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CHANGES IN THE INFLATION PROCESS IN CANADA:

Evidence and Implications

by
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The views expressed in this report are solely those of the author.
No responsibility for them should be attributed to the Bank of Canada.

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ABSTRACT

The Canadian economy is currently in transition from a period of disinflation to one with a very low and relatively stable inflation rate. Against this background, the author asks whether reduced-form parameters should be expected to be invariant to changes in the inflation process.

This raises two empirical issues. The first relates to whether shifts in the Canadian inflation process can be identified over time. It appears so, since casual observation as well as various statistical procedures indicate that there was a unique period from the mid-1950s to the early 1970s when inflation was low and relatively stable.

The second issue relates to whether there is evidence that parameter instability corresponds to shifts in the inflation regime. Statistical tests indicate that parameter instability is an important concern in reduced-form models of the inflation process, particularly for the early 1970s.

The evidence for Canada suggests that inflation forecasts from reduced-form models may be unreliable in the presence of important changes in the inflation process.

RÉSUMÉ

L'économie canadienne est en transition entre une phase de désinflation et une période caractérisée par un taux d'inflation très bas et relativement stable. Dans ce contexte, l'auteur se demande s'il faut s'attendre à ce que les paramètres d'une équation de forme réduite soient insensibles aux changements qui s'opèrent dans le processus d'inflation.

Deux questions empiriques se posent à cet égard. En premier lieu, il faut déterminer si des modifications peuvent être décelées au fil du temps dans le processus d'inflation au Canada. Il semble qu'il en soit ainsi, puisqu'une analyse des données, même superficielle, de même que diverses méthodes statistiques révèlent que le Canada a vécu une période unique de taux d'inflation bas et relativement stables, soit du milieu des années 50 au début des années 70.

En deuxième lieu, il faut établir s'il y a des preuves que l'instabilité des paramètres correspond à des changements du régime d'inflation. Les tests statistiques indiquent qu'il faut prendre en considération l'instabilité des paramètres dans les modèles de forme réduite relatifs au processus d'inflation, particulièrement pour le début des années 70.

Les résultats obtenus pour le Canada donnent à penser que les prévisions d'inflation faites à l'aide de modèles de forme réduite peuvent ne pas être fiables quand d'importants changements s'opèrent dans le processus d'inflation.

1 INTRODUCTION

In January 1988, Bank of Canada Governor John Crow announced that the central objective of monetary policy in Canada would be the pursuit of price stability.[1] At that time the inflation rate was in the 4 to 5 per cent range. In February 1991, the federal government and the Bank of Canada jointly announced inflation reduction guidelines. These guidelines set the goal of monetary policy to reduce inflation, as measured by the consumer price index (CPI), to a 1 to 3 per cent range by the end of 1995. In December 1993, the 1 to 3 per cent target range was extended to 1998.

A central concern of monetary policy in this setting is to foresee inflationary pressures and react in a timely manner before inflation becomes entrenched in expectations. The outlook for inflation in the economy is gauged using various sources of information, including empirical models of the inflation process. Structural stability is often an important concern in interpreting forecasts and policy implications of empirical models in general. This is of particular concern now for empirical models of inflation in Canada, given the recent disinflation and the emergence of a new low-inflation environment.

In light of the Lucas (1976) critique, one must question whether reduced-form parameters are invariant to the kind of changes in the inflation environment that are currently under way in Canada. There is a risk that the transition to a low-inflation environment will be accompanied by parameter instability in reduced-form models. This paper investigates whether there is empirical evidence of parameter instability associated with shifts in the inflation process.

Because the low-inflation environment is only just emerging in Canada, there are too few observations to test for parameter instability in the current transition period. The analysis therefore examines the historical period, focussing on the following two principal issues: 1) Can one

1. This announcement was made in the Eric J. Hanson Memorial Lecture; see Crow (1988).

identify distinct inflation regimes over the historical period? If so, then 2) is there evidence of structural instability corresponding to shifts between the regimes? My analysis seeks to determine whether we can expect parameter instability problems in models of the inflation process during the transition to a low-inflation environment. It is also hoped that my historical analysis can provide some insights into possible differences in the inflation process between high- and low-inflation environments, which could be of interest in evaluating what is likely to emerge for Canada in the 1990s.

The second section of the paper discusses how I identify inflation regimes over the historical period. The third section examines some tests for parameter instability using reduced-form models of inflation. The final section discusses some implications of the results.

2 IDENTIFYING INFLATION REGIMES

This section investigates the Canadian inflation environment over time in an attempt to isolate distinct inflation regimes. For the purposes of this paper, a shift in an inflation regime is equated with a change in the time-series properties of the measured inflation rate. The Canadian inflation experience is first described in an informal manner. A number of statistical procedures are then used in an effort to detect discrete shifts in the inflation process. This is implemented using an autoregressive model. These issues are then examined using a regime-switching model.

2.1 Descriptive analysis

The Canadian inflation experience is illustrated in Figure 1 (p. 32) by means of annual changes in the total CPI beginning in 1915, as well as annual changes in the gross domestic product (GDP) price deflator beginning in 1948. A number of extraordinary events correspond to the large fluctuations in inflation observed over the pre-1950 period. The suspension of the gold standard during the first world war led to a rapid increase in inflation. This was followed by a period of deflation, resulting from an attempt to reinstate the gold standard. There was another deflationary period a decade later corresponding to the Great Depression. The Second World War was followed by a sharp increase in inflation as price controls were lifted. This was quickly brought to a halt by a severe recession in 1949-50, which was followed by a brief increase in inflation in 1951 corresponding to the Korean War. The inflation environment throughout these years was determined primarily by international events rather than domestic economic developments per se. It is important to note that these events did not lead to higher rates of inflation on average over this period relative to later periods. Inflation over this period is better characterized in terms of its high variability.

The highly variable inflation rates observed in the pre-1954 period were followed by a period of low and stable inflation from the mid-1950s to the early 1970s. Inflation increased gradually throughout this period, exhibiting only minor fluctuations around its trend. It is interesting to note that this tranquil-inflation period corresponded to a vigorous pace of economic expansion. This period was followed by inflationary episodes that roughly correspond to two oil-price shocks in the early and late 1970s.[2] Inflation then declined sharply in two steps, during the recession of the early 1980s and that of the early 1990s.

2.2 An autoregressive model

In order to provide a more formal analysis of the inflation process over the historical period, I examine the time-series properties of the inflation rate using an autoregressive model given by

$$A(L)\Delta p_t = \mu A(1) + u_t \tag{1}$$

where Δp_t is the inflation rate and u_t is a random error term with zero mean and variance σ^2. $A(L)$ represents a polynomial lag operator (normalized so that $A(0) = 1$); $A(1)$ represents the sum of the autoregressive parameters.[3] I incorporate the possibility of shifts in the inflation process by letting the parameters $\{\mu, \sigma^2, A(L)\}$ vary over time at discrete intervals. For the case of one break point, the parameters are allowed to have different values in the subperiods around the break point. The timing of possible break points is treated as unknown. A number of statistical procedures are used to detect time variation in the parameters. This will help identify the number and timing of possible break points.

2.2.1 Shifts in the conditional mean of inflation

On the basis of casual observation of Figure 1, it is difficult to pick out one or two discrete shifts in the mean inflation rate. There is no period during which the inflation rate increased or decreased sharply and then stabilized at the new level for any considerable length of time. The inflationary

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2. It should be mentioned that during the 1970s, Canada had in place energy policies that effectively delayed the adjustment of domestic oil prices to world levels. Thus, the two oil price shocks in the 1970s did not have a full immediate effect on inflation in Canada, as was the case in other countries.

3. Unless otherwise stated, the inflation rate is assumed to be stationary around its mean, so that all roots of the polynomial $A(L)$ lie outside the unit circle.

episodes following the two world wars were relatively brief and highly volatile. The changes in the inflation rate during the 1970s were more persistent but not well-characterized as a shift in the mean. Perron (1994) examines this question using various formal statistical tests and finds some evidence that the mean inflation rate shifted up around 1973 and then shifted down in 1981-82. His inferences are, however, quite sensitive to a variety of factors, including the measurement of inflation, the frequency of the data and the specification of the tests.

I examine the possibility of discrete shifts in the mean inflation rate in the context of the autoregressive model given by (1). A second-order autoregressive model of inflation, measured as quarterly percentage changes in the total CPI, is estimated recursively over the period 1923Q2 - 1994Q1.[4] The recursive estimation procedure entails estimating the parameters using data up to period t and then forecasting inflation one period ahead (that is, over period t+1). One then reestimates the parameters using data up to period t+1 and again forecasts one period ahead (that is, over period t+2). This recursive procedure results in a series of parameter estimates and residuals that differ from the usual ordinary least squares (OLS) parameter estimates and residuals obtained using the entire sample period. The recursive estimates are useful for determining the timing of possible shifts in the parameters.

Recursive estimates of the conditional mean of inflation μ are shown in Figure 2 (p. 32). The sample period begins with an estimated conditional mean of about 4 per cent over the period 1915-23. This period is dominated by the burst of inflation that began towards the end of the first world war. The recursive estimates of the conditional mean decline to about 1 per cent by the early 1930s because of the deflationary periods in the early 1920s and early 1930s. The conditional mean then gradually increases to about 2 per cent by the late 1940s. Throughout the 1950s and

4. The CPI measures used in the empirical work are adjusted for the introduction of the Goods and Service Tax (GST) in January 1991. Reduced-form regressions indicate that the GST resulted in a 5.25 per cent level increase in the total CPI and a 6.33 per cent level increase in the CPI excluding food and energy.

1960s the conditional mean is stable at the 2 per cent level. It then rises to the 3 to 4 per cent range beginning at about the same time as the first oil price shock in 1973. If one interprets these recursive estimates of the conditional mean in terms of the steady-state inflation rate, one would conclude from Figure 2 that the steady-state inflation rate fluctuated somewhat prior to the early 1950s, was stable throughout the 1950s and 1960s and then gradually increased throughout the early 1970s. On the whole, there is little variation in this measure of the steady-state inflation rate.

One can test for shifts in the conditional mean of inflation by examining the cumulated sums of recursive residuals (CUSUM) obtained from the autoregressive model. This is illustrated in Figure 3 (p. 33).[5] The cumulated sums of recursive residuals indicate that the conditional mean drifted downward from the mid-1920s to the early 1930s and then subsequently drifted upward in the late 1940s and again in the early 1970s. This suggests that the steady-state inflation rate shifted at various times throughout the historical period, each time in a gradual fashion. This is in contrast to Perron's (1994) finding that the mean inflation rate shifted upward in the early 1970s and downward in the early 1980s, each time in a discrete manner. This apparent conflict is due, in part, to the fact that Perron's analysis is designed specifically to isolate discrete breaks in the conditional mean, whereas the analysis of recursive residuals enables one to detect either discrete or gradual shifts in the conditional mean.

Two results from the above analysis are worth noting. First, the conditional mean appears to have been quite stable from the mid-1950s to the early 1970s. Second, the largest shift in the conditional mean occurred in the early 1970s. These results suggest two break points roughly corresponding to 1954Q1 and 1971Q1. These two break points are incorporated into the analysis through estimation of the autoregressive model over the following three subperiods: (1) 1915Q2-1953Q4, (2) 1954Q1-1970Q4 and (3)

5. Figure 3 corresponds to the cumulated sums (CUSUM) test proposed by Brown, Durbin and Evans (1975). Kramer et al. (1988) show that the CUSUM procedure is essentially a test for instability in the conditional mean. Deviations in the cumulated sums of recursive residuals from the horizontal line indicate a shift in the conditional mean.

1971Q1-1994Q1. The results (reported in Table 2, p. 24) indicate that the mean CPI inflation rate increased from about 2.25 per cent in subperiods (1) and (2) to 5.87 per cent in subperiod (3). Similar results hold for inflation measured using the GDP price deflator.[6]

There is some question as to whether the third subperiod 1971Q1-1994Q1 constitutes a stable inflation regime. Figures 2 and 3 suggest that the conditional mean increased throughout the 1970s and then stabilized following the disinflationary period during 1983. This suggests that the subperiod 1984-93 can be viewed as another distinct inflation regime. Characterizing the historical period in this manner would be problematic in my analysis, because such short subperiods would leave too few degrees of freedom for specifying reasonable models of inflation. I characterize the entire subperiod 1971Q1-1994Q1 as a stable inflation regime to avoid this practical problem. This may have implications for some of the results, however, as discussed below.

A Chow test provides evidence of parameter instability in the autoregressive models across all three subperiods (see Table 2).[7] Further analysis indicates that the parameter instability detected by the Chow test does not arise solely from a shift in the conditional mean. Hansen's (1992) test for parameter instability is applied to provide further insights into the nature of the apparent parameter instability. Hansen's test is designed to detect gradual time variation in the parameters rather than discrete shifts as is the case for the Chow test. Hansen's joint test (reported in the bottom line of Table 3, p. 25) provides evidence of time-varying parameters in the autoregressive model of CPI inflation over the period 1915Q2-1970Q4 as well as in the autoregressive model based on the GDP deflator over the period 1954Q1-1994Q1. However, in neither case is there much evidence of time variation in the conditional mean.

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6. The GDP price deflator is available beginning in 1947, so I cannot examine the GDP deflator measure of inflation over subperiod (1).

7. Given our concern about possible heteroscedasticity, I perform the Chow tests using White's (1980) heteroscedastic-consistent estimate of covariance matrix.

2.2.2 Shifts in the conditional variance of the error term

As shown in Figure 1, inflation was quite volatile prior to the 1950s and quite stable during the 1950s and 1960s. This suggests that the conditional variance of the error term in the autoregressive model (σ^2) may be time-varying. The recursive residuals obtained from the autoregressive model (shown in Figure 4, p. 33) indicate that the conditional variance was much higher prior to the 1950s than during the 1950s and 1960s. Subsample estimates (reported in Table 2) indicate that $\hat{\sigma}$ declined from 4.17 per cent in subperiod (1) to 1.55 per cent in subperiod (2). This is supported by Hansen's test, which detects evidence of time variation in $\hat{\sigma}$ over subperiods (1) and (2) (see Table 3, p. 25). Note that the volatility of inflation increased considerably beginning in the early 1970s. This corresponds to an increase in uncertainty as measured by $\hat{\sigma}$, which increased from 1.55 per cent in subperiod (2) to 2.00 per cent in subperiod (3) (see Table 2). In this case, Hansen's test detects little evidence of time variation in σ (see Table 3). Similar results are obtained using an autoregressive model of inflation measured using the GDP deflator.

2.2.3 Shifts in inflation dynamics

The time-series properties of the inflation rate can be summarized by its autocorrelation and partial autocorrelation functions, which are shown in Figure 6 (p. 35) for the three subperiods considered above. Figure 6 shows that the time-series properties of inflation are considerably different in each of the three subperiods. Note, in particular, that the autocorrelations decline more gradually in the third subperiod relative to the first two subperiods. This indicates that innovations in inflation became more persistent after the early 1970s. Prior to the mid-1950s, there were many large innovations in inflation, but they tended to be reversed fairly quickly. After the early 1970s, innovations in inflation tended to persist beyond a few years.

This notion of persistence can be measured by the largest autoregressive root in the inflation process. This corresponds to the sum of the autoregressive parameters A(1) in (1). Recursive estimates of A(1) (shown in Figure 5, p. 34) indicate that the largest autoregressive root in the CPI inflation series increased considerably throughout the 1970s, beginning at about the time of the first oil price shock in 1973.

It is important to note that the above analysis implicitly assumes that the inflation rate is *stationary* around its mean. If this assumption does not hold (in which case the inflation rate would be *nonstationary*), most of the above statistical analysis would be invalid. In particular, the confidence intervals corresponding to the largest autoregressive root (shown in Figure 5) would not be valid for testing the hypothesis that the inflation rate is nonstationary, which corresponds to the unit-root hypothesis: $A(1) = 1$. Formal unit-root tests are required for this hypothesis.

I consider two unit-root tests that have become widely used in applied work – the augmented Dickey-Fuller (ADF) t-test and the Phillips-Perron (PP) parameter bias test.[8] Unit-root tests examine the null hypothesis of non-stationarity against the alternative hypothesis of stationarity. I also "reverse the burden of proof" by considering the stationarity test proposed by Kwiatkowski et al. (1992) (henceforth KPSS). The KPSS test examines the null hypothesis of stationarity against the alternative hypothesis of nonstationarity.[9]

The results from the ADF and PP unit-root tests and the KPSS stationarity test are reported in Table 4 (p. 26). The tests indicate that CPI inflation is stationary over the full sample period as well as over the first subperiod – the ADF and PP tests reject the unit-root hypothesis, while the KPSS test is unable to reject the stationarity hypothesis. The results over the other two subperiods are mixed. The PP test rejects the unit-root hypothesis in each case (at the 0.10 level or higher), indicating that inflation

8. The ADF t-test was developed by Dickey and Fuller (1979) and Said and Dickey (1984), while the PP parameter bias test was developed by Phillips (1987) and Phillips and Perron (1988). Simulation experiments indicate that the PP parameter bias test is more powerful than the ADF t-test but tends to suffer from size distortion problems in certain situations. See Schwert (1989) and Stock (1994).

9. For the PP and KPSS tests, a non-parametric estimate of long-run covariance is obtained using the VAR prewhitened quadratic spectral kernel estimator proposed by Andrews and Monahan (1992). This was implemented using a RATS procedure provided by Robert Amano and Simon van Norden.

is stationary in each subperiod. This inference, however, is not supported by the ADF and KPSS tests. The results are sensitive to other factors not shown in Table 4 (p. 26), including the frequency of the data and the specification of the tests (see Perron 1994). On the basis of these statistical tests, it is unclear whether inflation is best characterized as a stationary or nonstationary process in subperiods (2) and (3).

We should emphasize that it may be inappropriate to consider subperiod (3) as a stable inflation regime, for the reasons given earlier. It may be more accurate to characterize inflation as being nonstationary over the early part of this subperiod and stationary over the latter part. This characterization is supported by the regime-switching results obtained by Laxton, Ricketts and Rose (1994). The stationarity tests considered above are not designed to address issues of this nature. The question is, hence, deemed to be beyond the scope of this paper.

To summarize, the above analysis of an autoregressive model indicates that the time-series properties of inflation changed substantially in the early 1950s and again in the early 1970s. The statistical tests suggest that one can broadly characterize the changes as follows. The volatility of inflation declined substantially in the mid-1950s, accompanied by a decrease in the estimated conditional variance. The persistence of movements in inflation increased considerably in the early 1970s. After the first oil price shock in 1973, inflation tended to converge more slowly to its mean (if at all). There is little evidence of a significant (discrete or gradual) shift in the mean inflation rate in the early 1970s or at other points in the sample.

2.3 A regime-switching model

With the exception of Hansen's parameter instability tests, the statistical procedures considered above are designed to detect a few shifts in the inflation process. I now consider the possibility that there might have been numerous shifts in the inflation process. This is implemented using a two-state Markov switching model given by

$$\Delta p_t = \mu_1 (1 - \rho_1) + \rho_1 \Delta p_{t-1} + u_{1t} \tag{2a}$$

$$\Delta p_t = \mu_2 (1 - \rho_2) + \rho_2 \Delta p_{t-1} + u_{2t} \tag{2b}$$

where $u_{1t} \sim N(0, \sigma_1^2)$ and $u_{2t} \sim N(0, \sigma_2^2)$. The inflation rate follows a first-order autoregressive process in each of the two states.[10] Each state is characterized by its own conditional mean (μ_i), autoregressive parameter (ρ_i) and standard error (σ_i). Using the methodology followed by Hamilton (1989), one can estimate the conditional probabilities of switching between the two states.[11] The parameters defining the two states $\{\mu_i, \rho_i, \sigma_i\}$ as well as the transition probabilities are estimated simultaneously using annual CPI data over the period 1917-93.[12] The results are shown in Table 1 (p. 23).

Relative to state 2, state 1 is characterized by a lower mean (μ_1 = 3.15 vs. μ_2 = 4.59), higher persistence (ρ_1 = 0.718 vs. ρ_2 = 0.489) and a lower standard error (σ_1 = 1.6 vs. σ_2 = 7.6). Note that there is a positive correspondence between the level of inflation and its uncertainty in the two states, as measured by the estimated standard error. Shifts between the states identified by the Markov switching model are shown in Figure 7 (p. 36). The solid line represents the estimated *ex ante* probability of being in state 1, the low inflation – low uncertainty state.[13] There are numerous shifts between the two states prior to the mid-1950s. Inflation then settles into the low level – low uncertainty state (state 1) from the mid-1950s to the early 1970s. There is evidence of shifts out of the low level – low uncer-

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10. First-order autoregressive dynamics are found to adequately explain the annual data. The results were found to be unchanged using second-order autoregressive dynamics.

11. See Laxton, Ricketts and Rose (1994) for a further description of the Markov switching model.

12. I gratefully acknowledge the support of Nick Ricketts, who provided me with estimates of the regime-switching model.

13. This refers to the estimated probability of being in state 1 in the current period before inflation is observed in the current period.

tainty state corresponding to each of the inflationary episodes in the 1970s as well as in the disinflationary period at the end of the sample.

The estimates of the Markov switching model indicate that shifts in the inflation process are not well-characterized solely in terms of the conditional mean. The difference in the estimated standard error of the disturbance term appears to be particularly important for distinguishing between the two states. This corroborates our previous results. Note that the estimated persistence parameter ρ is higher in state 1, the low-inflation state. This is contrary to our earlier characterization of the third subperiod in terms of high inflation – high persistence. This difference can be explained as follows. In the autoregressive model, inflation increases beginning in the early 1970s and displays little tendency to revert to its historical mean. In the regime-switching model, inflation is characterized as being in state 1 thoughout most of the post-1970 period. Inflation is high throughout this subperiod relative to the conditional mean in state 1, which results in a low estimate of persistence. This counterintuitive result suggests that a three-state regime-switching model may be more appropriate, for it would allow inflation to be characterized by a high mean with low persistence over most of the post-1970 period (see Laxton, Ricketts and Rose 1994).

The above analysis indicates that Canada has had some experience with a low and stable inflation regime in place from the mid-1950s to the early 1970s. Inflation increased very gradually over this period but fluctuated very little around its trend. The Canadian inflation environment appears to have changed in an important way when this regime began in the early 1950s and when it ended in the early 1970s. The next section of the paper examines whether there is evidence of parameter instability in reduced-form equations corresponding to these shifts in the inflation regime.

3 PARAMETER INSTABILITY

Ideally one would want to test for parameter instability across the three subperiods considered above. However, owing to data limitations, it is difficult to specify inflation equations prior to the 1950s. For this reason, the analysis is limited to the period 1954-93, with a focus on a possible break point in the early 1970s. Before presenting the parameter instability tests, I will first discuss the specification of the reduced-form equations.

3.1 Long-run analysis

For the purposes of this paper, I consider reduced-form equations similar to those specified in the existing empirical literature for Canada.[14] In this literature, inflation is typically determined by its autoregressive lags, a measure of excess supply or demand and various relative prices. I include relative-price movements arising from commodity prices, energy prices and import prices as well as two leading indicators – money growth and nominal wage growth. This is summarized by the following equation:[15]

$$\Delta p_t = \beta_0 + \sum_{i=1}^{m1} \beta_{1i} \Delta p_{t-i} + \beta_2 (y_{t-1} - yp_{t-1}) + \sum_{i=1}^{m3} \beta_{3i} \Delta m_{t-i} + \sum_{i=1}^{m4} \beta_{4i} \Delta rpm_{t-i} + \sum_{i=1}^{m5} \beta_{5i} \Delta rpcne_{t-i} + \sum_{i=1}^{m6} \beta_{6i} \Delta rpeng_{t-i} + \sum_{i=1}^{m7} \beta_{7i} \Delta w_{t-i} + u_t \tag{3}$$

where $(y_t - yp_t)$ represents the log deviation of real output (y) from its potential level (yp) and

Δm_t represents the growth rate of nominal money,
Δrpm_t represents the relative price of imports,
$\Delta rpcne_t$ represents the relative price of (non-energy) commodities,
$\Delta rpeng_t$ represents the relative price of energy,
Δw_t represents the growth rate of nominal wages,
and u_t is a random error term.

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14. See Poloz and Wilkinson (1992) and the references therein.

15. See the appendix for a detailed description of the data.

Equation (3) is intended to represent the reduced-form approach to modelling the inflation process. This equation blends together empirical work on Phillips curves (see Poloz and Wilkinson 1992), the information content of monetary aggregates (see Hostland, Poloz and Storer 1988, and Caramazza and Slawner 1991), and wage-price dynamics (see Cozier 1991). Note that there is no explicit separation made between *expectational* and *intrinsic* dynamics, so that one cannot interpret the estimated linkages with reference to the effects of anticipated versus unanticipated shocks. Furthermore, it is unclear how the steady-state inflation rate is determined within this reduced-form framework. Inflation is generally viewed as being determined by the monetary authority in the long run; but the role of the monetary authority is unclear in the above equation. Monetary policy can be thought of as operating through its effects on the level of excess demand or supply (which is proxied by the output gap: $y_t - yp_t$). Monetary policy can also be characterized in terms of setting the pace of monetary expansion, which may be captured in part by the growth rate of a monetary aggreate (M2 in this case). Moreover, the perceptions of monetary policy no doubt play an important role in the formation of inflation expectations, which underlies the price-setting and wage-bargaining process. From this perspective, the reduced-form parameters implicitly involve an interaction between monetary policy, inflationary expectations and the determination of wages and prices. Hence, it is difficult to give the reduced-form equation a structural interpretation. Given these shortcomings, the reduced-form equation should be thought of in the spirit of documenting “stylized facts” associated with the data.

Three measures of inflation are examined – quarterly percentage changes in the total CPI, the CPI excluding food and energy, and the GDP price deflator. The dynamics of the equations are specified as follows. In order to focus on leading information, only lags of the explanatory variables are considered. I apply a general-to-specific model specification procedure to specify lag lengths, using Akaike’s (1969) information criterion. Preliminary regressions over the period 1954Q1-1994Q1 revealed that the lagged level of the output gap is significant, while its lagged growth rate is not significant in all three equations.[16] Moreover, significant leading information was found in nominal wage growth and nominal money growth in all of the equations examined. Given that parsimony is an important concern for stability tests, restrictions were imposed across the distributed lag structures to attain more parsimonious specifications. These restrictions summarize the distributed lag structures on each of the variables by means of moving averages. The moving-average restrictions could not be rejected by the data on the basis of likelihood ratio (LR) tests.

3.2 Testing for parameter instability

3.2.1 Statistical tests

Estimates of the reduced-form parameters over the subperiods (2) and (3) are reported in Table 5 (p. 27). Note that the fit of the regressions, as measured by the R^2, is much higher in subperiod (3) than in subperiod (2). This is particularly the case for the GDP deflator equation. Although the volatility of inflation increased substantially in subperiod (3), the estimated standard error of the regression ($\hat{\sigma}$) increases only slightly for the two CPI inflation equations and in fact declines for the GDP deflator equation.

Many of the above inferences made with reference to the full sample period are not robust across the two subperiods. In particular, the estimated response of inflation with respect to relative import prices, relative commodity prices and nominal wage growth is much stronger in subperiod (2) relative to subperiod (3) (see the estimates of parameters β_4, β_5 and β_7, respectively, reported in Table 5). Each of these variables is statistically significant over the full-sample period and subperiod (3), but are not statistically significant over subperiod (2). The estimates indicate that the reduced-form linkages are not well specified for the low-and-stable inflation period – subperiod (2).

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16. For the purposes of this paper, potential output is proxied as a 13-quarter weighted, centred, moving average of actual output. This measure is very similar to that obtained by applying the Hodrick-Prescott filter to real output with the “smoothness parameter” set to 500 (see Côté and Hostland 1994).

The diagnostic tests reported in Table 6 (p. 28) are intended to provide insights into the statistical properties of the reduced-form equations for the two subperiods. The diagnostic tests detect evidence of second-order serial correlation and second-order ARCH effects in the reduced-form residuals obtained from subperiod (2). There is also evidence of skewness and kurtosis in the reduced-form residuals obtained from subperiod (3). The diagnostic tests indicate that the statistical properties of the reduced-form equations are quite different over the two subperiods.

A Chow test is performed on the reduced-form equations using 1971Q1 as the hypothesized break point. There is strong evidence of parameter instability in the total CPI and GDP deflator equations but not in the equation for the CPI excluding food and energy (see Table 5). This suggests that parameter instability depends upon the measurement of inflation. More specifically, excluding the volatile food and energy component from the CPI appears to alleviate the parameter instability problem.

It is important to note that the above Chow tests assume that the 1971Q1 break point is known *a priori*. This assumption may not be appropriate given the pretest bias involved in examining the data to isolate the break point. Hansen's (1992) test for parameter instability can be used to avoid any pretest bias, since it assumes that the break point is unknown. Hansen's test detects evidence of parameter instability in the GDP deflator equation but not in the two CPI equations (see Table 7, p. 29). The instability arises from time variation in the autoregressive parameter (β_1) and the standard error (σ). When Hansen's test is applied over the two subperiods, parameter instability is detected over subperiod (2) but not over subperiod (3) for all three equations (see Table 8, p. 30). In these cases, the instability arises from time variation in other parameters besides the autoregressive parameter (β_1) and the standard error (σ). These results suggest that the reduced-form equations exhibit parameter instability prior to the early 1970s.

To provide insights into the timing of alleged break points, I examine both the cumulated sums of recursive residuals and the cumulated sums of squared recursive residuals obtained from the reduced-form equations.[17] The cumulative sums of recursive residuals, shown in Figure 8 (p. 36), indicate that the conditional mean underlying the reduced-form equations shifted upward in the early 1970s.[18] Note that the shift in the conditional mean appears to be more pronounced in the reduced-form equations corresponding to the GDP deflator and the total CPI. The cumulated sums of squared recursive residuals, shown in Figure 9 (p. 37), indicate an increase in the conditional variance of the error term (σ^2), beginning at about the same time as the first oil price shock in 1973.[19] Once again, the shift appears more pronounced in the reduced-form equations corresponding to the GDP deflator and the total CPI.

The timing of possible break points is also examined using rolling Chow tests,[20] the results of which are illustrated by Figure 10 (p. 37). Critical values are shown for the case where the break point is known a priori, which corresponds to the conventional Chow test, and also for the case where the break point is unknown, which corresponds to the Sup test proposed by Andrews (1993).[21] The rolling Chow test provides strong evidence of parameter instability in the GDP deflator equation. There is evidence of parameter instability at virtually all the break points examined, with the most probable break point occurring in about 1971. Parameter instability appears to be somewhat less of a problem in the CPI equations. There is evidence of parameter instability in the total CPI equation prior to the mid-1970s, with the most probable break point occurring in about 1970. The equation based on the CPI excluding food and energy exhibits

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17. This entails using the recursive estimation procedure described earlier. The 1954Q1-1957Q4 period is used to obtain initial estimates of the parameters; recursive residuals are then generated over the 1958Q1-1994Q1 period.

18. See footnote 4.

19. Figure 10 corresponds to the cumulated sums of squares (CUSUMSQ) procedure proposed by Brown, Durbin and Evans (1975). Ploberger and Kramer (1990) show that the CUSUMSQ procedure is essentially a test for instability in the conditional variance of the error term. Deviations in the cumulated sums of squared recursive residuals from the dotted line indicate a shift in the conditional variance.

20. Given the concern about possible heteroscedasticity, the Chow tests are performed using White's (1980) heteroscedastic-consistent estimate of covariance matrix.

21. See Hansen (1992) and the references therein on this distinction.

parameter instability problems over the period 1974-80. In this last case, the Chow test is, in general, only significant when the break point is treated as known (using the conventional critical values for the Chow test). This suggests that excluding the volatile food and energy components from the CPI tends to alleviate parameter instability problems.

3.2.2 Forecasting performance

The forecasting performance of the reduced-form equations are examined to gauge their reliability over the two subperiods of interest. The autoregressive models considered in the previous section of the paper are used as a benchmark. One- and four-quarter-ahead forecasts are generated from the reduced-form and autoregressive equations. The forecasts are based on recursive estimates of the parameters so that they involve only information known at the time that they are made. The forecast errors, hence, involve uncertainty arising from parameter estimation as well as uncertainty arising from the error term in the models. The forecasting performance of the models are compared in Table 9 (p. 31) using the root-mean-square-error (RMSE) criterion.

The reduced-form equations forecast quite poorly relative to the autoregressive models over subperiod (2) (1958Q1-1970Q4). Note in particular that at the one-quarter-ahead forecasting horizon, the autoregressive models for the two CPI measures of inflation result in lower RMSEs relative to the reduced-form equations. This is also the case for the GDP deflator equations at the four-quarter-ahead forecasting horizon. The reduced-form equations forecast uniformly better than the autoregressive models over subperiod (3). These forecast comparisons indicate that the estimated linkages underlying the reduced-form models are informative during the volatile inflation period (subperiod 3) but are not very informative during the low-and-stable inflation period (subperiod 2). This suggests that forecasts of inflation from the reduced-form equations may be unreliable in a low-and-stable inflation environment.

4 IMPLICATIONS

To summarize, the analysis indicates that Canada experienced a unique period of low and stable inflation from the mid-1950s to the early 1970s. The time-series properties of inflation over this period are quite different from those before and after. Prior to the mid-1950s, inflation was highly volatile and undoubtedly difficult to forecast from year to year. Beginning in the early 1970s, movements in inflation became much more persistent and more volatile. The steady-state inflation rate appears to have shifted in a gradual, rather than discrete, manner across these periods.

The Canadian inflation experience does not provide the basis for a "clean experiment" corresponding to a discrete shift in the steady-state inflation rate, with everything else unchanged. Hence, one cannot infer how changes in the steady-state inflation rate have affected the structure of the economy. There is, however, a period of low and stable inflation followed by a period of high persistence and high uncertainty. We have examined whether changes of this nature have led to parameter instability problems in reduced-form equations.

The analysis indicates that it is difficult to specify reduced-form equations that can capture the inflation process during the low-and-stable inflation period. The economic and statistical properties of the reduced-form equations are found to be quite different when estimated over subperiods that correspond to a shift in the inflation regime. Moreover, there is evidence of parameter instability corresponding to the regime shift. The reduced-form equations provide leading information about inflation during the volatile-inflation regime but tend to generate unreliable forecasts during the low-and-stable inflation regime. These findings support the view that reduced-form parameters are dependent on the particular inflation regime in place over the sample period. This implies that one should be extremely cautious when forecasting and performing policy analysis with reduced-form models of the inflation process.

To understand why this might be the case, consider what underlies the estimated linkages between relative-price movements and inflation. It is useful to make a distinction here between factors that have an impulse effect on inflation and those that propagate the impulse effects. Relative energy and commodity prices were relatively stable during the 1950s and 1960s, but fluctuated widely during the 1970s and 1980s (see Figure 11, p. 38). There is little doubt that the large movements in relative energy and commodity prices in the 1970s had a substantial impulse effect on the inflation rate. If one believes that inflation is a monetary phenomenon in the long run, then the propagation of relative-price shocks would ultimately depend on the stance of monetary policy. One can then interpret the correlation between relative-price shocks and inflation observed over the historical period along the following lines.

The large relative-price movements in the 1970s were, to a large extent, accommodated by the pace of monetary expansion at the time. This resulted in a sustained increase in inflation throughout the 1970s. Reduced-form equations estimated over this period capture the impact effect of the relative-price shocks combined with the stance of monetary policy. Previous to this period, the monetary authority was not faced with such large relative price shocks. The comparatively small movements in relative energy and commodity prices in the 1950s and 1960s had little effect on the setting of monetary policy and hence had neglible effects on the inflation rate on a sustained basis.

The above interpretation suggests that the reduced-form estimates of the linkages between relative prices and inflation obtained over the period 1971Q1-1994Q1 are probably higher than what one should expect in the near future. Given that the objective of monetary policy is currently defined with reference to inflation-rate target bands, agents may not perceive relative price movements as affecting the rate of monetary expansion to the extent that they might have in the early 1970s. Estimates of the reduced-form linkages obtained over the low-inflation – low-uncertainty period 1955-70 are probably more reliable in this respect.

Our interpretation of the results echoes the critique of reduced-form modelling put forth by Lucas and Sargent (1979) among others. This view advocates that macroeconomists develop a deeper understanding of the interaction between inflation expectations, monetary policy, and wage and price determination. This entails specifying models of the inflation process that make an explicit separation between *intrinsic* and *expectational* dynamics, and also developing microfoundations for nominal rigidities. This view also emphasizes the need to model explicitly the behaviour of the monetary authority so that monetary policy plays an integral role in the inflation process.[22] Credibility and learning are both important elements in modelling how inflationary expectations adjust to shifts in inflation regimes in the presence of uncertainty (see Laxton, Ricketts and Rose 1994, and Ricketts and Rose 1994). It is hoped that further research along these lines will lead to a better understanding of the inflation process in different regimes as well as during the transition state between regimes.

22. These arguments were key to the decision to support development of a new structural model of the economy for forecasting and policy analysis at the Bank of Canada. See Poloz, Rose and Tetlow (1994).

APPENDIX

Description of the data

p = the log of the price level, alternatively defined using
the total CPI (P484549)[23]
the CPI excluding food and energy (P484571)
the GDP price deflator at market prices (D20011 / D20463)

m = the log of the monetary aggregate M2 (B1630)

rpcne = the relative price of non-energy commodities defined using the Bank of Canada non-energy commodity price index in U.S. dollars / the U.S. producer price index

rpeng = the relative price of energy defined using the Bank of Canada energy price index in U.S. dollars / the U.S. producer price index

rpm = the log of the real effective exchange rate defined using a trade-weighted index of GDP / GNP price deflators for six of Canada's major trading partners[24]

w = the log of the nominal wage rate defined using total labour income or the number of total employed persons excluding the armed services

y = the log of real GDP (D20463)

yp = the log of potential output defined using a 13-quarter, centred, weighted moving average of real GDP

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23. The mnemonics in parentheses refer to CANSIM data series. All data series are available upon request.

24. Weights for the six countries are as follows: United States: 0.831, Japan: 0.078, United Kingdom: 0.038, Germany: 0.025, France: 0.015, Italy: 0.013

TABLES

Table 1
Estimates of the Markov switching model

	μ	ρ	σ	$P(S_i \mid S_j)$[a]
State 1:	3.146	0.718 (0.074)[b]	1.608 (0.238)	0.103
State 2:	4.590	0.489 (0.241)	7.608 (1.374)	0.277

a. $P(S_i \mid S_j)$ represents the estimated transition probabilities. That is, the conditional probability of switching from state 1 to state 2: $P(S_2 \mid S_1)$ and the conditional probability of switching from state 2 to state 1: $P(S_1 \mid S_2)$.

b. Standard errors are reported in parentheses.

Table 2

Estimates of the autoregressive model over subperiods

$$A(L)\Delta p_t = \mu A(1) + u_t$$

where Δp represents quarterly percentage changes in the total CPI and GDP deflator

Inflation measure	**Total CPI** *(3 autoregressive lags)*[a]			**GDP deflator** *(4 autoregressive lags)*	
Subperiod[b]	**(1)**	**(2)**	**(3)**	**(2)**	**(3)**
μ	2.247 (1.169)	2.264 (0.581)	5.870 (1.948)	3.040 (0.723)	5.187 (2.077)
$A(1)$	0.761 (0.048)	0.675 (.133)	0.893 (0.064)	0.587 (0.197)	0.880 (0.072)
Summary statistics[c]					
s.d.(Δp)	6.595	1.806	3.564	2.635	3.911
σ	4.170	1.552	1.998	2.310	2.356
R^2	0.605	0.295	0.696	0.277	0.653
Chow tests for parameter instability[d]					
χ^2-statistic	12.50 ~ $\chi^2(4)$ [0.02]				
χ^2-statistic		10.29 ~ $\chi^2(4)$ [0.03]		15.23 ~ $\chi^2(5)$ [0.01]	

a. The number of autoregressive lags was chosen using Akaike's information criterion.

b. Subperiods: (1) 1915Q2-1953Q4; (2) 1954Q1-1970Q4; (3) 1971Q1-1994Q1.

c. The abbreviation s.d.(Δp) represents the standard deviation of inflation; σ represents the estimated standard error of the regression.

d. The Chow test examines whether the parameters are stable across subperiods. A rejection of the null hypothesis is evidence that the parameters are jointly unstable. The test is applied using White's (1980) consistent estimate of the covariance matrix, in which case the Chow test statistic has a χ^2 distribution. Probability values are reported in square brackets.

Table 3

Hansen's test for parameter instability: autoregressive model

$$\Delta p_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \Delta p_{t-1} + u_t$$

(Hansen's L_C test statistics reported below.)[a]

Inflation measure	Total CPI		GDP deflator
Subperiods	**(1) and (2) 1915Q2-1970Q4**	**(2) and (3) 1954Q1-1994Q1**	**(2) and (3) 1954Q1-1994Q1**
α_0	0.091	0.145	0.163
α_1	0.022	0.100	0.240
α_2	0.038	0.083	0.100
α_3	0.034	0.065	0.090
α_4	--	--	0.177
σ	1.827 [0.01]	0.099	0.341
Joint test	2.543 [0.01]	0.719	1.772 [0.05]

a. Hansen's (1992) instability test examines whether the individual parameters are time-varying over the indicated sample periods. The bottom line examines whether all the parameters together are time-varying. A rejection of the null hypothesis is evidence of parameter instability. Probability values in the 0.01 to 0.10 range are reported in square brackets, obtained from the asymptotic critical values reported in Hansen (1992, Table 1).

Table 4

Unit-root and stationarity tests

Sample period[a]	**Inflation measure**	**Unit-root tests**[b]		**Stationarity test**[c]
		ADF: $\hat{\tau}_\mu$	***PP:*** $Z(\hat{\alpha})$	***KPSS:*** $\hat{\eta}_\mu$
Full sample: 1917Q1-1994Q1	Total CPI	-3.89 (8)[d] [0.002]	-65.84 [<0.001]	0.388
Subperiod (1): 1917Q1-1953Q4	Total CPI	-3.07 (8) [0.028]	-37.70 [<0.001]	0.127
Subperiod (2): 1954Q1-1970Q4	Total CPI	-4.25 (1) [0.004]	-48.61 [0.004]	0.105
	GDP deflator	-2.16 (7) [0.48]	-75.11 [< 0.001]	0.219 [0.01]
Subperiod (3): 1971Q1-1994Q1	Total CPI	-1.95 (6) [0.31]	-16.34 [0.03]	0.228
	GDP deflator	-1.94 (1) [0.31]	-11.51 [0.09]	0.715 [0.01]

a. Estimates of the standardized trend measure proposed by Schmidt (1990) indicate the presence of drift only for subperiod (2). A time trend was included only for this subperiod.

b. The ADF and PP statistics test the null hypothesis of nonstationarity against the alternative hypothesis of stationarity. Probability values (reported in square brackets) are obtained from the asymptotic critical values calculated by MacKinnon (1991, Tables 3 to 6).

c. The KPSS test statistics test the null hypothesis of stationarity against the alternative hypothesis of nonstationarity. Probability values (reported in square brackets) are obtained from the critical values reported by KPSS (1992, Table 1).

d. The number of autoregressive lags in the ADF regression is reported in parentheses. This was determined using the sequential testing procedure advocated by Ng and Perron (1994).

Table 5
Estimates of reduced-form equations across subperiods

Inflation measure	Total CPI		CPI excluding food and energy		GDP deflator	
Subperiod[a]	**(2)**	**(3)**	**(2)**	**(3)**	**(2)**	**(3)**
β_0	0.869 [0.05][b]	-0.474 [0.343]	0.506 [0.150]	-0.077 [0.880]	1.712 [0.042]	-0.788 [0.213]
β_1	0.261 [0.102]	0.635 [0.001]	0.660 [0.001]	0.733 [0.001]	-0.237 [0.345]	0.601 [0.001]
β_2	0.219 [0.162]	0.196 [0.203]	0.100 [0.384]	0.365 [0.014]	0.615 [0.036]	0.247 [0.186]
β_3	0.105 [0.069]	0.123 [0.011]	0.058 [0.186]	0.082 [0.072]	0.143 [0.119]	0.083 [0.173]
β_4	-0.040 [0.322]	0.067 [0.006]	0.008 [0.795]	0.026 [0.277]	-0.049 [0.624]	0.107 [0.002]
β_5	0.000 [0.998]	0.045 [0.007]	0.004 [0.920]	0.028 [0.106]	-0.063 [0.416]	0.083 [0.001]
β_6	0.051 [0.075]	0.010 [0.087]	0.034 [0.113]	0.005 [0.335]	-0.002 [0.967]	0.005 [0.429]
β_7	0.073 [0.212]	0.180 [0.001]	0.023 [0.590]	0.088 [0.068]	0.177 [0.395]	0.288 [0.007]
Summary statistics[c]						
s.d.(Δp)	1.807	3.564	1.597	3.020	2.635	3.911
σ	1.543	1.648	1.160	1.570	2.448	1.998
R^2	0.347	0.802	0.527	0.750	0.227	0.759
Chow test for parameter instability over subperiods[d]						
χ^2-statistic	24.26 ~ $\chi^2(8)$ [0.002]		9.25 ~ $\chi^2(8)$ [0.32]		47.25 ~ $\chi^2(8)$ [0.001]	

a. Subperiods: (2) 1954Q1-1970Q4; (3) 1971Q1-1994Q1.

b. Probability values corresponding to hypothesis: $\beta_i = 0$ given in square brackets.

c. The abbreviation s.d.(Δp) represents the standard deviation of inflation; σ represents the estimated standard error of the regression.

d. The Chow test examines whether the parameters are stable across subperiods. A rejection of the null hypothesis is evidence that the parameters are jointly unstable. The test is applied using White's (1980) consistent estimate of the covariance matrix, in which case the Chow test statistic has a χ^2 distribution. Probability values are reported in square brackets.

Table 6
Diagnostic tests on residuals from reduced-form equations

Inflation measure	Total CPI		CPI excluding food and energy		GDP deflator	
Subperiod[a]	**(2)**	**(3)**	**(2)**	**(3)**	**(2)**	**(3)**
LM test for serial correlation[b]						
1st order	[0.41][c]	[0.216]	[0.093]	[0.585]	[0.018]	[0.214]
2nd order	[0.040]	[0.123]	[0.014]	[0.030]	[0.006]	[0.350]
LM test for ARCH						
1st order	[0.121]	[0.822]	[0.709]	[0.602]	[0.013]	[0.900]
2nd order	[0.050]	[0.401]	[0.885]	[0.857]	[0.041]	[0.798]
RESET test						
2nd order:	[0.548]	[0.837]	[0.980]	[0.867]	[0.765]	[0.997]
3rd order:	[0.369]	[0.492]	[0.861]	[0.472]	[0.873]	[0.986]
LM test for normality						
Skewness	[0.693]	[0.001]	[0.041]	[0.001]	[0.111]	[0.453]
Kurtosis	[0.468]	[0.001]	[0.501]	[0.001]	[0.560]	[0.025]

a. Subperiods: (2) 1954Q1-1970Q4; (3) 1971Q1-1994Q1.

b. See Pagan and Hall (1983) for a descriptive of the above diagnostic tests.

c. Probability values are reported in square brackets.

Table 7
Hansen's test for parameter instability: reduced-form equations

(Hansen's L_C test statistics reported below.)[a]

(Sample: 1954Q1-1994Q1)

Parameter	Inflation measure: Total CPI	Inflation measure: CPI excluding food and energy	Inflation measure: GDP deflator
β_0	0.098	0.057	0.088
β_1	0.173	0.091	0.387 [0.10]
β_2	0.030	0.194	0.098
β_3	0.125	0.057	0.175
β_4	0.221	0.211	0.066
β_5	0.055	0.053	0.240
β_6	0.062	0.116	0.239
β_7	0.210	0.110	0.195
σ	0.190	0.204	0.778 [0.01]
Joint test	1.519	1.167	2.292 [0.05]

a. Hansen's test examines whether the individual parameters are unstable over the indicated sample periods. The joint test examines whether all the parameters together are unstable. A rejection of the null hypothesis is evidence of parameter instability. Probability values in the 0.01 to 0.10 range are reported in square brackets, obtained from the asymptotic critical values reported in Hansen (1992, Table 1).

Table 8
Hansen's test for parameter instability: reduced-form equations

(Hansen's L_C test statistics reported below.)[a]

	Inflation measure					
	Total CPI		CPI excluding food and energy		GDP deflator	
Subperiod:[b]	**(2)**	**(3)**	**(2)**	**(3)**	**(2)**	**(3)**
β_0	0.242	0.097	0.199	0.091	0.465 [0.05]	0.065
β_1	0.387 [0.10]	0.153	0.101	0.117	0.565 [0.05]	0.071
β_2	0.083	0.040	0.063	0.042	0.069	0.066
β_3	0.562 [0.05]	0.049	0.309	0.049	0.576 [0.05]	0.053
β_4	0.105	0.055	0.541 [0.05]	0.340	0.155	0.084
β_5	0.204	0.111	0.153	0.088	0.110	0.175
β_6	0.045	0.304	0.160	0.115	0.149	0.073
β_7	0.597 [0.05]	0.080	0.303	0.046	0.580 [0.025]	0.050
σ	0.477 [0.05]	0.395 [0.075]	0.390 [0.10]	0.170	0.705 [0.025]	0.184
Joint test:	2.133 [0.10]	1.928	2.442 [0.05]	1.537	2.306 [0.05]	0.971

a. See notes to Table 6.

b. Sample periods: (2) 1954Q1-1970Q4; (3) 1971Q1-1994Q1

Table 9
Forecasting performance of the reduced-form and autoregressive models

RMSE of one-quarter-ahead forecasts[a]

Inflation measure	Model	Subperiod[b]	
		1958Q1-1970Q4	1971Q1-1994Q1
GDP deflator	Autoregressive	2.331	2.693
	Reduced form	2.280	2.522
Total CPI	Autoregressive	1.665	2.142
	Reduced form	1.820	1.856
CPI excluding food and energy	Autoregressive	1.191	1.868
	Reduced form	1.306	1.666

RMSE of four-quarter-ahead forecasts

Inflation measure	Model	Subperiod	
		1958Q1-1970Q4	1971Q1-1994Q1
GDP deflator	Autoregressive	1.404	2.891
	Reduced form	1.776	2.424
Total CPI	Autoregressive	1.156	2.496
	Reduced form	0.991	1.445
CPI excluding food and energy	Autoregressive	0.951	2.003
	Reduced form	0.713	0.979

a. The root-mean-squared errors (RMSE) are calculated as follows:

For the one-quarter-ahead forecasts: $\text{RMSE} = \left\{ T^{-1} \sum_{i=1}^{T} \left[\left(\frac{p_t - p_{t-1}}{p_{t-1}} \right) - E_{t-1} \left(\frac{p_t - p_{t-1}}{p_{t-1}} \right) \right]^2 \right\}^{1/2}$

For the four-quarter-ahead forecasts: $\text{RMSE} = \left\{ T^{-1} \sum_{i=1}^{T} \left[\left(\frac{p_t - p_{t-4}}{p_{t-4}} \right) - E_{t-4} \left(\frac{p_t - p_{t-4}}{p_{t-4}} \right) \right]^2 \right\}^{1/2}$.

b. The period 1954Q1-1957Q4 is used to provide initial estimates of the parameters; the recursive estimation procedure begins in 1958Q1.

FIGURES

Figure 1
Annual inflation rates in Canada
(year-to-year percentage changes)

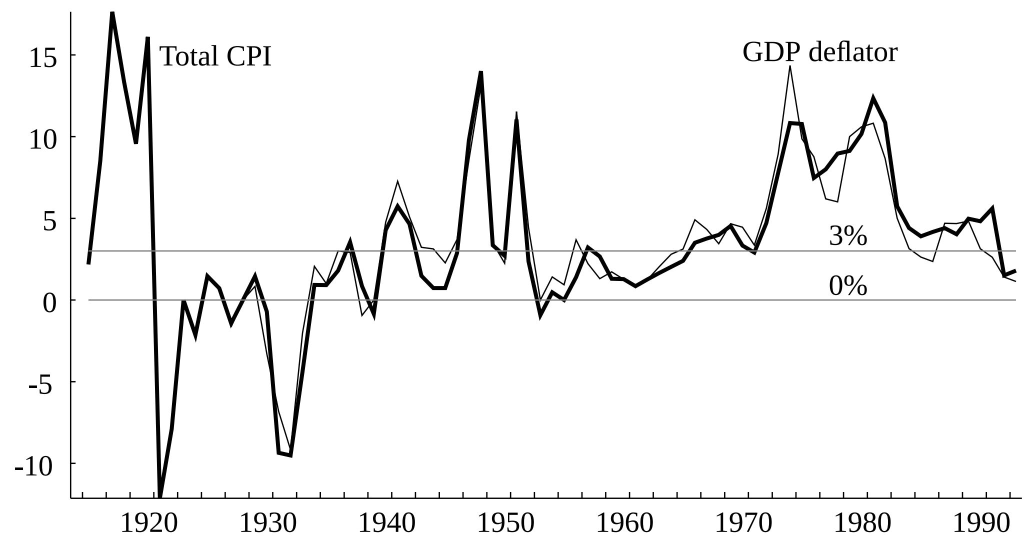


Figure 2
Recursive estimates of the mean inflation rate
(based on an autoregressive model of quarterly changes in the CPI)

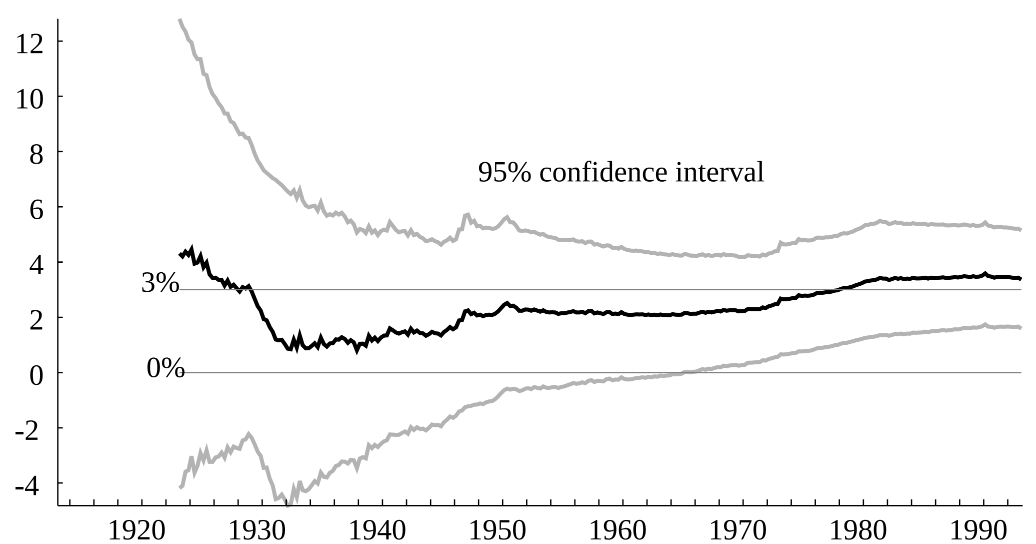


Figure 3
Cumulated sums of recursive residuals
(based on an autoregressive model of quarterly changes in the CPI)

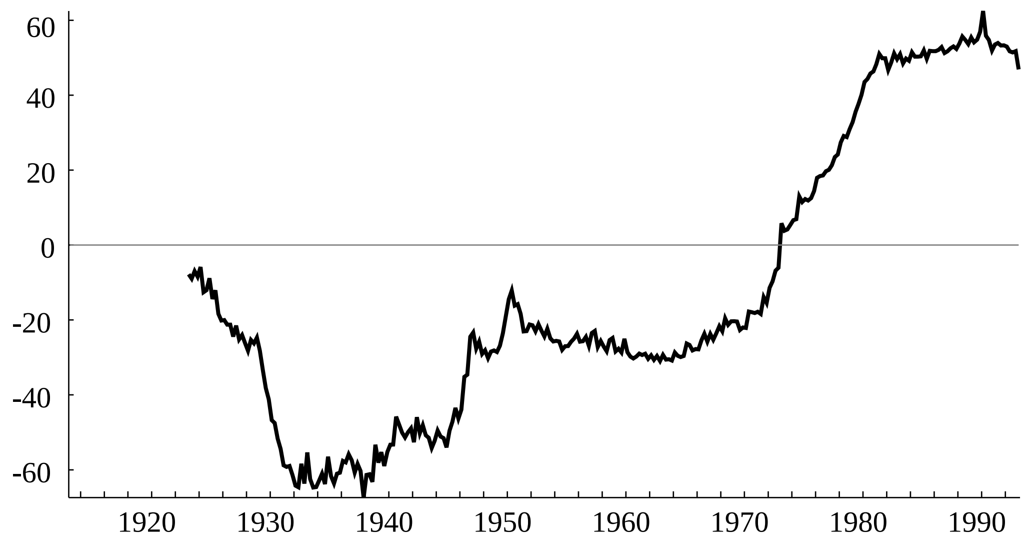


Figure 4
Recursive residuals
(based on an autoregressive model of quarterly changes in the CPI)

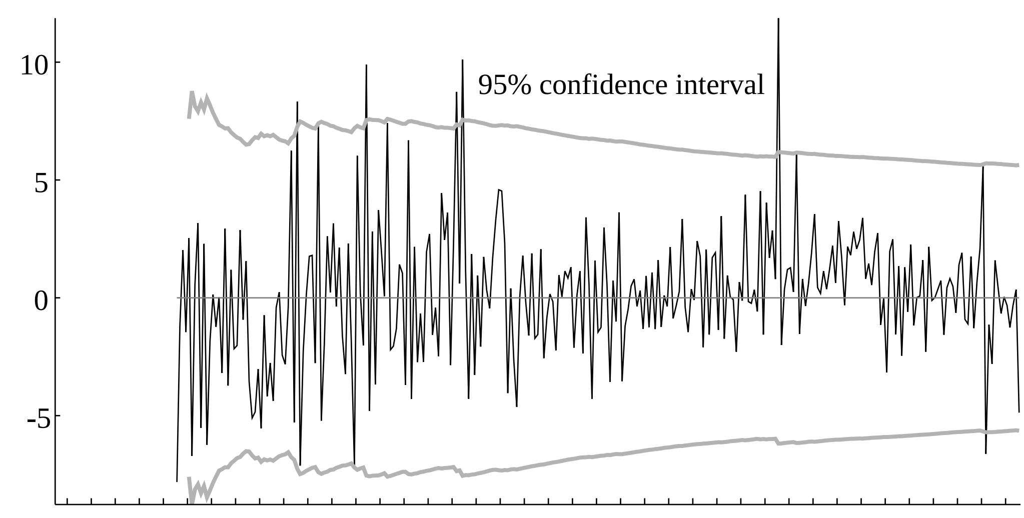


Figure 5
Recursive estimates of the largest autoregressive root
(based on an autoregressive model of quarterly changes in the CPI)

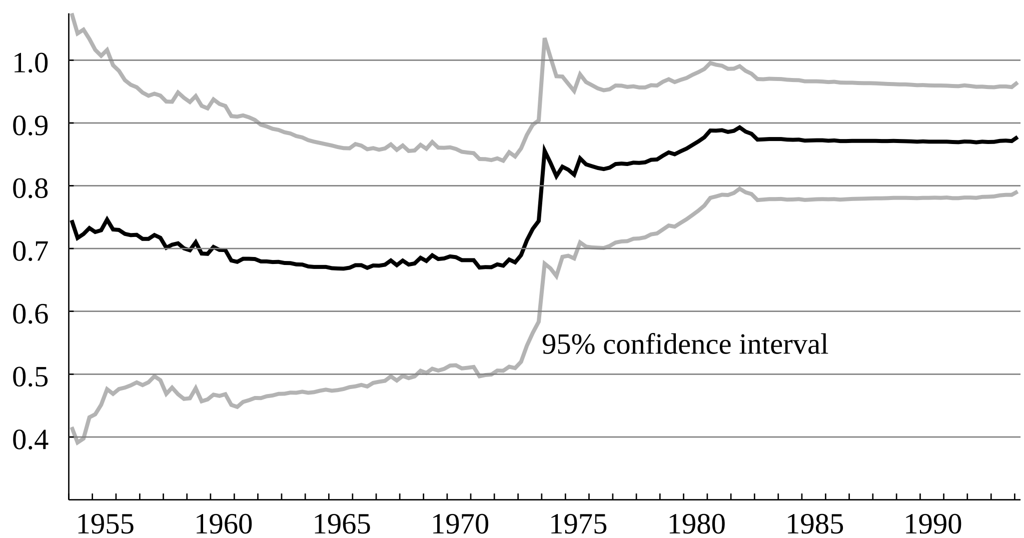


Figure 6
Time-series properties of inflation over subperiods
(based on quarterly changes in the total CPI)

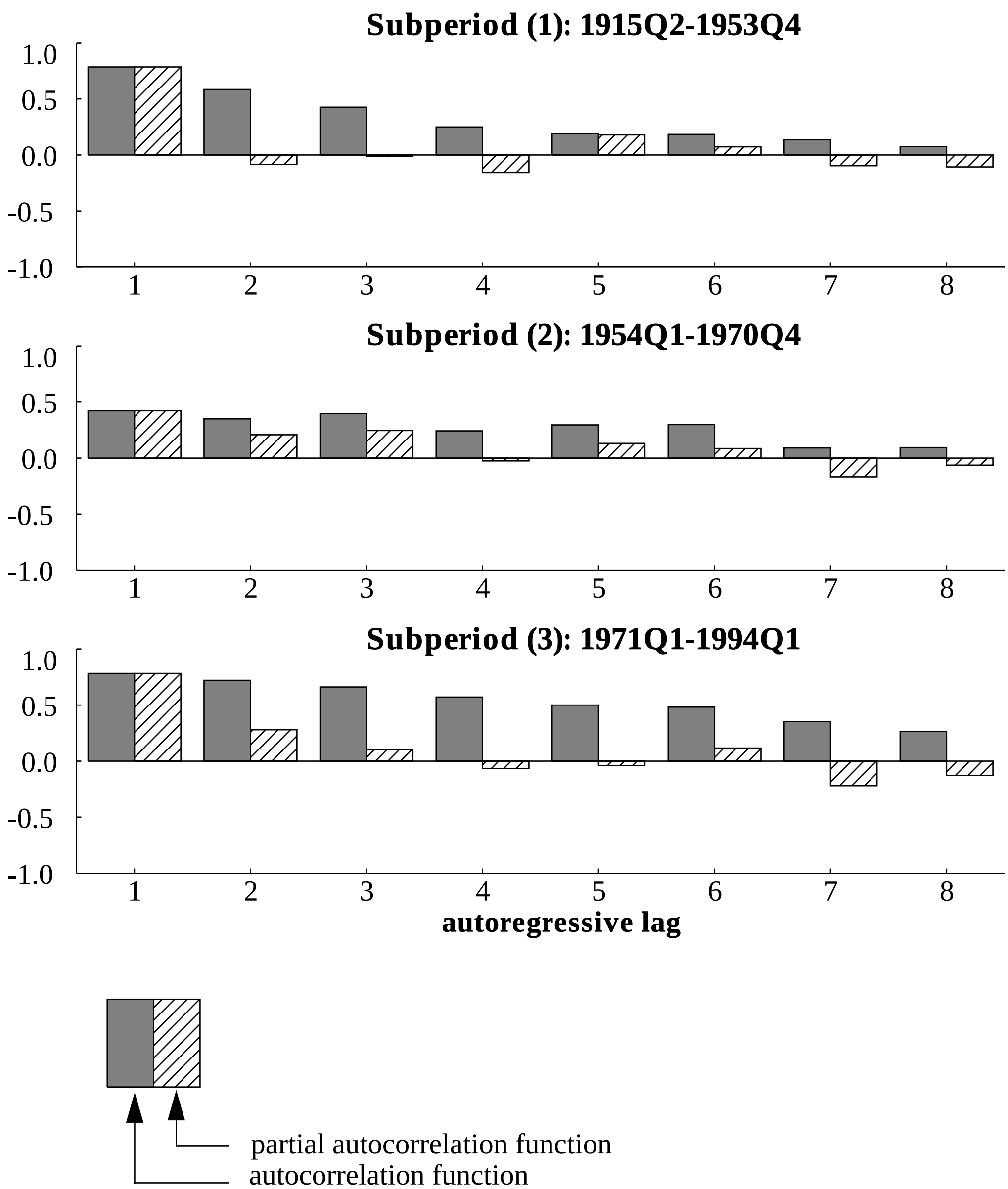


Figure 7
***Ex ante* probability of being in state 1**
(estimates obtained from the Markov switching model)

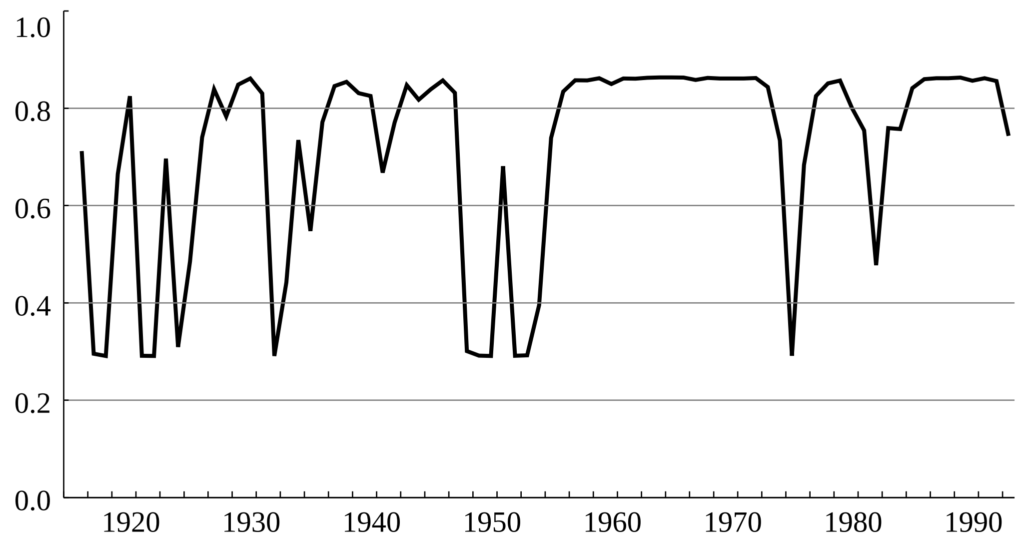


Figure 8
Cumulated sums of recursive residuals
(obtained from the reduced-form equations)

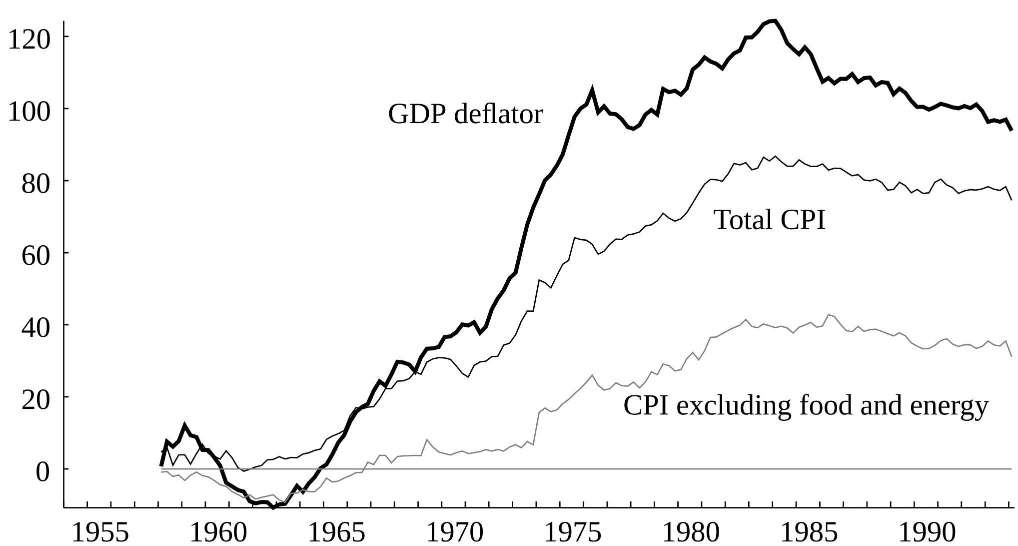


Figure 9
Cumulated sums of squared recursive residuals

(obtained from the reduced-form equations)

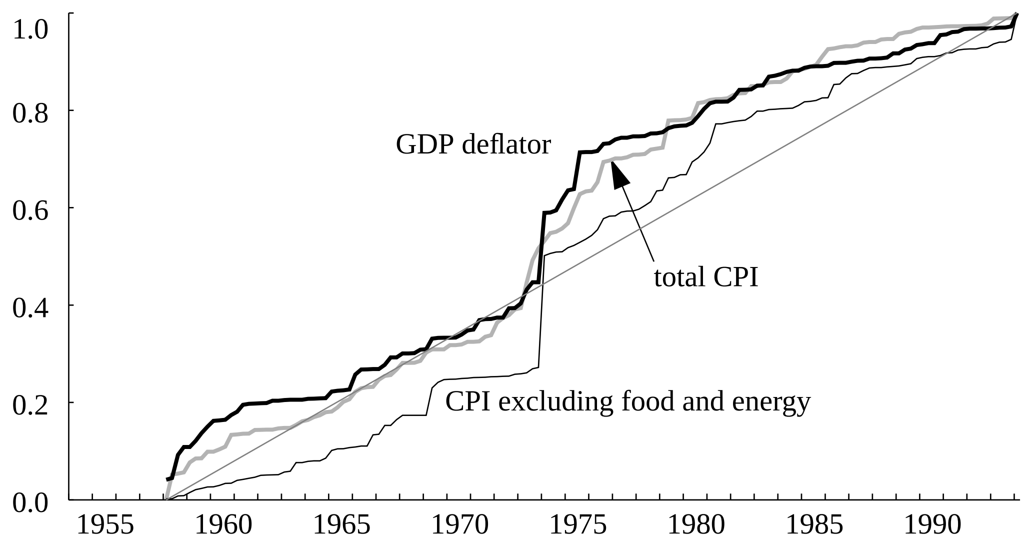


Figure 10
χ^2 statistics from rolling Chow tests

(based on reduced-form equations)

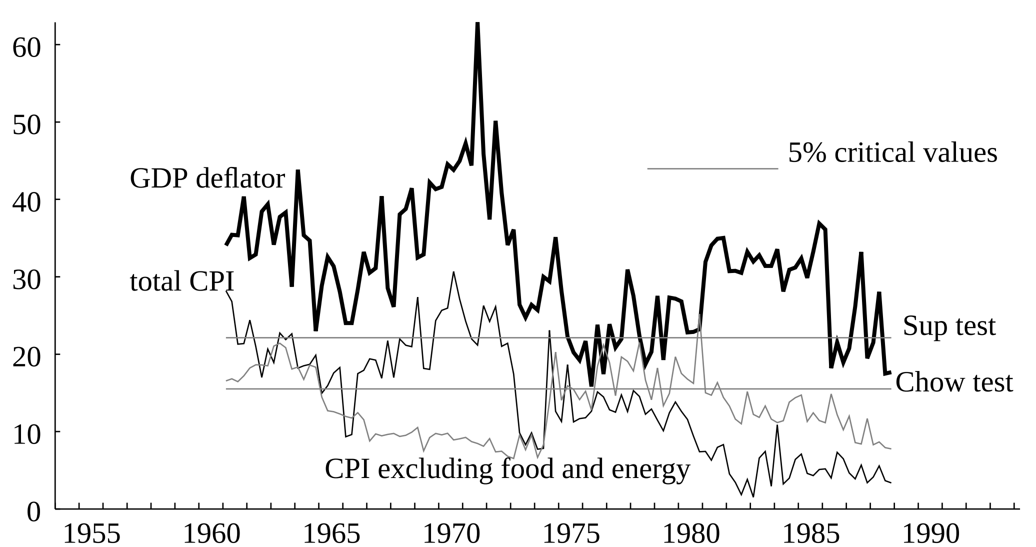
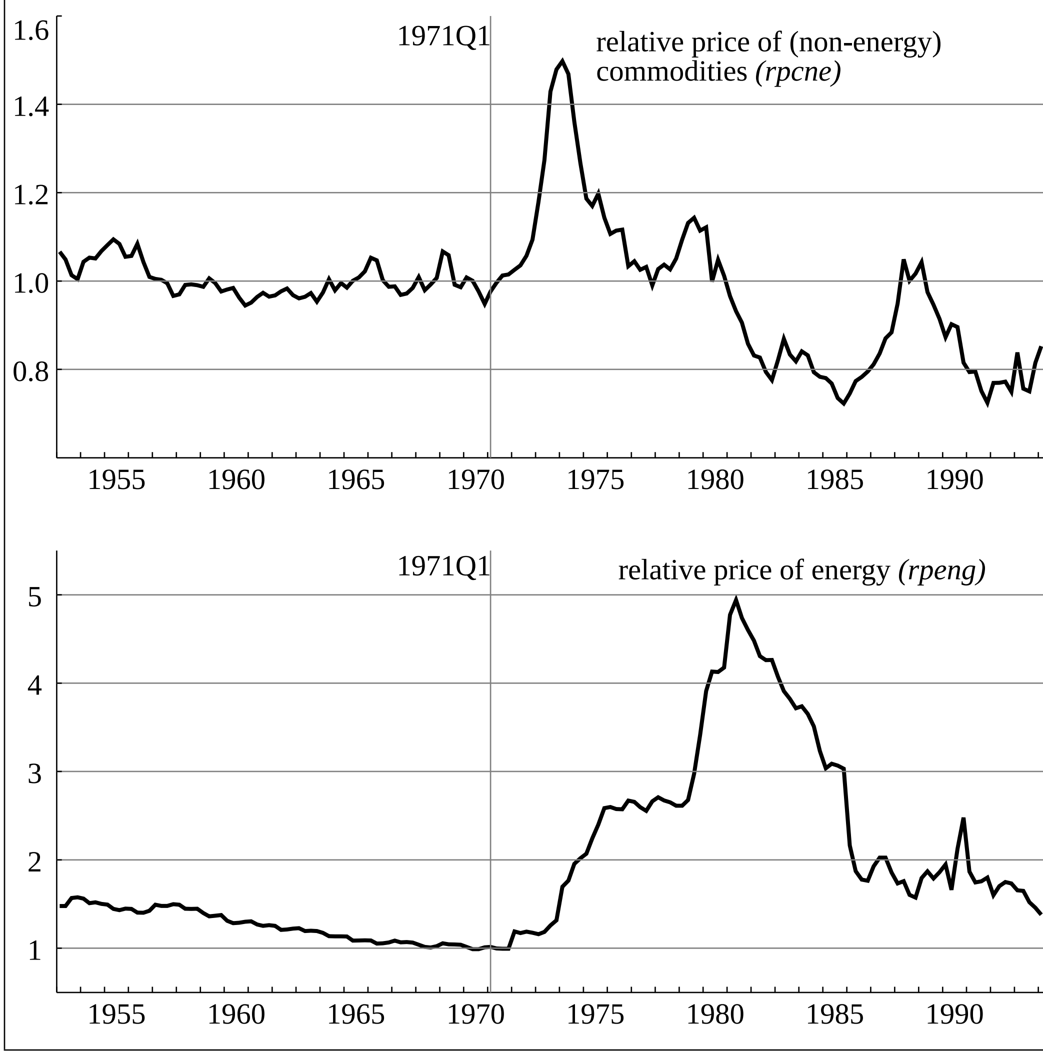


Figure 11
Relative commodity and energy prices

(1971 = 1.00)



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