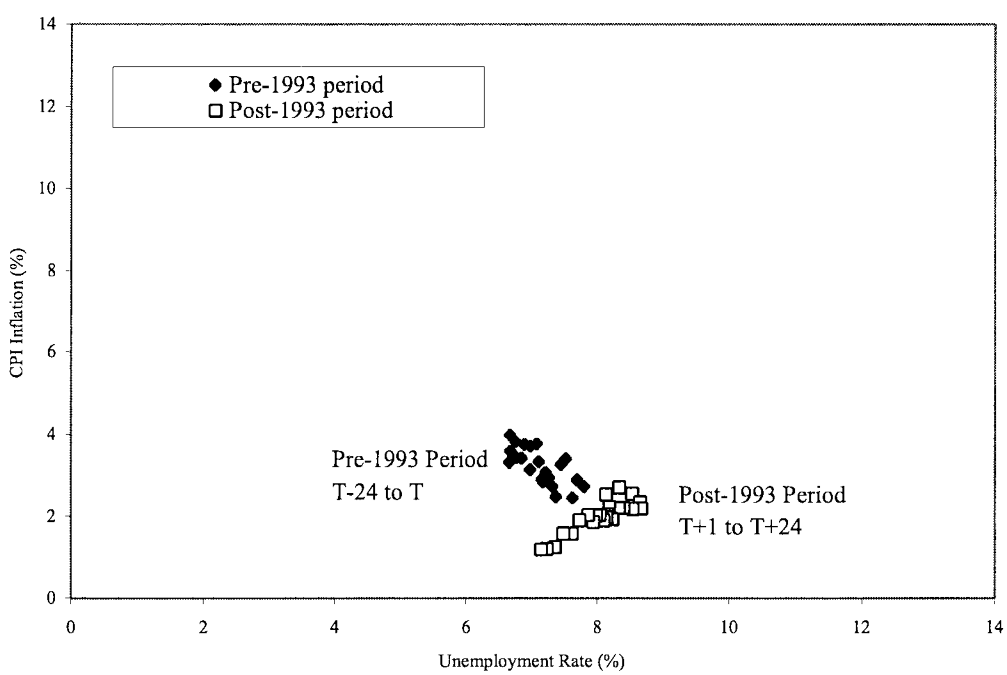
Figure 2. Inflation Targeting Countries: Time Path of Unemployment and Inflation Averages



T is defined as the quarter in which inflation targeting was adopted.

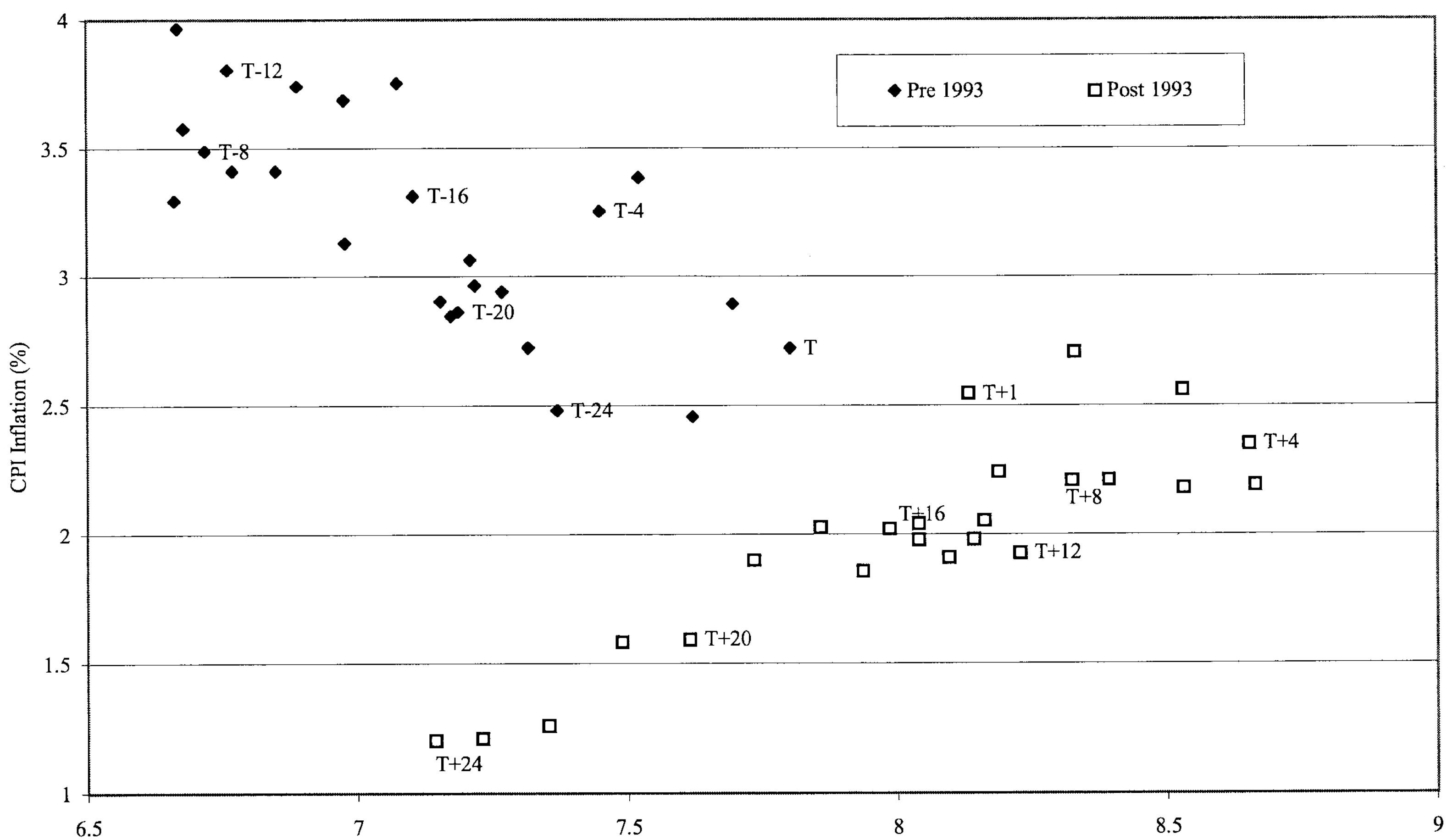
Figure 3. Non-Inflation Targeting Countries: Unemployment and Inflation Averages Pre- and Post-IT





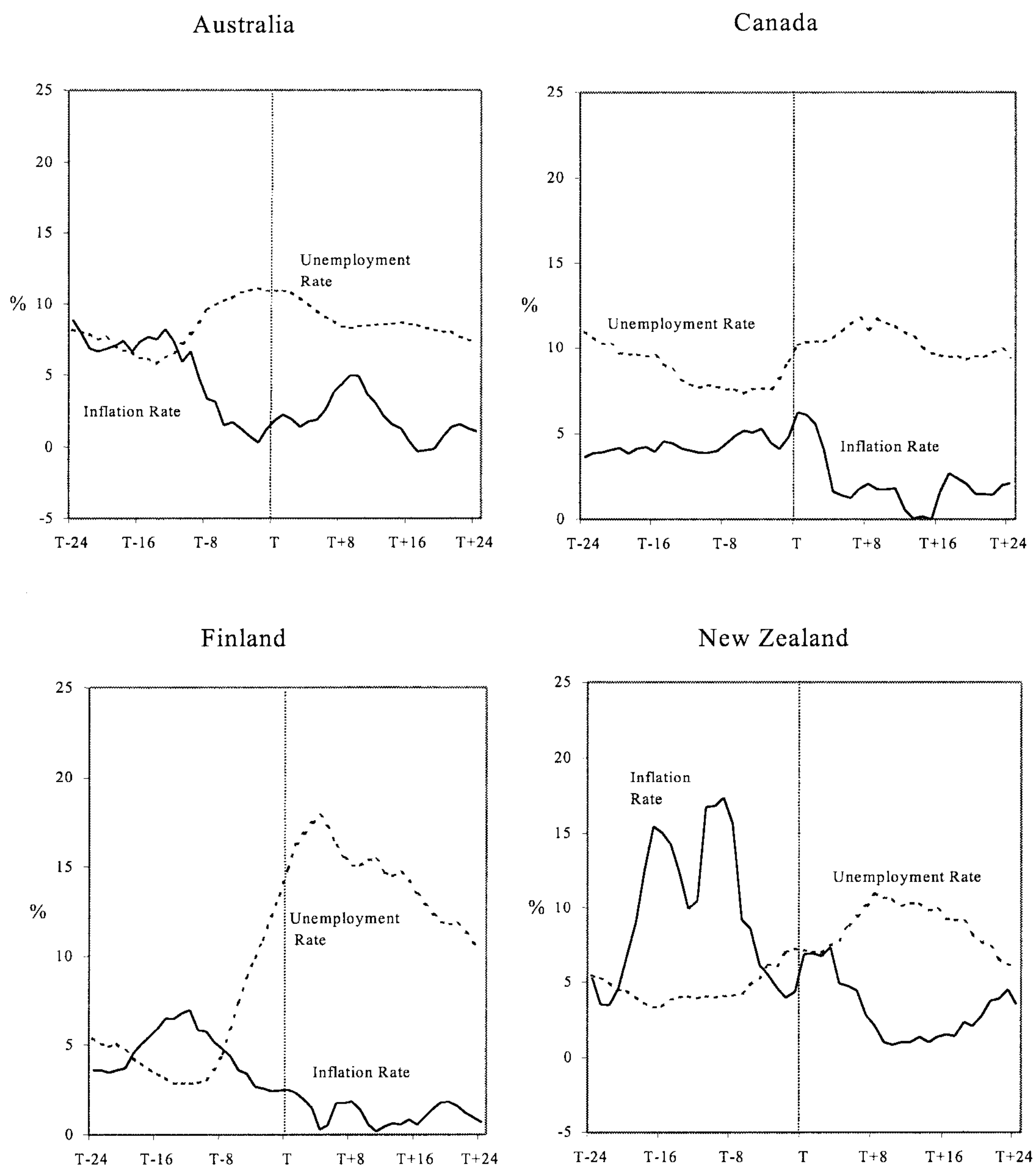
Source: Datastream, International Monetary Fund and Organization for Cooperation and Development.
T is defined as 1993Q1.

Figure 4. Non-Inflation Targeting Countries: Time Path of Unemployment and Inflation Averages



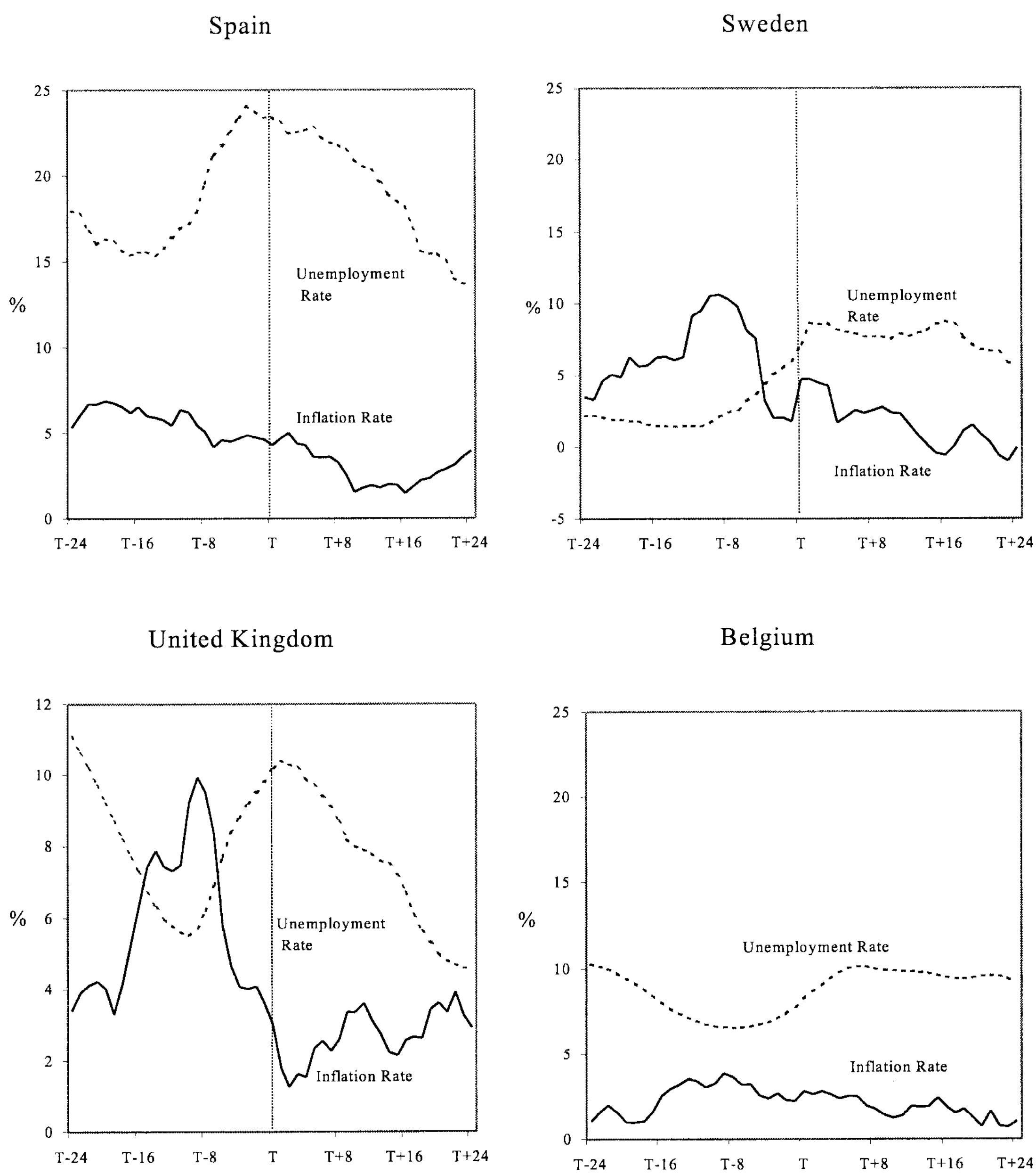
T is defined as 1993Q1

Figure 5. Country Unemployment and Inflation Rates



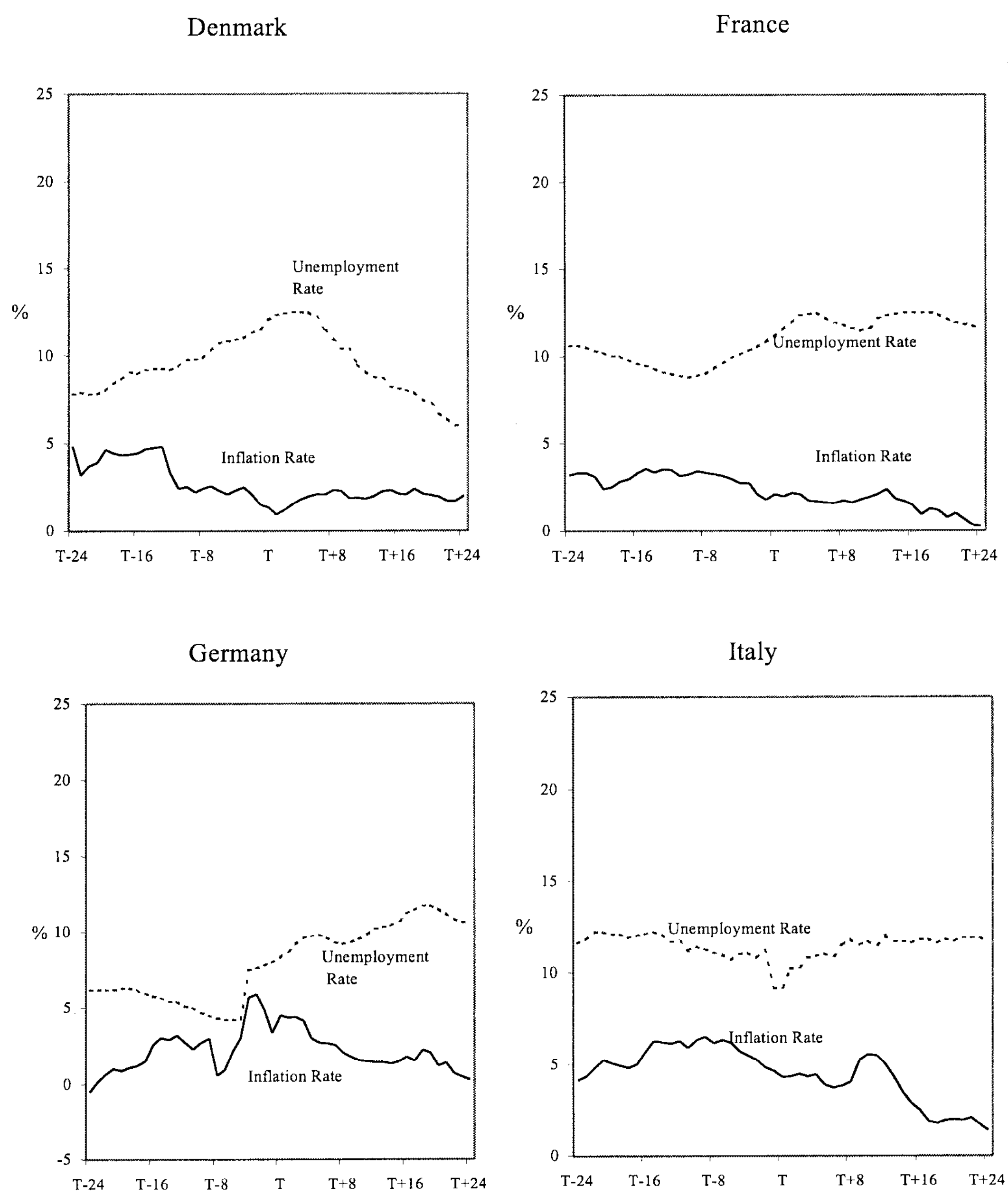
Source: Datastream, International Monetary Fund and Organization for Economic Cooperation and Development.
T is defined as the quarter in which inflation targeting was adopted.

Figure 5. Country Unemployment and Inflation Rates (contd.)



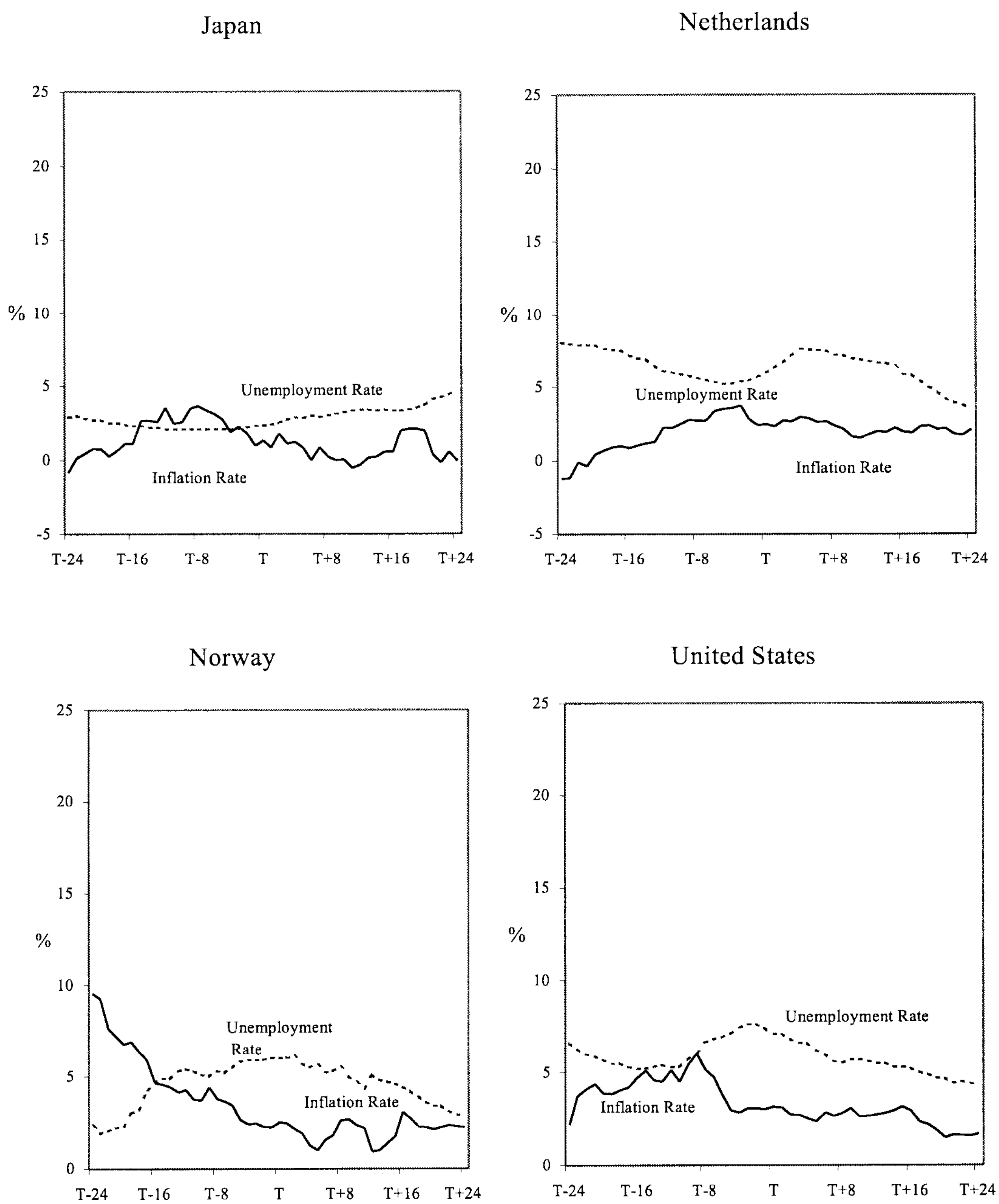
Source: Datastream, International Monetary Fund and Organization for Economic Cooperation and Development.
T is defined as the quarter in which inflation targeting was adopted. Non-inflation targeting countries' T period begins at 1993Q1.

Figure 5. Country Unemployment and Inflation Rates (contd.)



Source: Datastream, International Monetary Fund and Organization for Economic Cooperation and Development.
T is defined as 1993Q1 for non-inflation targeting countries.

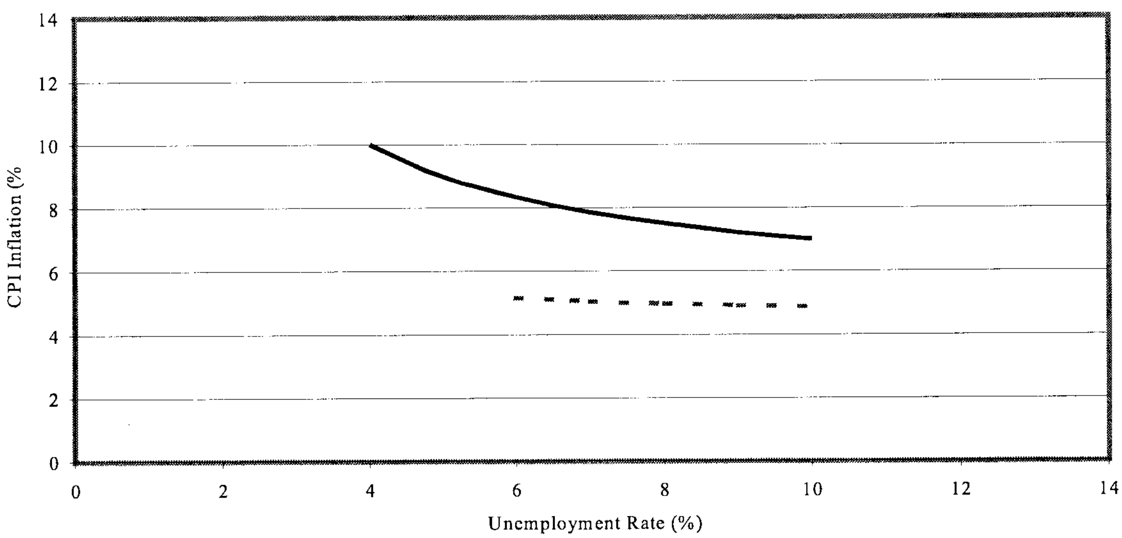
Figure 5. Country Unemployment and Inflation Rates (contd.)



Source: Datastream, International Monetary Fund and Organization for Economic Cooperation and Development.
T is defined as 1993Q1 for non-inflation targeting countries.

Figure 6. Phillips Curve Shifts

(a) Worsening Trade-off



(b) Improving Trade-off

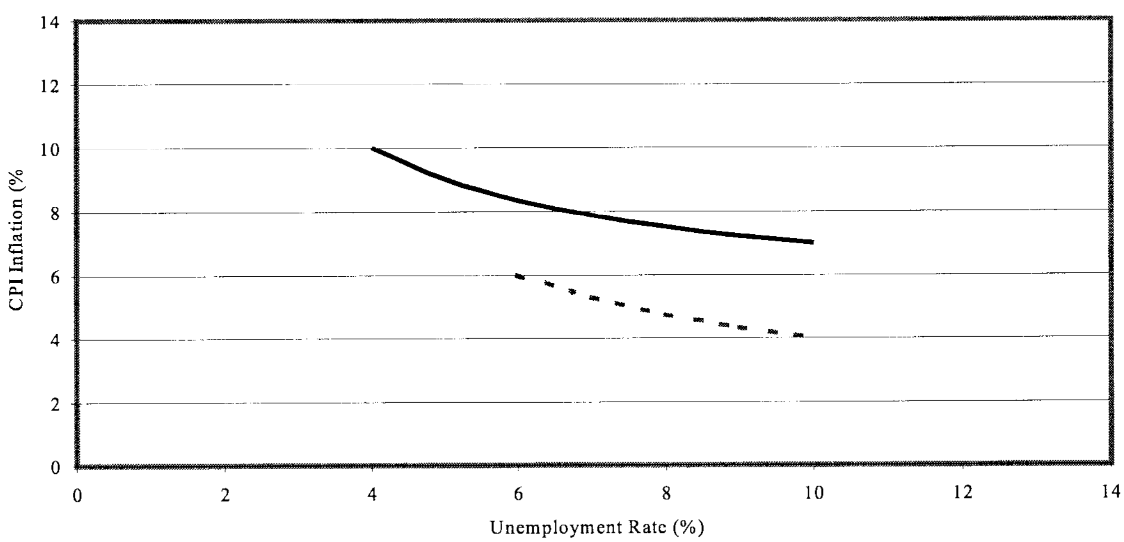
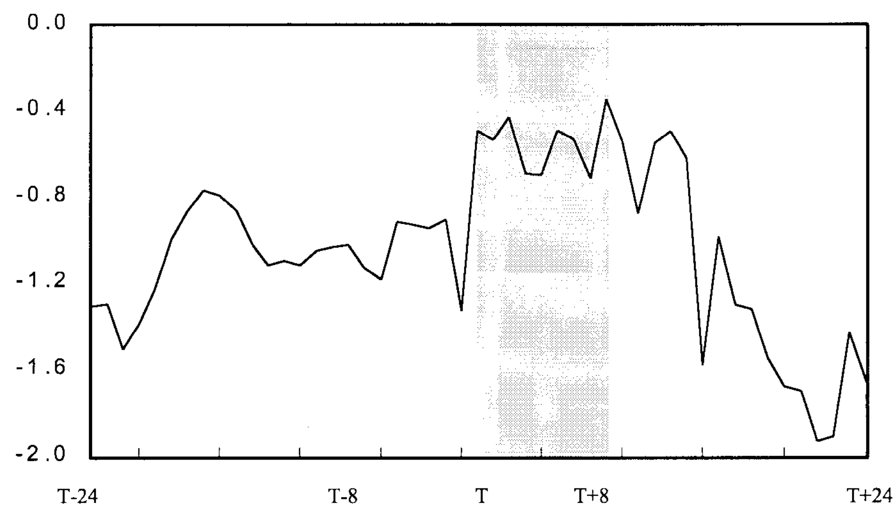
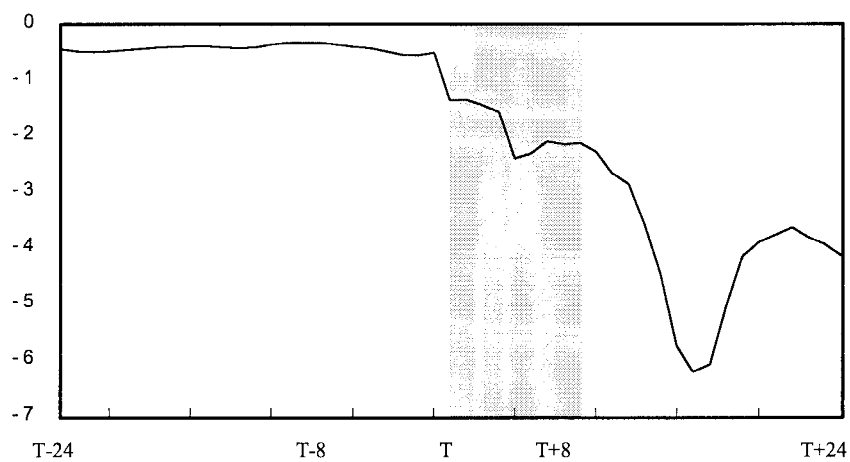


Figure 7. Unemployment-Inflation Trade-off Elasticities[1/]

(a) STR Model



(b) Model 1B



[1/] T is defined as the quarter in which inflation targeting was adopted.
The shaded period is the two years following IT.

Modeling Procedure

We conducted linearity tests for the less restricted version of our model using inverse unemployment, lagged productivity, trend, and up to the sixth lag of inflation as the potential transition variables. Table A1 shows that linearity is rejected for every transition variable at the 1 percent level. The strongest rejection is for the sixth lag of inflation (π_{t-6}), for the null of linearity against a model with time varying parameters. The choice of transition function (logistic or exponential) follows Terasvirta (1998) and is based on a higher-order Taylor expansion of the transition function.[29] In both cases, an exponential transition function (ESTR) was indicated.

Our results for the single transition ESTR model, using π_{t-6} as the transition variable, does not reject parameter constancy against a first-order time varying alternative. As regards remaining nonlinearity, rejections occur for $Dlprod_{t-1}$, $Invump_t$, and π_{t-4} (see Table A2). Using $Dlprod_{t-1}$, the variable with the strongest rejection, as a second transition variable and imposing zero and equal-coefficient restrictions as necessary, we obtain the model reported in Table 3 in the main text.[30]

The model reported in Table 3 allows us to distinguish different characterizations of the dynamics of the process[31]: both transition functions equal zero (linear model); $F(\pi_{\tau-6})=0$ and

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[29] The test function is $y_t = \alpha x_t + \beta_1 x_t z_d + \beta_2 x_t z_d^2 + \beta_3 x_t z_d^3 + \eta_t$. The hypotheses are H_{03}: $\beta 3=0$; H_{02}: $\beta 2=0 \,|\, \beta 3=0$; H_{01}: $\beta 1=0 \,|\, \beta 2=\beta 3=0$. If H_{02} is the strongest reject, select an ESTR model; else select an LSTR model.

[30] In estimating the conditional model for inflation, we assume weak exogeneity of unemployment for α_1 in equation (1), our main parameter of interest. Starting from a vector autoregression in inflation, unemployment, and productivity, we obtain a marginal process for unemployment, which was used in the test for weak exogeneity. For our choice of marginal process, weak exogeneity is not rejected; further, while the CUSUM plot for the marginal process suggests parameter nonconstancy for the sample period, the conditional process reported in Table 3 does not.

[31] The dynamics of the STR model depends on the transition function: the ESTR has dynamics that are similar in the two regimes but differ for the transition period; the LSTR has different dynamics in the two regimes. For the ESTR, when $|z_{t-d}| > c$, $F(z_{t-d};\gamma,c) \approx 1$, defining the "outer" linear regime. When $|z_{t-d}| \approx c$, $F(z_{t-d};\gamma,c) \approx 0$, defining the "middle" regime. For the LSTR, when $z_{t-d} < c$, $F(z_{t-d};\gamma,c) \approx 0$ and the "lower" regime holds; similarly, when $z_{t-d} > c$, $F(z_{t-d};\gamma,c) \approx 1$ and we have the dynamics of the "upper" regime.

$F(Dlprod_{t-1}) = 1$; $F(\pi_{\tau-6}) = 1$ *and* $F(Dlprod_{t-1}) = 0$; and $F(\pi_{\tau-6}) = 1$ *and* $F(Dlprod_{t-1}) = 1$.[32] Our results show explosive roots for regime combinations that include $F(Dlprod_{t-1}) = 1$ (see Table A3).[33] We can interpret these results as implying asymmetric behavior in the two regimes, with the characterization that the process stays for a shorter time in the upper regime than in the stable lower regime. When we combine $F(\pi_{\tau-6}) = 0$ *and* $F(Dlprod_{t-1}) = 1$ (the upper regime of the productivity transition function with the lower regime of the inflation transition function) the prominent roots are explosive, indicating that the dynamics of the process will drive the system relatively quickly to the more stable lower regime. On the other hand, the roots for $F(\pi_{\tau-6}) = 1$ *and* $F(Dlprod_{t-1}) = 0$ suggest that inflation may remain in its outer regime if the value of the productivity transition function is low, but the cycles are likely to be very short. In fact, the shortest cycle corresponds to the combination of the upper regime for the lagged inflation transition function and the lower regime for the productivity transition function. Intuitively, inflation should be more stable relative to an "expected or targeted norm" the nearer productivity is to its expected value.

For illustration, we calculated the dynamics of the inflation process using the means of the transition functions for the pre- and post-IT periods. The prominent roots for the pre-IT period are near explosive and the sum of coefficients of the lagged inflation variables is 0.92, suggesting a near unit root; in contrast, for the post-IT period, the sum of lagged inflation coefficients is 0.56. This indicates that the coefficients of the autoregressive component of the process varied over the sample period and offers some support for our assumption of local nonstationarity. Comparing the pre- and post-IT periods, average (mean) inflation and productivity were higher and unemployment lower in the pre-IT period. An examination of the transition functions for two-year intervals around the introduction of IT indicates that in the first two years after the introduction of inflation targeting, the nonlinearity in the estimated coefficients is due mostly to interaction with the productivity transition function (the inflation transition function having fallen to almost zero); in the subsequent two-year periods, the interaction dynamics is dominated by the inflation transition function, the productivity transition function being close to zero.

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[32] For each configuration, we solve for the roots of the polynomial in π_{t-6}. Complex roots indicate cyclical movements during both phases (regimes), and different dynamics in the lower and upper regimes suggest asymmetric behavior. For the ESTR, an explosive root in the middle (lower) regime indicates quick passage through the mid-phase both on the way-up to and way-down from the outer (upper) regimes; conversely, an explosive root in the outer regime indicates quick recovery from either of the outer regimes towards the middle ("normal") regime.

[33] When both transition functions are in their lower regimes (linear model), the prominent roots of the characteristic polynomial ($m^5 - .38m^4 - .39m^2 + .57m - .15 = 0$) have moduli of .72 and .91, with corresponding cycles of 10.4 and 7.1 quarters. When both transition functions are in the upper regime, the prominent roots of the characteristic polynomial ($m^6 - .38m^5 + .47m^4 - .39m^3 + .28m^2 - .15m - .9 = 0$) have moduli of 1.0 and 0.92, with cycles of 6.4 and 6.8 quarters respectively.

The speed of transition is not fast for either transition function. The graph of the transition functions against the transition variables are shown in Figures A1(a) and A1(b). The estimated threshold coefficients indicate "normal" levels (lower regime) for inflation of about 3.7 percent and for productivity of about 1.4 percent. For the sample period, mean inflation was 4 percent and median inflation was 3.5 percent; mean productivity was 1.1 percent and median productivity was 1 percent. Estimated values of the threshold in the neighborhood of the sample mean suggest that the observations are distributed about equal between the left and right tails of the exponential function. Figure A1(c) graphs the combined transition function against time. It shows a clear shift of regime around the introduction of IT.

Table A1: Linearity Test for Set of Potential Transition Variables

Non-restricted Model Solution

	π_{t-1}	π_{t-4}	π_{t-6}	$Invump_t$	$Dlprod_{t-1}$
β=π=θ=0	5.79 (0.00)	5.15(0.00)	14.80(0.00)	4.75(0.00)	4.30(0.00)
β=θ=0	4.00(0.00)	3.48(0.00)	11.40(0.00)	3.15(0.00)	2.78(0.02)
π=θ=0	7.41(0.00)	3.73(0.00)	11.92(0.00)	5.80(0.00)	5.55(0.00)
β=0|π=θ=0	0.81(0.59)	3.81(0.00)	3.89(0.00)	0.99(0.46)	0.72(0.66)
π=0|β=θ=0	4.24(0.00)	4.24(0.00)	4.24(0.00)	4.24(0.00)	4.24(0.00)

Note: The test equation is $y_t = \alpha x_t + \beta x_t y_d + \pi x_t t + \theta x_t y_d t + \varepsilon_t$, where y is inflation. y_d is the transition variable, t is a time trend and x is the vector of independent variables in the linear model. Values are for F-statistics of the restrictions; the numbers in parentheses are the corresponding p-values.

Table A2: Single Transition Function – Lagged Inflation

$$\pi_t = \underset{(2.90)}{2.80} + \underset{(9.61)}{0.76}\pi_{t-1} + \underset{(1.99)}{0.24}\pi_{t-3} - \underset{(4.66)}{0.70}\pi_{t-4} + \underset{(3.45)}{0.37}\pi_{t-5} - \underset{(3.56)}{0.07}Trend + \underset{(5.03)}{0.06}Dlprod_{t-1}$$

$$+\left(-\underset{(6.99)}{7.96} - \underset{(3.76)}{0.69}\pi_{t-2} + \underset{(4.40)}{0.75}\pi_{t-4} + \underset{(5.01)}{0.10}Trend + \underset{(7.15)}{0.38}Invump_t + \underset{(2.76)}{0.06}Dlprod_{t-1} + \underset{(3.98)}{0.93}\pi_t^*\right) * F(\pi_{t-6})$$

$$F(\pi_{t-6}) = \left[1 - \exp\left\{-\underset{(2.85)}{0.38}.\sigma_{\pi_{t-6}}^{-1}(\pi_{t-6} - \underset{(24.95)}{3.26})^2\right\}\right]$$

Log-likelihood = 26.38; Std. Error =0.1721; AIC = -0.424; Q(5)=5.42 (0.37); $Q^2(5)$=3.87 (0.57); SK = 0.31; KT =3.94; JB =2.58 (0.27); FLMSC(2) =1.54 (0.23); FLMSC(5) =1.11 (0.38); FARCH(2) =1.35 (0.27); FARCH(5) = 0.71 (0.62); PCALL = 1.86 (0.11); RNL(Invump) = 3.03 (0.01); RNL(Dlprod) = 3.09 (0.01); RNL (π_{t-1}) = 1.61 (0.17); RNL (π_{t-4}) = 2.87 (0.02)

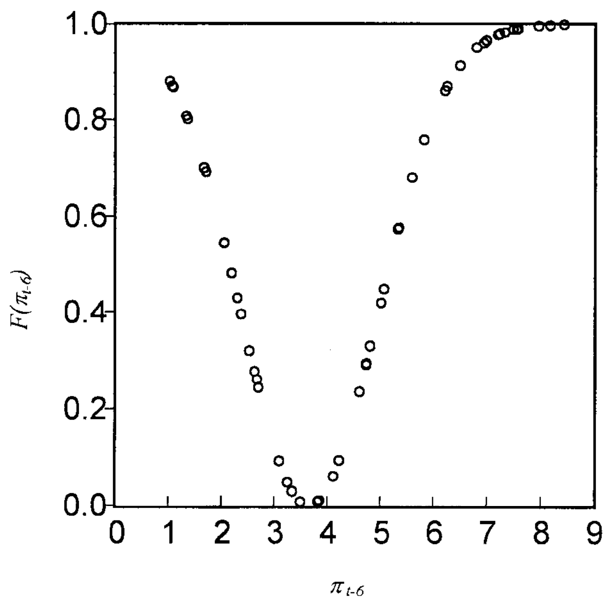
Note: *Q(k)* and *$Q^2(k)$* are the Lung-Box statistics for *k* autocorrelations of the residuals and the squared residuals, respectively; *JB* is the Jarque-Bera test for normality, with *SK* and *KT* denoting skewness and kurtosis; *FLMSC(p)* and *FARCH(p)* test for serial correlation and autoregressive conditional heteroscedasticity up to *p* lags, respectively; *PCALL* is the test for constant parameters (all estimated parameters with first-order trend term); *RNL(z)* tests for remaining nonlinearity in variable *z*. Numbers in parentheses in the equation are t-statistics and numbers in parentheses in the diagnostics section refer to p-values.

Table A3: Prominent Characteristic Roots

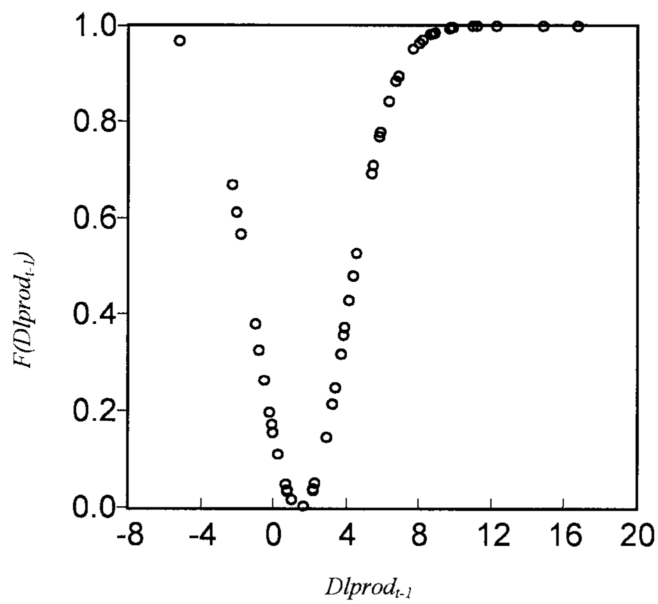
Regime	Prominent Roots	Modulus	Cycle
$F(\pi_{\tau-6}) = 0$ $F(Dlprod_{t-1}) = 0$	-0.576±0.710*i*	0.914	7.07
	0.346	0.346	
	0.593±0.409*i*	0.720	10.42
$F(\pi_{\tau-6}) = 1.0$ $F(Dlprod_{t-1}) = 1.0$	-0.857	0.857	
	1.238	1.238	
	-0.56±0.826*i*	0.998	6.44
	0.56±0.733*i*	0.922	6.84
$F(\pi_{\tau-6}) = 0$ $F(Dlprod_{t-1}) = 1.0$	-0.732	0.732	
	1.045	1.045	
	-0.632±0.878*i*	1.082	6.63
	0.666±0.75*i*	1.003	7.44
$F(\pi_{\tau-6}) = 1.0$ $F(Dlprod_{t-1}) = 0$	0.735	0.735	
	-0.235±0.458*i*	0.515	5.73
	0.057±0.876*i*	0.878	4.17
$F(\pi_{\tau-6}) = 0.8$ $F(Dlprod_{t-1}) = 0.8$ (Pre-IT)	-0.713	0.713	
	0.983	0.983	
	-0.468±0.912*i*	1.025	5.73
	0.522±0.84*i*	0.989	6.19
$F(\pi_{\tau-6}) = 0.4$ $F(Dlprod_{t-1}) = 0.3$ (Post-IT)	-0.505	0.505	
	0.858	0.858	
	-0.491±0.804*i*	0.942	6.15
	0.505±0.688*i*	0.853	6.71

Figure A1. Transition Functions

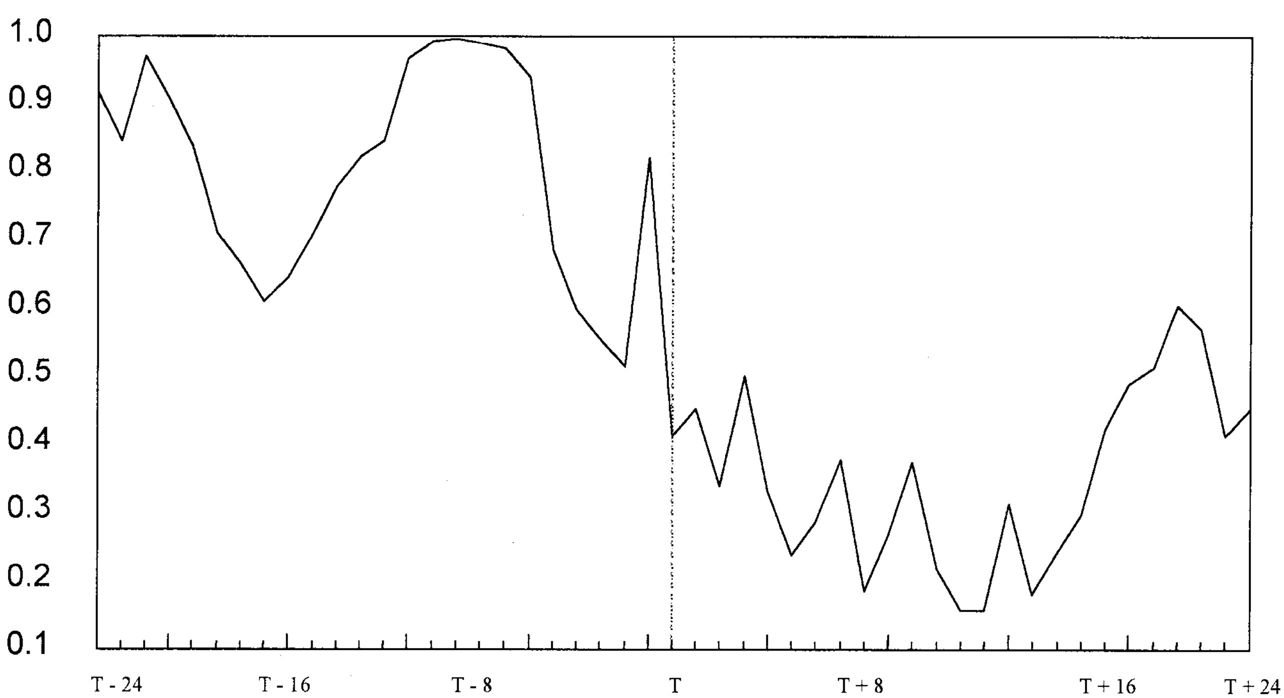
(a) Inflation Transition Function against Lagged Inflation



(b) Productivity Transition Function against Lagged Productivity



(c) Combined Transition Function



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