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LONG MEMORY IN INFLATION EXPECTATIONS: EVIDENCE FROM INTERNATIONAL FINANCIAL MARKETS

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ABSTRACT

This study provides evidence that 10-year-ahead inflation expectations adapt very slowly to changes in realized inflation. This evidence derives primarily from yields on 10-year government bonds in a sample of OECD countries, including inflation-indexed bonds where they are available. The study examines both the cross-country and time-series behavior of interest rates and inflation rates. For the United States, additional evidence is provided from a survey of 10-year inflation expectations held by market participants. This study does not present a theoretical model of expectations formation. However, long memory of the type documented in this study would be implied by a model of multiple inflationary regimes in which agents base their probability distributions of future regimes on past inflationary experience.

Long Memory in Inflation Expectations: Evidence from International Financial Markets

Joseph E. Gagnon[1]

I. Introduction and Motivation

This study provides evidence that 10-year-ahead inflation expectations adapt very slowly to changes in realized inflation. This evidence derives primarily from yields on 10-year government bonds in a sample of OECD countries, including inflation-indexed bonds where they are available. The study examines both the cross-country and time-series behavior of interest rates and inflation rates. For the United States, additional evidence is provided from a survey of 10-year inflation expectations held by market participants.

Ever since Irving Fisher's *The Theory of Interest* (1930), economists have argued that, *ceteris paribus,* interest rates ought to move one-for-one with expected inflation.[2] There are two difficulties in proving this hypothesis: First, inflation expectations are not observed directly. Second, in the real world the *ceteris paribus* assumption does not hold, so that other factors must be taken into consideration. Fisher himself focused on the formation of expectations. He believed that the primary determinant of expected inflation is likely to be past inflation. By regressing interest rates on past inflation Fisher found

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[1]Senior Economist in the Division of International Finance, Board of Governors of the Federal Reserve System. This paper developed out of work for a study by the G-10 Deputies on *Saving, Investment, and Real Interest Rates*, October 1995. I received helpful comments from fellow drafters of that study, as well as David Bowman, Jon Faust, Dale Henderson, and Andrew Levin. This paper represents the views of the author and should not be interpreted as reflecting those of the Board of Governors of the Federal Reserve System or other members of its staff.

[2]Darby (1975) and Feldstein (1976) showed that in a theoretical closed economy, income taxation causes a greater than one-for-one response of interest rates to expected inflation. Hartman (1979) showed that in a theoretical small open economy, interest rates move one-for-one with expected inflation even in the presence of residence-based income taxes. Tobin (1969) argued that higher inflation leads to a less than one-for-one increase in interest rates because it reduces the demand for the monetary base relative to productive capital. However, given the small size of the monetary base relative to the capital stock, the Tobin effect is likely to be extremely small for any reasonable estimate of the elasticity of demand for the monetary base.

that a long distributed lag of past inflation provided the best fit, but that the total effect of lagged inflation on the interest rate was much less than one-for-one. This study concurs with Fisher that a long lag of past inflation provides the best fit, but in postwar data for the United States the total effect is shown to be almost exactly one-for-one. The discrepancy between Fisher's results and the postwar results is almost certainly due to the fact that under the Gold Standard the price level had no long-run drift, as long periods of inflation were followed by long periods of deflation.

The Fisher effect has been the subject of numerous studies in the past 30 years. Many of these studies model the expectations formation process explicitly. Nearly all empirical studies have concluded that interest rates move less than one-for-one with inflation expectations. Some studies, such as Summers (1983), have pointed to irrationality in the formation of inflation expectations as the source of the apparent rejection of the Fisher effect. Other studies, such as Mishkin (1984), have conjectured that there is a systematic tendency for high inflation rates to be associated with low real interest rates.[3] This violation of the *ceteris paribus* assumption may be due to the effects of monetary policy. A sustained monetary expansion tends to keep the short-term interest rate low even as the inflation rate begins to rise. However, most economists believe that monetary policy cannot lower the real interest rate indefinitely.

Most studies of the Fisher effect in postwar data have focused on short-term interest rates and allowed only short lags (up to three years) in the inflation expectations process. In order to minimize the influence of monetary policy this study focuses on long-term interest rates. Many economists believe that long-term interest rates are more important for consumption and investment decisions than short-term rates. Following the lead of Irving Fisher, this study examines the role of long lags in the formation of inflation expectations.

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[3]Mishkin (1992) shows that it is possible to accept the hypothesis of a one-for-one Fisher effect over certain sample periods using U.S. short-term interest rates. Peng (1995) finds similar evidence for France and the United Kingdom, but not for Germany and Japan.

One complication introduced by the focus on long-term interest rates is the potential for significant risk premia due to the lower liquidity of long-term bonds in many countries and due to the sensitivity of bond prices to changes in inflation expectations and real interest rates. (These risk premia are much less likely to be significant for short-term interest rates.) It is difficult to distinguish between the inflation expectation, the inflation-risk premium, and other risk premium components of the nominal bond yield. The primary focus of this study is on the sum of these components, which is loosely referred to as inflationary expectations, but some efforts are devoted to examining the inflation-risk premium independently.

The analysis presented here is purely empirical, but it does lend support to a class of theoretical models of inflation chracterized by occasional shifts in policy regimes. Evans and Lewis (1995) show that a regime-switching model of inflation can explain the empirical failure of the Fisher relation. In their paper, the regimes differ by the variance and persistence of shocks to inflation. The evidence presented in this study suggests an alternative specification, in which regimes differ by the average rate of inflation. If agents' beliefs about the relative probabilities of future inflation regimes are based on past experience, then the unobserved inflation expectations process will be correlated with past inflation over a long horizon.

II. Cross-Country Evidence

The cross-country analysis is based on data for 16 OECD countries.[4] The interest rate is the annual yield on 10-year government bonds supplied by the OECD Secretariat. The inflation rate is the percentage increase in the CPI over the previous four quarters, taken from *International Financial Statistics (IFS)*. The real exchange rate is a multilateral weighted average against the other 15 countries

[4]Australia (AL), Austria (AT), Belgium (BE), Canada (CA), Denmark (DE), France (FR), Germany (GE), Ireland (IR), Italy (IT), Japan (JA), the Netherlands (NE), New Zealand (NZ), Spain (SP), Sweden (SD), the United Kingdom (UK), and the United States (US).

in the sample using CPIs and weights based on each country's share in total world trade in 1993. Each country's real exchange rate is normalized by its average value over the period 1975-94. The exchange rates and trade shares are taken from *IFS*. Net public sector debt is taken from *OECD Economic Outlook* (December 1994).[5] The averages and standard deviations are computed with quarterly data over five-year periods.

IRLxy	Ave. Interest Rate, x-y	INFxy	Ave. Inflation Rate, x-y
RERxy	Ave. Real Ex. Rate, x-y	VEXxy	Std.Dev.(Real Ex. Rate)
VPIxy	Std.Dev.(Inflation Rate)	DEBTx	Net Debt/GDP in x

Interest rate regressions are run over three different time periods: 1980-84, 1985-89, and 1990-94. The study employs a general-to-specific strategy, but, due to limited degrees of freedom, the initial general specification does not include all possible independent variables. The initial specification is

$$IRL9094_i = \alpha + \beta\, INF9094_i + \gamma\, INF8589_i + \delta\, INF8084_i + \theta DEBT89_i + \lambda DEBT94_i + \varepsilon_i$$

and similarly for the other time periods. In every period, the restriction that the coefficients on current and lagged inflation sum to unity could not be rejected at the 10 percent level, so this restriction was imposed before further analysis. If inflation-risk premia were important in countries with a history of high inflation, one would expect to find the sum of these coefficients to be greater than unity. In fact, the unrestricted estimates always summed to less than unity. This result casts doubt on the importance of inflation-risk premia in countries with high inflation, at least for interest rates averaged over long periods of time.

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[5]Austria and Ireland report only gross debt. New Zealand debt is for central government only, from *IFS*. The findings with respect to debt are not sensitive to the exclusion of these countries.

In no case was a coefficient on debt individually significant, and in every case the coefficient on lagged debt was negative. This result suggests that the change in debt might be the relevant variable, so the regression was respecified in terms of the difference between current and past debt, and the implied restriction could not be rejected in any case. However, even the change in debt was never significant--although it always had a small positive coefficient--so that it was dropped from the preferred regressions, which are reported in Table 1.

Table 1. Interest Rates and Inflation Rates

Dep.Var.	Intercept	INFxy	INFxy-5	INFxy-10	R^2	std. err.
IRL9094	4.03** (.42)	0.66** (.07)	0.11 (.09)	0.23** (.07)	.83	0.76
IRL8589	4.67** (.37)	0.80** (.06)	0.31** (.08)	-0.11 (.07)	.95	0.58
IRL8084	4.29** (.64)	0.87** (.25)	-0.21 (.24)	0.34* (.16)	.67	1.92

* (**) significant at 5 (1) percent level. Sample of 16 OECD countries.

In every period, the current inflation rate is the single most important factor behind the long-term interest rate. Lagged inflation is also important in every period, although the nature of the lag pattern differs across periods. The R^2 statistics indicate that current and lagged inflation explain most of the differences in interest rates across countries. If current and lagged inflation are proxying for expected future inflation, the estimated intercepts indicate that the real interest rate lies between 4 and 5 percent over the past 15 years.

A number of variables were added sequentially to the preferred specification to test for additional factors influencing interest rates. The current level of the real exchange rate is expected to be positively correlated with the interest rate according to standard "overshooting" models of the exchange rate with sticky prices and imperfect goods substitution across countries. In practice, it had a significantly negative coefficient in 1985-89, and it was not significant in the other periods. The change in the real exchange rate between the current five-year period and the previous period also had a negative coefficient in 1985-89 and no significant coefficient in the other periods.

Variability of inflation or the real exchange rate is expected to have a positive effect on the interest rate if it increases the risk premium demanded by investors. The variability of the real exchange rate is measured as the quarterly standard deviation of the real exchange rate from 1975 through the current period. This variable was never significantly correlated with the interest rate. The variability of inflation is measured as the quarterly standard deviation of the annual inflation rate from 1970 through the current period. This variable always had a strongly *negative* coefficient, and it is significant in 1990-94 and 1985-89. Each percentage point increase in the standard deviation of inflation is estimated to reduce the interest rate by around 50 basis points. This result is puzzling, but its statistical significance is not robust to excluding one country--Japan--from the sample. However, even without Japan the coefficient is consistently negative.

Chart 1 displays cross-country scatter plots of interest rates and inflation rates. Each plot contains a 45 degree line with an intercept of 4. The upper left panel displays the current interest rates and inflation rates for 1990-94. The remaining three panels display the current interest rate in different five-year periods against a weighted average of current and past inflation.[6] Clearly, adding inflation rates from the earlier periods helps to explain the cross-country differences in nominal interest rates. A common world real interest rate of 4 percent would imply that all countries should lie on the 45 degree line, assuming that the weighted past inflation is a good proxy for expected future inflation.

[6]In each case the weights are 0.75 on current inflation, 0.15 on inflation from the previous period, and 0.10 on inflation from two periods ago.

Chart 2 displays scatter plots of nominal interest rates in the 1990s and net debt ratios at the beginning and end of this period (the top two panels). Very little correlation is apparent. The bottom left panel plots interest rates against the change in debt ratios over this five-year period. In this panel, there is a weak positive relationship, which is consistent with the regression results described above. In the bottom right panel interest rates are plotted against the historical variability of inflation. There appears to be a weak positive correlation, with Japan as an outlier near the bottom of the plot. This correlation appears to contradict the regression results described above, in which the coefficient on variability was negative. These contradictory results are due to the collinearity of the level and variability of past inflation. Once the level of past inflation is controlled for, the effect of variability turns negative, although the significance of this effect is dependent on the inclusion of the Japanese outlier.

III. Time-Series Evidence

This section examines the time-series evidence on the Fisher effect in individual countries. Table 2 presents augmented Dickey-Fuller statistics on quarterly interest rates and inflation rates. The data are the same as those used in the previous section except for the exclusion of Australia, Austria, and Japan due to missing data in the 1960s and early 1970s. The 2-year inflation rate is calculated as the annualized growth rate of the CPI over the previous 8 quarters. The 10-year inflation rate is calculated as the annualized growth rate over the previous 40 quarters.

Table 2 shows that both the interest rate and the inflation rate appear to be nonstationary with the notable exception of Germany, where the interest rate and the 2-year inflation rate appear to be stationary.[7] A standard property of many theoretical economic models is that the real rate of interest is stationary.

[7] The augmented Dickey-Fuller tests use four lagged differences of the variable being tested. F-tests against regressions with five and eight lagged differences reveal that longer lags are often significant in the inflation regressions, where they tend to reduce the magnitude and significance of the test statistics for 2-year inflation. Longer lags are almost never significant for the other variables, and where they are significant they do not change the results presented in Table 2.

Table 2. Augmented Dickey-Fuller Tests, 1961Q2-1994Q4					
				10-Year Bond Rate less	
	10-Year Bond Rate	2-Year Inflation	10-Year Inflation	2-Year Inflation	10-Year Inflation
Belgium	-1.90	-2.75*	-1.79	-2.14	-2.85*
Canada	-1.90	-2.06	-1.86	-1.41	-3.70***
Denmark	-1.44	-2.11	-1.58	-2.64*	-1.99
France	-1.63	-2.10	-1.31	-1.38	-2.36
Germany	-3.43**	-3.66***	-1.75	-3.13**	-3.02**
Ireland	-1.70	-2.49	-1.98	-2.32	-2.24
Italy	-1.54	-1.98	-1.98	-1.27	-1.86
Netherlands	-2.54	-2.24	-1.63	-1.74	-1.98
New Zealand	-1.36	-1.86	-1.41	-1.57	-2.72*
Sweden	-1.53	-2.66*	-1.59	-1.71	-3.57***
United Kingdom	-1.83	-2.34	-2.16	-2.50	-2.06
United States	-1.97	-2.54	-1.92	-2.32	-4.21***

***, **, * denote significance at 1, 5, and 10 percent levels, respectively.
All tests use 4 lagged differences.

Table 2 also presents stationarity tests of two measures of the real rate of interest. When the real interest rate is measured using the inflation rate from the previous 2 years, one can reject the hypothesis of nonstationarity in only two cases. However, when the real interest rate is measured using the inflation rate from the previous 10 years, one can reject nonstationarity for 6 of the 12 countries. Given the low power of the test, this is a strong result.[8]

Table 3 presents estimates of the cointegrating coefficient between the long-term bond rate and the inflation rate. Only in the case of Germany does the interest rate appear cointegrated with the 2-year inflation rate. However, in 6 countries the interest rate appears cointegrated with the 10-year inflation rate. Also, in every country except Germany and Denmark the cointegrating coefficient is closer to 1 when 10-year inflation is used, which is consistent with a stationary real interest rate.

Table 3. Estimated Cointegrating Coefficients, 1960Q1-1994Q4

	10-Yr. Bond Rate and	
	2-Year Inflation	10-Year Inflation
Belgium	0.40	0.88
Canada	0.60	0.93**
Denmark	1.02	1.48
France	0.63	0.99
Germany	0.54***	0.53**
Ireland	0.51	0.72*
Italy	0.56	0.82
Netherlands	0.35	0.62
New Zealand	0.47	0.89
Sweden	0.63	1.08**
U. K.	0.42	0.59*
U. S.	0.60	1.03***

OLS regression of bond rate on inflation rate and intercept. ***, **, * denote significance at 1, 5, and 10 percent levels, respectively, using the Engle-Granger test on the residuals of the cointegrating regression. All tests use 4 lagged differences of the residuals.

Because high inflation tends to be associated with more variable inflation, one might expect the inflation-risk premium to increase with the level of inflation. Such behavior would imply a cointegrating coefficient greater than 1. In practice, the estimated coefficient is less than 1 in nearly all countries for both proxies of inflation expectations, thus casting doubt on the importance of the inflation-risk premium. It should be noted that

[8]Horvath and Watson (1993) propose a multivariate test of a known cointegrating vector that generally has a higher power than the univariate test used here. The higher power derives from the modeling of the different dynamic properties of the component series. In this example, however, the Horvath-Watson test also rejects non-cointegration in only 6 of the 12 countries at the 10 percent level, and only 3 countries at the 5 percent level.

since both 2-year and 10-year lagged inflation are imperfect measures of inflationary expectations, their estimated coefficients are biased downwards. However, the finding of a stationary real interest rate in Table 2 implies that the inflation-risk premium must be stationary and that it cannot have drifted over time.

Chart 3 plots the measured real interest rate using 2-year inflation. One common feature for many of the countries in Chart 3 is the sharp drop in the measured real rate in the 1970s and the sharp rise in the 1980s. This pattern reflects the rise and fall of inflation rates in these countries. There are two possible explanations for this common pattern: First, 2-year lagged inflation does not proxy well for expected future inflation. Second, expansionary monetary policy drove the real rate down at the same time that it increased inflationary expectations. While the second explanation surely played some role, it is difficult to believe that monetary policy drove the 10-year real interest rate down by as much as 10 percentage points in some countries. Almost no economist believes that monetary nonneutralities are as large and persistent as that.

It is particularly interesting to note that Germany did not share this common pattern of the measured real interest rate. German inflation over this period was much more stable than inflation in the other countries. Thus, it is reasonable to suppose that the 2-year proxy for inflation expectations does not perform as badly for Germany as for the other countries. The relative stability of the measured German real interest rate provides further evidence against the argument that expansionary monetary policy drastically lowered the true real long-term interest rate in most of these countries. If the real interest rate did drop precipitously in the rest of the world in the 1970s, Germany should have experienced a similar decline in its real interest rate or a massive real appreciation of its exchange rate.[9] On the other hand, if

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[9]To fully offset a 5 percentage point decrease in the world 10-year real interest rate, a country's real exchange rate would have to appreciate by 70 percent. Between December 1971 and December 1975 the Deutschemark appreciated against the dollar by 25 percent in nominal terms and 18 percent in real terms using CPIs.

2-year inflation is not a good proxy for expected future inflation in most of these countries, there would be no reason to expect a drop in the measured real rate for countries where inflation has been more stable.

Chart 4 shows that measured real interest rates are more similar across countries, and their movements over time are smaller and less persistent, when 10-year lagged inflation rates are used to proxy for inflationary expectations. (The real interest rates using 2-year lagged inflation are plotted as dotted lines.) The only exceptions to this pattern are Germany, where measured real rates are insensitive to the choice of expectations proxy, and Denmark, where the real rate appears to undergo a structural break in the early 1980s when 10-year lagged inflation is used. Overall, the visual evidence of Charts 3 and 4 confirms the statistical evidence provided by Tables 2 and 3.

If a long lag of past inflation helps to explain the long-term interest rate, it is natural to ask whether a long lag of past inflation is a better predictor of future inflation over a long horizon. Somewhat surprisingly, the answer is no. However, in order to test whether 10-year lagged inflation is a good predictor of 10-year ahead inflation, one would like to have many independent observations of 10-year ahead inflation. In the postwar period we effectively have 5 such observations, one of which must be used for initial conditions. This is simply not a long enough sample to test the predictive property of long-term inflation models.

The small sample problem is evident in the inflation experience of many countries, including the United States. Between 1948 and 1995, the years 1974-82 stand out as high inflation years, while the remaining years have much lower inflation rates. Thus, in the early 1960s and early 1990s (so far) a long lag of inflation was a better predictor of 10-year ahead inflation, but in the mid 1970s and the late 1980s a short lag of inflation was a better predictor of 10-year ahead inflation.

It is possible that the 1974-82 period reflects a different inflation regime than the other years. In the presence of infrequent regime shifts, a long backward average of inflation may provide a reasonable proxy for the formation of expectations, especially as agents themselves learn about the regime-switching process over time. Thus, in the mid-1970s, agents may have expected an early return to the low inflation of the previous two decades. After inflation remained high for several years, agents may have upgraded their subjective probabilities of remaining in a high-inflation regime. The converse may be true in the 1980s.

IV. Survey Expectations

The Federal Reserve Bank of Philadelphia conducts a quarterly survey of 10-year ahead inflationary expectations held by financial market participants in the United States, including investment banks and consulting firms. Chart 5 plots these long-term inflation expectations as well as average past inflation rates over various horizons.[10] Although none of the past inflation series exactly matches the survey expectations, the 10-year past inflation measure comes closest.

To confirm this visual impression more accurately, the root mean squared deviations (RMSDs) between survey expectations and past average inflation were calculated for backward horizons of 1 to 15 years. The minimum RMSD of 1.04 is obtained with a backward horizon of 9 years, the maximum of 2.35 is associated with a horizon of 1 year.

In order to compare survey expectations with *ex post* future inflation, the sample was shortened to 1978-85. RMSDs were calculated for future inflation over horizons from 1 to 10 years. RMSDs were also calculated for past inflation over horizons from 1 to 15 years. The closest proxy to survey expectations in this sample is a backward average of 14 years with an RMSD of 1.09. All of the backward average RMSDs except the 1-year were smaller than the smallest future average RMSD, which was the 8-year at 2.75.

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[10]The Philadelphia Fed survey begins in 1980. A similar survey by Barclay's extends back to 1978, but it contains many missing observations. During the periods of overlap the two surveys are essentially identical. In order to extend the sample for comparison, Chart 5 uses the Barclay's data for 1978-79 and interpolates some missing observations for these two years only.

V. Index-Linked Bonds

For countries that have bonds linked to the consumer price index, the real interest rate on these bonds provides additional evidence on the behavior of inflationary expectations in nominal bond yields. Two factors must be taken into consideration when comparing index-linked yields to yields on nominal bonds. First, the markets for index-linked bonds are much less liquid than the markets for nominal bonds, so that index-linked yields may include a significant liquidity premium. Second, index-linked bonds are largely free of inflation risk, so their yields are lower than nominal yields due to the absence of both expected inflation and any inflation-risk premium.

Charts 6-8 plot the long-term index-linked bond yields for the three countries that have historical data on such bonds.[11] In recent years, the best proxy for the real indexed yield has been the nominal yield minus a long average of past inflation.[12] In the early 1980s in the United Kingdom, a short average of past inflation performs better, possibly because of the improved inflation credibility associated with the change of government in 1979.

Table 4. Root Mean Squared Deviation from Index-Linked Rate

	Nominal yield less 2-year inflation	Nominal yield less 10-year inflation
Australia	1.43	0.89
Canada	1.22	0.48
U.K.	1.50	1.76

Over the entire sample available, the RMSD between the real indexed yield and the nominal yield less past inflation is substantially smaller for Australia and Canada when 10 years of inflation are used

[11]A constant-maturity 10-year index-linked yield is available only for the United Kingdom. For Australia, the chart uses the yield on an index-linked bond maturing in 2005. For Canada, the chart uses the yield on an index-linked bond maturing in 2021.

[12]The volatility of the nominal bond yield relative to the real indexed bond yield provides some evidence in favor of a time-varying risk premium, as both survey expectations of inflation and past averages of inflation are quite smooth.

than when 2 years of inflation are used. (See Table 4.) For the United Kingdom, the RMSD is somewhat lower when 2-year inflation is used.

VI. Conclusion

This study is an empirical exercise demonstrating that expectations about future inflation over a long horizon appear to be better explained by a long average of past inflation than by a short average. This conclusion does not imply that market expectations about future inflation are irrational. This study has not presented a theoretical model of expectations formation. However, long memory of the type documented in this study would be implied by a model of multiple inflationary regimes in which agents base their probability distributions of future regimes on past inflationary experience.

This study has not focused attention on the issue of the inflation-risk premium in nominal long-term bonds. However, the limited evidence that is examined does not support a significant risk premium that is systematically related to the level or variability of inflation.

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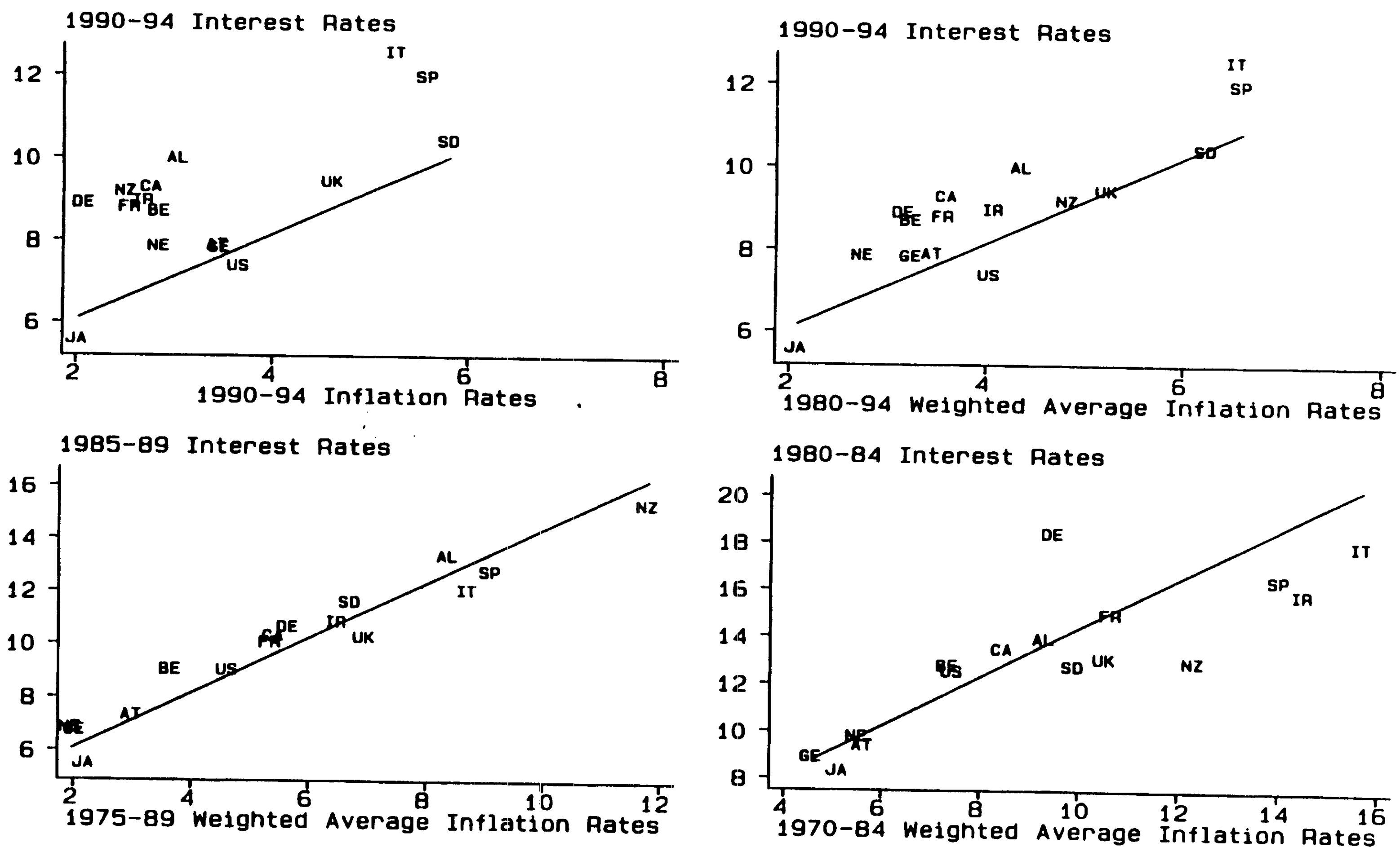


Chart 1. Interest Rates and Inflation Rates

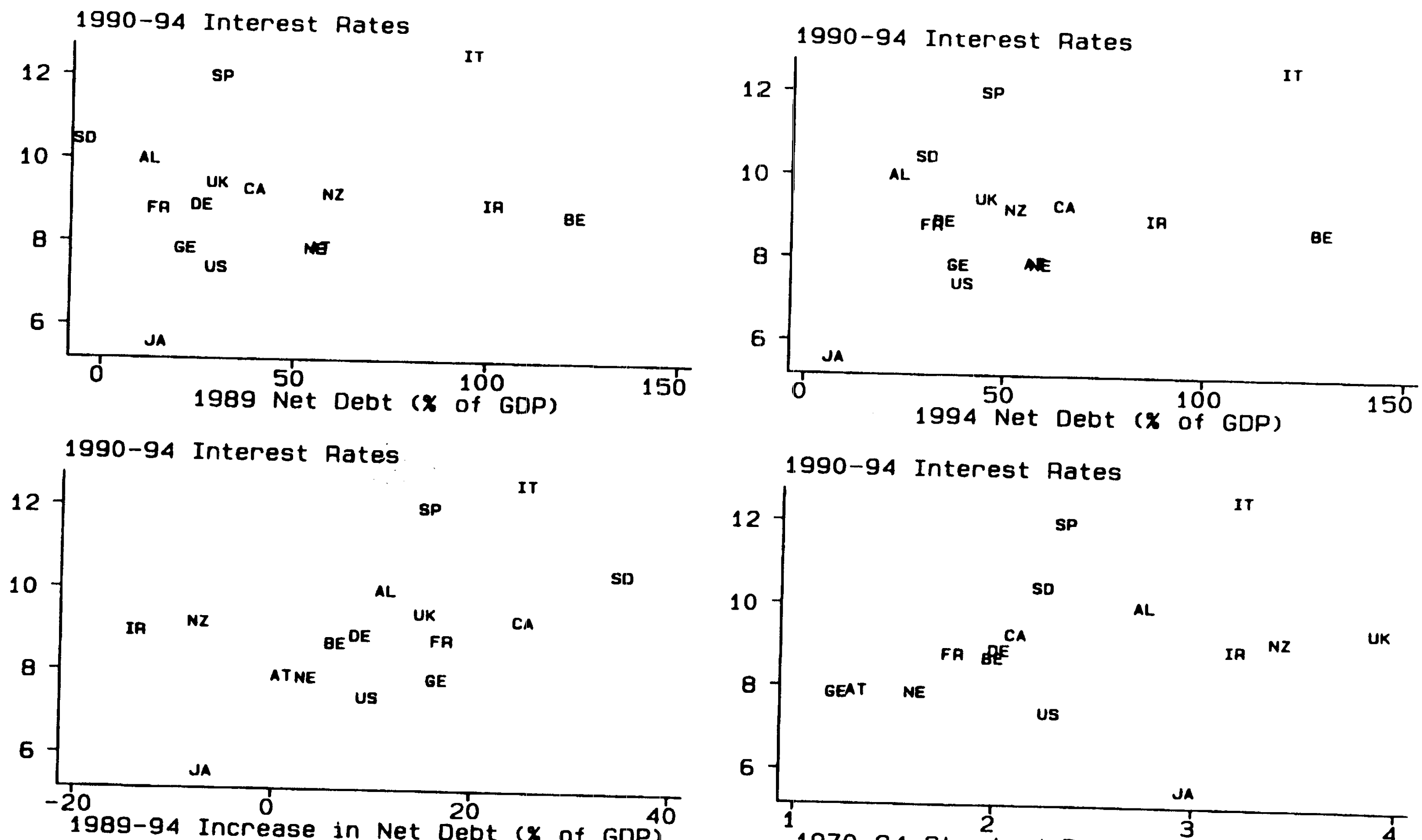


Chart 2. Interest Rates, Public Debt, and Inflation Volatility

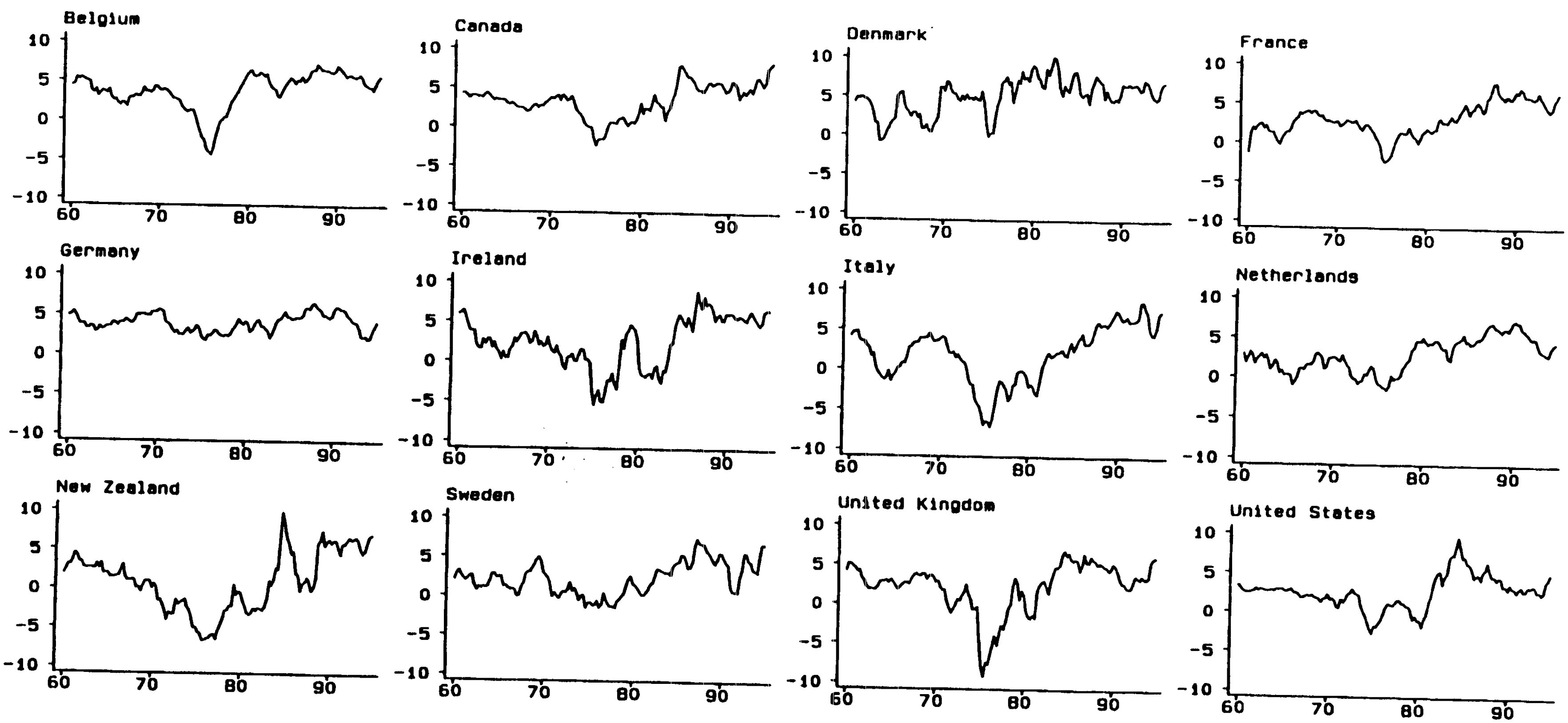


Chart 3. 10-Year Bond Rate Minus 2-Year Lagged Inflation

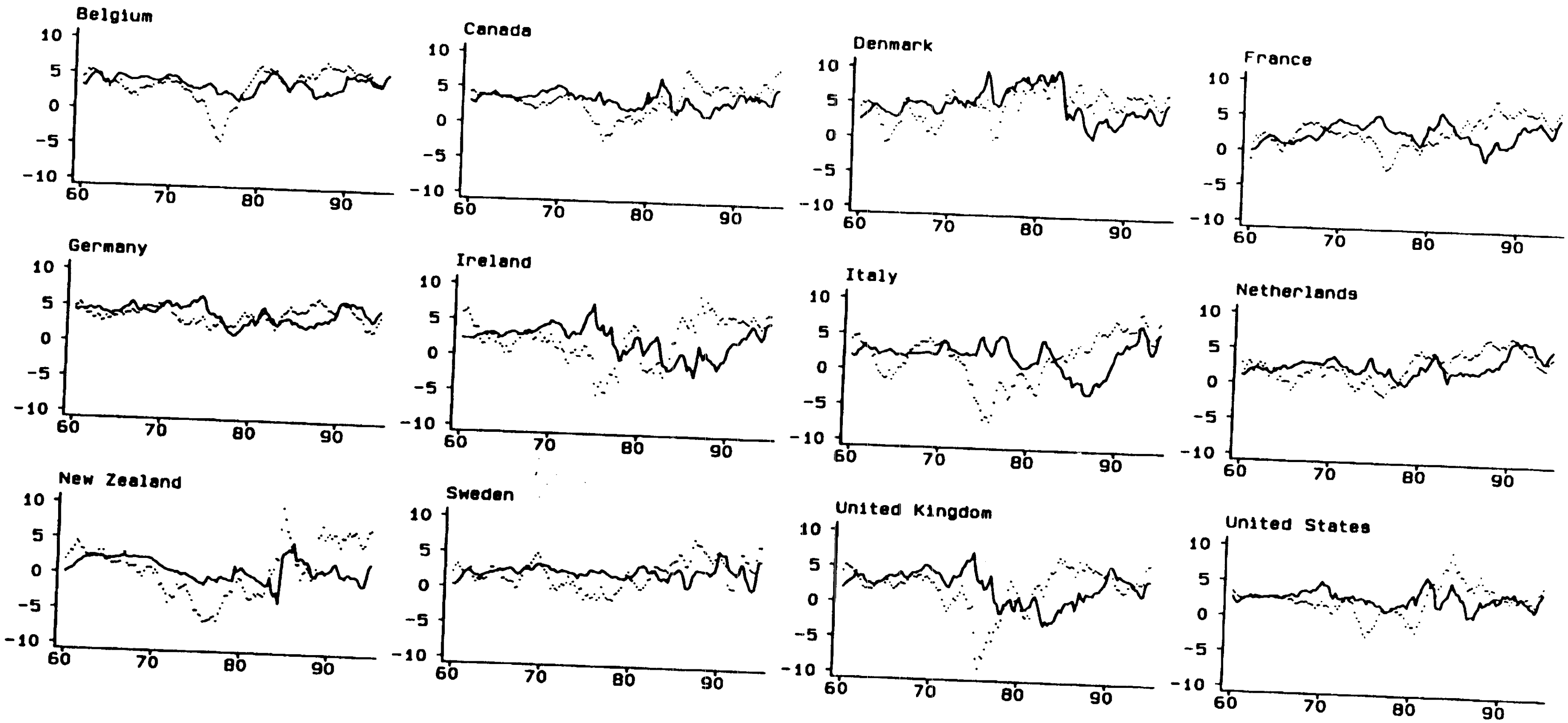


Chart 4. 10-Year Bond Rate Minus 10-Year Lagged Inflation

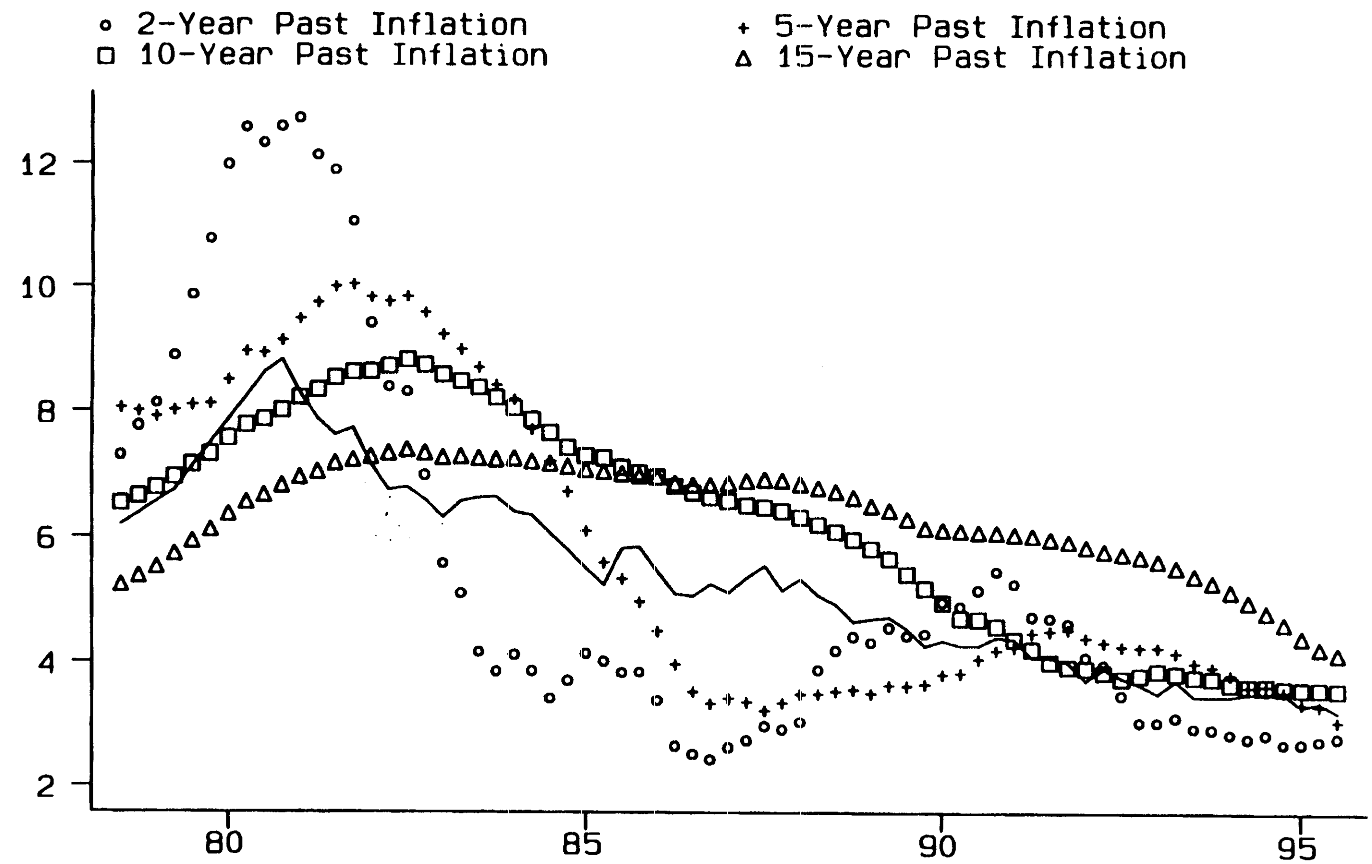


Chart 5. Survey of 10-Year Inflation Expectations (solid line)

Chart 6. Real Long-Term Interest Rates
Australia, 1985-94

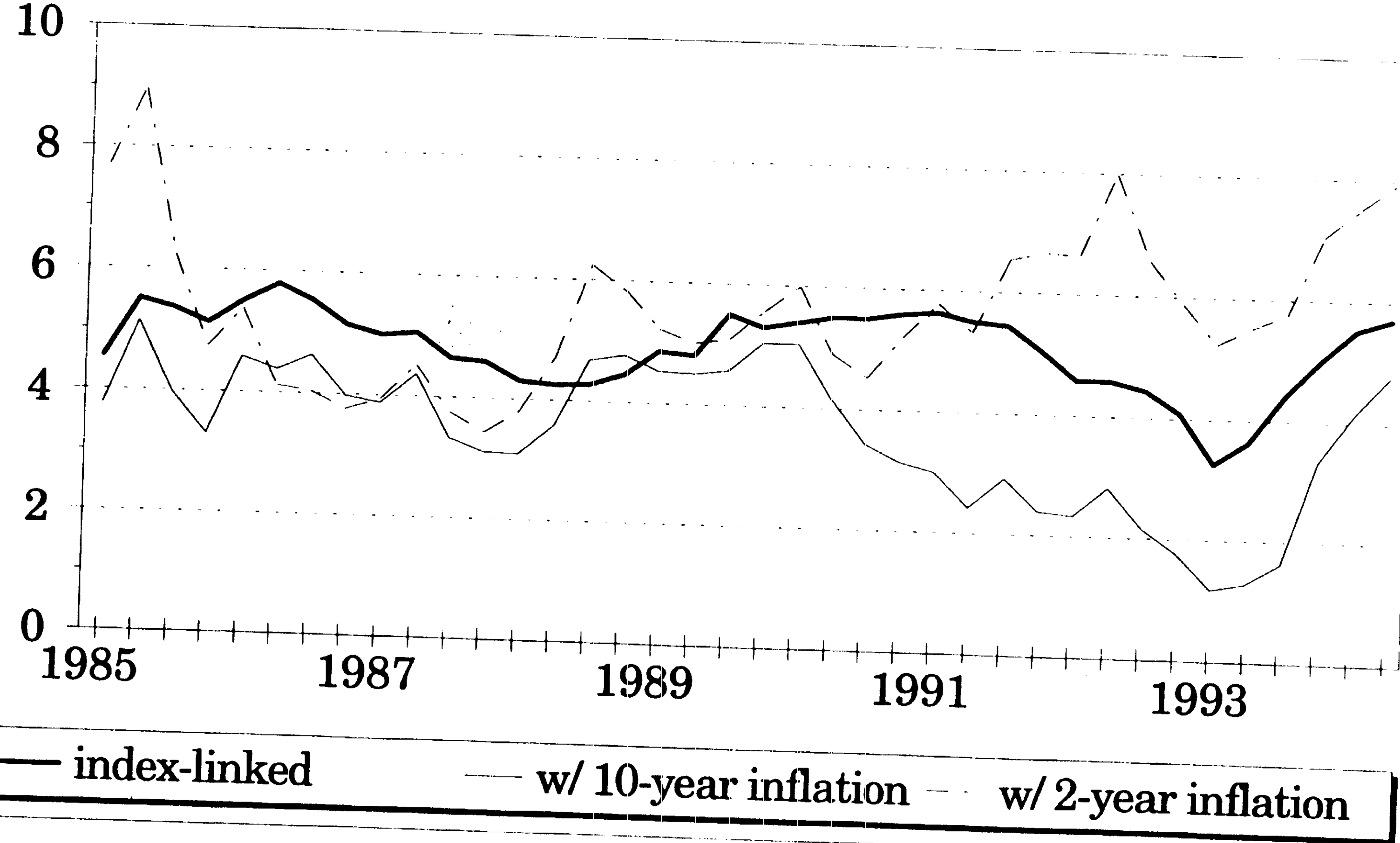


Chart 7. Real Long-Term Interest Rates
Canada, 1991-94

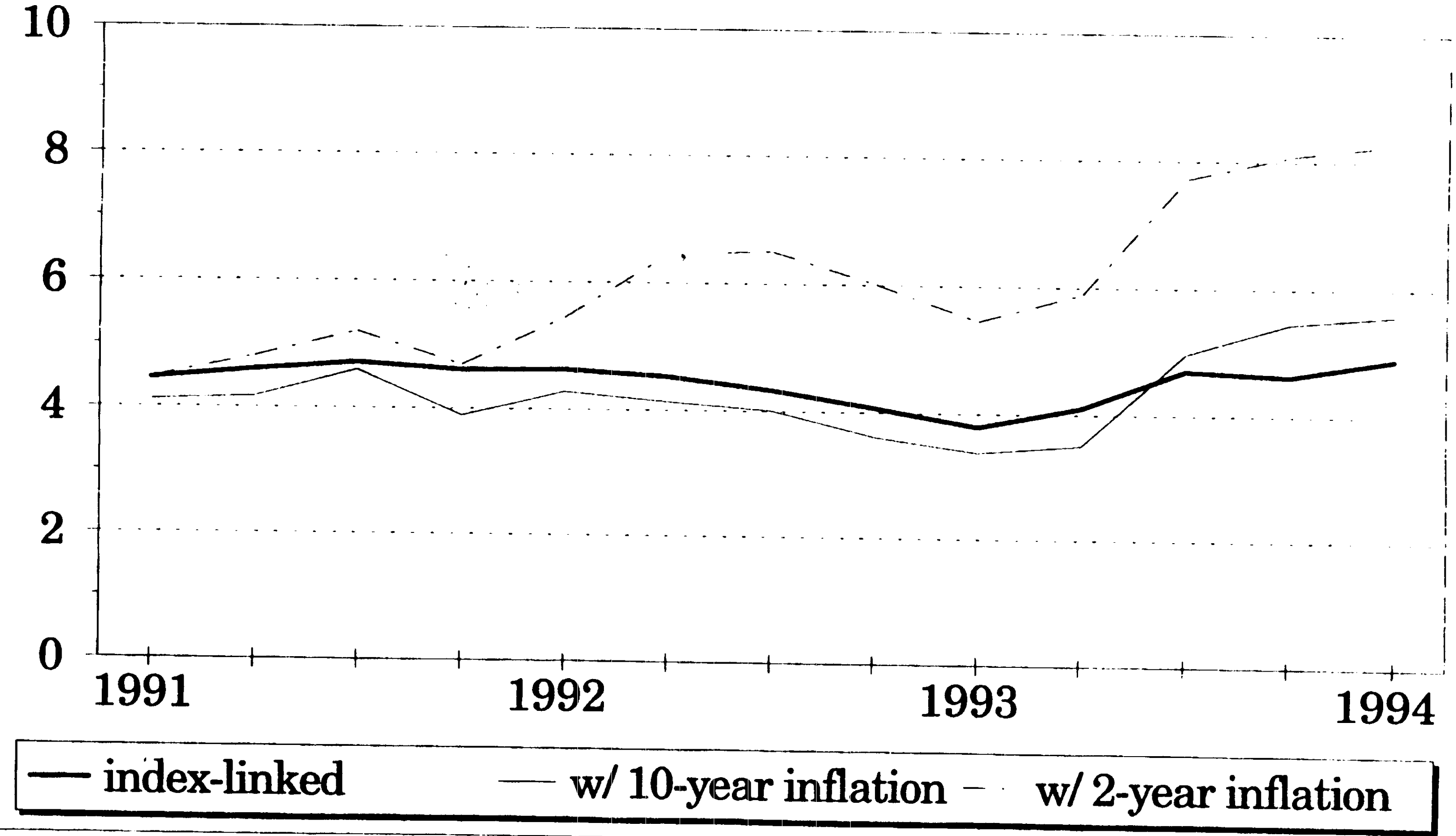
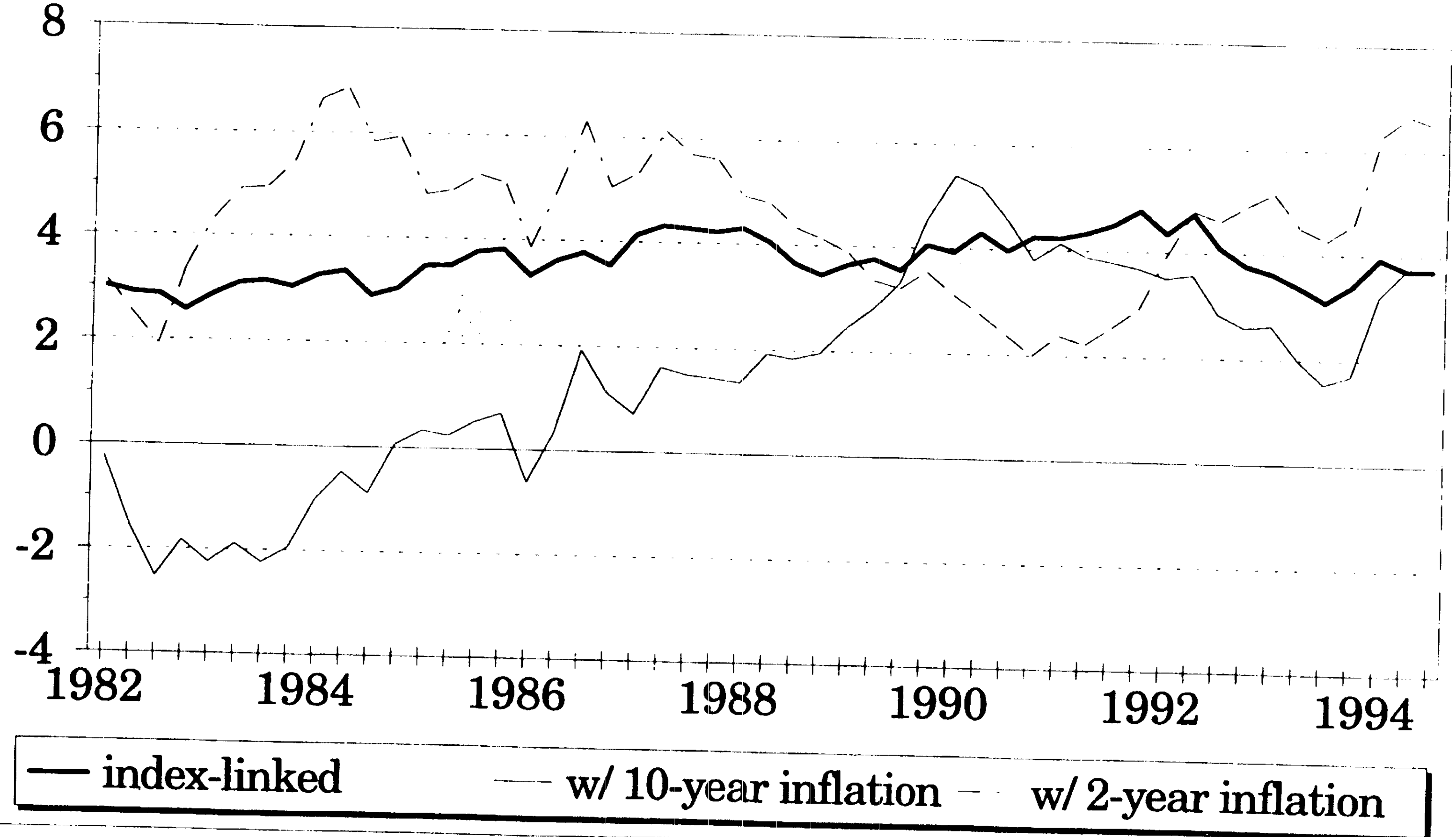


Chart 8. Real Long-Term Interest Rates

United Kingdom, 1982-94



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