NBER WORKING PAPER SERIES

AN EXAMINATION OF AGGREGATE PRICE UNCERTAINTY IN FOUR COUNTRIES AND SOME IMPLICATIONS FOR REAL OUTPUT

Richard T. Froyen

Roger N. Waud

Working Paper No. 1460

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
September 1984

We would like to thank participants in the Macroeconomics workshop at UNC, Chapel Hill for helpful comments on an earlier draft of this paper. Similarly, we are thankful to the participants in the NBER Summer Institute 1983, Program in Financial Markets and Monetary Economics, for their comments on an earlier draft. Financial support for this project was provided by the Faculty Research Council, University of North Carolina, Chapel Hill. The research reported here is part of the NBER's research programs in Financial Markets and Monetary Economics and Economic Fluctuations. Any opinions expressed are those of the authors and not those of the National Bureau of Economic Research.

NBER Working Paper #1460
September 1984

An Examination of Aggregate Price Uncertainty in Four Countries and Some Implications for Real Output

ABSTRACT

This study constructs measures of aggregate price uncertainty for four industrialized countries (Canada, West Germany, Great Britain, and the United States) and attempts to assess the extent to which more rapid and more variable price changes appear to have contributed to increased aggregate price uncertainty. For this purpose we examine the relationship across countries and through time between the rate of inflation, inflation variability, and our measures of price uncertainty. In addition we use our measures of price uncertainty to examine the hypothesis, variously put forward by Marshall, Keynes, Milton Friedman, and Okun, that higher aggregate price uncertainty is likely to result in lower real output and higher unemployment. Our results suggest that the higher and more variable inflation of the 1970s did increase uncertainty about the aggregate price level in Canada, Great Britain and the United States, but the evidence for West Germany would not sustain such a conclusion. Finally, we did find evidence of a significant negative output effect of aggregate price uncertainty for Canada and the United Kingdom, but not for the United States or West Germany.

Richard T. Froyen
Roger N. Waud
Department of Economics
Gardner Hall
University of North Carolina
Chapel Hill, NC 27514

(919) 966-5375
or
(919) 966-5332

I. Introduction

An important consideration in evaluating the costs of price level instability is the degree to which such instability increases uncertainty about the aggregate price level. Many costs of movements in the aggregate price level pertain only to unanticipated changes.[1] These costs include random income distribution effects and some (though not all) of the misallocations of resources attributed to price level instability. During the past two decades the United States and a number of other industrialized countries have experienced both more rapid and more variable rates of price change. This study assesses the degree to which these more rapid and more variable price changes have caused increased aggregate price uncertainty. For this purpose we construct measures of price uncertainty. We then examine the relationship across countries and through time among these measures of price uncertainty, inflation variability and the rate of inflation.

Additionally, economists going back to Marshall (1886) and including Keynes (1924), Friedman (1977), and Okun (1981) have argued that higher aggregate price uncertainty will likely result in lower real output and higher unemployment -- as expressed by Marshall almost 100 years ago "A great cause of the discontinuity of industry is the want of a certain knowledge as to what a pound is going to be worth a short time hence, [Marshall 1886, p. 9]." Having constructed measures of aggregate price uncertainty, we apply them to examine this hypothesis.

Quarterly measures of price uncertainty are constructed for Canada, the United Kingdom, the United States and West Germany for the time period from 1965 to the early 1980s. The measure of uncertainty is the error variance of the one-step ahead prediction of the price level based on a simple model containing both aggregate supply and demand factors--a modified version of the Lucas (1973) model.

The organization of the paper is as follows. Section II presents the model. Section III explains the uncertainty measure. Section IV considers some details of the empirical specification of the model's price equation. Section V presents our empirical results. Section VI compares our measures of uncertainty with those of earlier studies, particularly those of Robert Engle (1982, 1983), for the United States and United Kingdom. Section VII examines the relationship between our measures of aggregate price uncertainty and the level of real output. Section VIII summarizes our results.

II. The Model

The model from which we derive our price prediction equation is similar to that used by Lucas (1973), as amended by Cukierman and Wachtel (1979) and Froyen and Waud (1983).

A. Market Supply Equations

We assume the economy is composed of a large number of scattered, competitive markets. For each of these markets we derive short-run output supply schedules based on factor demand equations for labor and for an energy (or, alternatively a more general raw material) input, as well as labor supply functions at the individual market level. The factor demand equations are log linear functions of the product price, input prices and the fixed stock of capital. Labor supply in each market is assumed to be a log linear function of the money wage in that market and the laborers' expectation of the general price level (conditioned on information in that market). This expectation is modeled below.

To solve for individual market supply functions, the labor supply function is first used to substitute the money wage out of the factor demand functions. The resulting equations express the quantities of labor and energy as functions of product price, laborers' expectations of the aggregate price level, the price of energy, and the capital stock. These equations are then substituted into the production function for each market to yield the supply functions[2]

$$y_t(v) = g_0 + g_1 p_t(v) + g_2 p_t^* + g_3 q_t(v) + g_4 K_t(v) \quad v = 1,\ldots,m \tag{1}$$

where v indexes the market and for each market,

$y_t(v)$ = output

$p_t(v)$ = market specific producer price

p_t^* = the expectation of the aggregate price level conditioned on information in market v.

$q_t(v)$ = price of energy

$K_t(v)$ = quantity of capital

with all variables in logs and where g_1, $g_4 > 0$ and g_2, $g_3 < 0$.

B. <u>The Demand Side</u>

Following Cukierman and Wachtel (1979) market demand is specified as

$$p_t(v) = x_t + w_t(v) - y_t(v) \tag{2}$$

where $w_t(v)$ is the market specific demand shock, $y_t(v)$ is market specific real output, x_t is the aggregate demand shock (again all variables in logs) and where

$$w_t(v) \sim N(0,\sigma_w^2) \tag{3}$$

$$x_t = x_{t-1} + \Delta x_t,\ \Delta x \sim N(\delta,\sigma_x^2) \tag{4}$$

We take x_t to be measured by nominal income, assuming the aggregate demand curve to be unit elastic.[3]

C. Expectations Formation

Current market specific product price is used together with aggregate information to form an optimal expectation of the aggregate price p_t^*.[4] This optimal expectation (in individual market v) is given by

$$p_t^* = (1-\theta)p_t(v) + \theta\bar{p}_t \tag{5}$$

where $\bar{p}_t$ is the expectation of aggregate price conditional on information prior to time period t, i.e., conditional on available aggregate information, and θ is a function of the variances of market specific and aggregate demand shocks as well as other variances and parameters to be introduced below.

D. The Aggregate Price Equation

To solve for the equilibrium price level, we first compute a quasi-reduced-form expression aggregating over the equilibrium price levels ($p_t(v)$) for the individual markets. This is a quasi-reduced-form expression in that it still contains $\bar{p}_t$. From this expression we compute $\bar{p}_t$. We substitute the result back into the condition for the equilibrium aggregate price level to obtain the reduced form price equation.[5]

$$\begin{aligned} p_t = {} & -g_0 - \frac{g_2\theta\delta}{1-g_2\theta} - g_3(\phi(t) + \lambda\mu_{t-1}) + x_{t-1} + \\ & \frac{1}{1-g_2\theta}\,\Delta x_t - \frac{g_3}{1-g_2\theta}\,\varepsilon_t - g_4 K_t \end{aligned} \tag{6}$$

In the derivation of (6) we make the following assumptions about market specific and aggregate energy prices.

$$q_t(v) = q_t + \eta_t(v) \tag{7}$$

$$q_t = p_t + \phi(t) + \mu_t \tag{8}$$

where: $q_t(v)$ is the market-specific energy price, q_t is the economy-wide aggregate energy price, and $\eta_t(v)$ is the market-specific energy price disturbance; p_t is the aggregate output price, $\phi(t)$ is a linear time trend in the relative price of energy, and μ_t is the aggregate energy price disturbance; with

$$\eta_t(v) \sim N(0,\sigma_\eta^2) \text{ for all } v, \tag{9}$$

$$\mu_t = \lambda\mu_{t-1} + \varepsilon_t \tag{10}$$

$$\varepsilon_t \sim N(0,\sigma_\varepsilon^2) \tag{11}$$

and $\eta_t(v)$ and ε_t are independently distributed and serially uncorrelated.[6]

Equation (6) indicates that the aggregate price level depends on the trend term on the relative price of energy and the lagged value of the energy price ($\phi(t)$ and μ_{t-1}), the lagged level and current rate of change in aggregate demand (x_{t-1} and Δx_t), and the current level of the energy price shock (ε_t), and on the level of the capital stock (K_t). The parameter θ, which characterizes the information structure of the model, can be shown to depend on the variances of the economy-wide and market-specific disturbances.[7]

III. The Measure of Uncertainty

Our purpose is to measure the degree to which economic agents, using available data, were able to predict the behavior of the aggregate price level. For this reason we have chosen an uncertainty measure based upon a period by period or "rolling regression" technique rather than an estimate based on the whole sample period.

Economic agents are assumed to use a generalized least squares (GLS) procedure to estimate the parameters of the aggregate price equation based on past data. The error variance of the one period ahead GLS predictor for the aggregate price level is computed as a measure of aggregate price uncertainty. A GLS procedure is used since examination of estimated residuals of our price prediction equation, described in Section IV revealed a pattern of first-order autocorrelation. It seems reasonable to infer that such autocorrelation would be taken into account in price forecasts, though the autocorrelation coefficient is assumed to be estimated each period along with the other coefficients in the equation.

The individual economic agent in time period (t) is assumed to predict the aggregate-price level one period ahead (t+1). The error variance of the GLS predictor can be expressed, in general notation, as [Goldberger (1962), Theil (1971, p. 282)]

$$U = \sigma^2(1-\rho^2) + \sigma^2(\xi_1-\rho\xi_0)'(X'V^{-1}X)^{-1}(\xi_1-\rho\xi_0) \qquad (12)$$

where X is the TxK matrix of observations on the independent variables in the particular forecast equation; where

$$\xi_0' = [x_{t,1},\ldots,x_{t,K}]$$

$$\xi_1' = [x_{t+1,1},\ldots,x_{t+1,K}],$$

with ρ being the first order autocorrelation coefficient and with $\sigma^2(X'V^{-1}X)^{-1}$ the covariance matrix of the GLS coefficient estimator. [V is defined in Theil (1971), p. 252).]

IV. Empirical Specification of the Price Prediction Equation

The following adjustments were made to equation (6) prior to constructing our uncertainty measures.

A. An Output Adjustment Lag

As implemented empirically, the Lucas-type output equation has generally included the lagged value of cyclical output to capture the persistence in deviations of output from the natural rate. Rationales for such persistence have been offered in Lucas (1975) and Sargent (1977). If for given levels of nominal income and the supply variable output in a given time period depends positively on the lagged deviation of output from trend, then correspondingly the price level will depend negatively on this lagged deviation of output from trend. To capture this influence we include the lagged deviation of output from trend as an independent variable in our price equation.

B. The Capital Stock and Trend in the Supply Variable

The capital stock term (K_t) in (6) is assumed to follow a linear time trend. We also assume that this time trend represents the effects of systematic movements in the relative price of energy, $\phi(t)$, in (6).

C. Partial Indexing of Energy Prices

The energy (or import) price specification given by (8) in Section II.D presumes that energy prices were fully indexed to the aggregate price level. There is of course no formal indexing of energy prices. Equation (8) presumes that, allowing for the factors that cause the relative price of energy products to change in a systematic way ($\phi(t)$) and in the absence of supply shocks ($\mu_t = 0$), producers of the energy input would increase price proportionately with the domestic price level. If we suppose instead that indexing is only partial, equation (8) would be replaced by

$$q_t = \psi p_t + (1-\psi) z_t + \phi(t) + \mu_t \tag{8'}$$

where z_t is another predetermined variable (the average of other countries' price levels, for example) and $0 < \psi < 1$.

Within our model, the implication of replacing (8) with (8') is that with the energy price given by (8') the coefficient on x_{t-1} in (6) is no longer one. The coefficient is instead

$$0 < \frac{1}{1-g_2\theta-g_3} < 1 . \tag{13}$$

Price rises less than proportionately with an anticipated increase in aggregate demand (x_{t-1}), for example, because output also rises. Output rises because the increase in aggregate demand and, therefore, the price level lowers the real price of the energy input and stimulates aggregate supply.

V. Results

Our measures of uncertainty are derived on the basis of the price equation (6), using all available information, and with the adjustments discussed in the previous subsection. This price prediction equation can be written as

$$p_t = \alpha_0 + \alpha_1 \mu_{t-1} + \alpha_2 x_{t-1} + \alpha_3 t + \alpha_4 y_{c,t-1} + e_t \qquad (14)$$

where $y_{c,t-1}$ is the lagged deviation of output from trend and where

$$\alpha_0 = -g_0 - \frac{g_2\theta\delta}{1-g_2\theta}$$

$$\alpha_1 = -\lambda g_3 > 0$$

$$\alpha_2 = \begin{cases} 1 & \text{(case of perfect indexing)} \\ 0 < \dfrac{1}{1-g_2\theta-g_3} < 1 & \text{(case of less than perfect indexing)} \end{cases}$$

$$\alpha_4 < 0.$$

$$e_t = \rho e_{t-1} + \nu_t \quad \text{where } \nu_t \sim N(0,\sigma_\nu^2)$$

Since Δx_t and ε_t are unobservable prior to time t, they do not appear in the prediction equation. Together with other non-systematic influences on the price level they would appear in the error term of (14).[8]

For a given quarter economic agents will be assumed to have estimated (14) through the preceding period using the 32 most recent quarterly data observations. There is an element of arbitrariness in this choice of sample period. Eight years of past data seem to be a reasonable number of observations to characterize recent price behavior which economic agents might view as relevant to current price determination. For Canada, the United Kingdom and the United States these estimates of the price prediction equation begin in 1965:2. The last quarter for which we compute a measure of uncertainty is 1982:3 for Canada, 1982:2 for the United Kingdom and 1983:1 for the United States. The data for these three countries began in 1957:1 but one observation is lost in differencing x and computing lagged values for x, y_c, and μ; then 32 observations are used to obtain the beginning estimate of the price prediction equation. For West Germany consistent data series were available starting in 1960:1, so the first period for which we compute a measure of price uncertainty is 1968:2. The last observation for West Germany is 1982:4.[9,10]

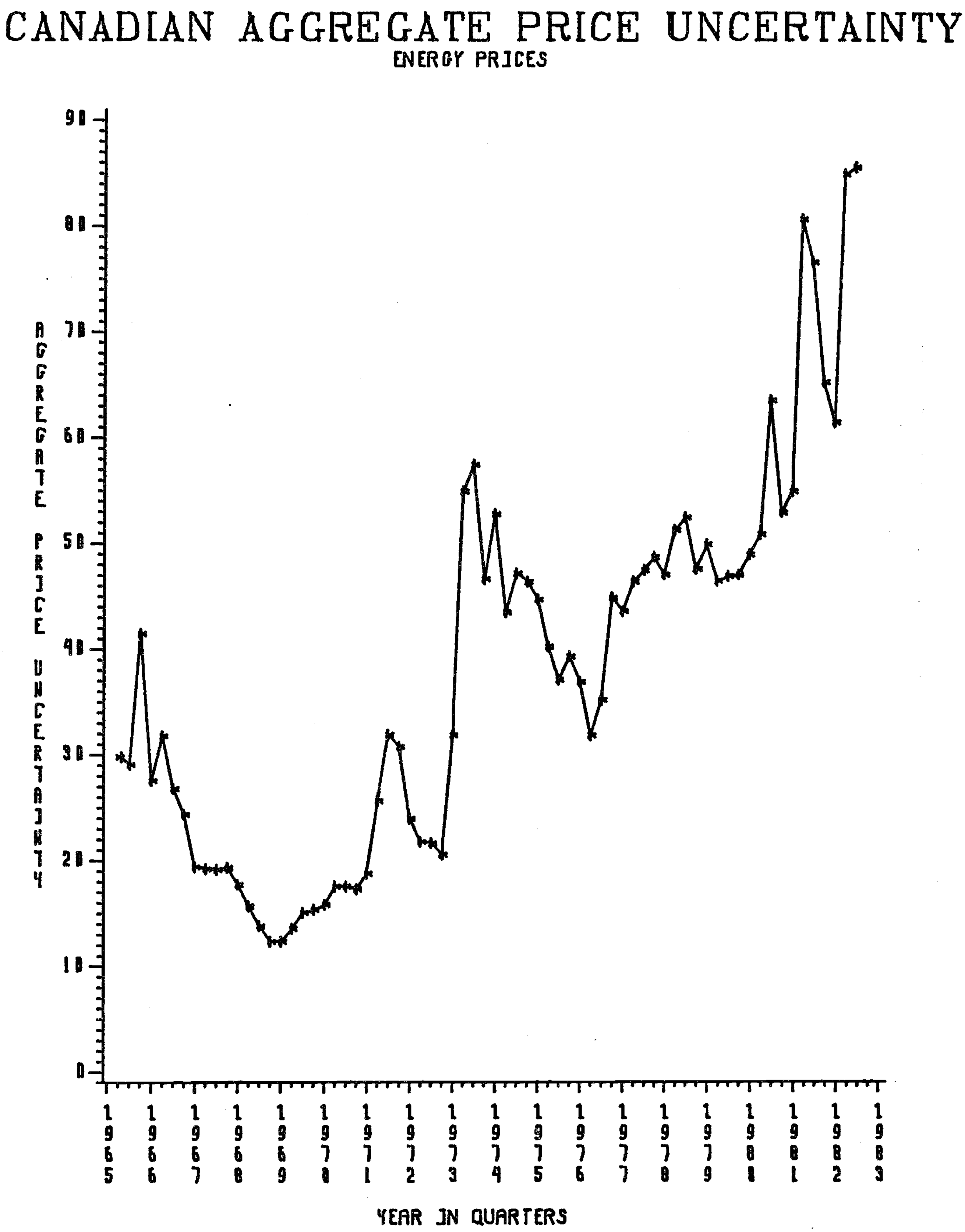
Figures 1-4 show the uncertainty statistics for each of the four countries. The uncertainty measures in these figures are for the energy price measures of the supply shock, except for the case of West Germany where only the import price data were available. For the three countries for which both measures of the supply shock were available, the uncertainty statistics based on the import and energy price measures were quite similar.

To assess the interrelationship between aggregate price uncertainty and both the level and variance of inflation we examine the behavior of the uncertainty statistic both across countries and through time. To begin, we consider the general pattern of the uncertainty statistic as illustrated in Figures 1-4. Below we look at some correlation coefficients between the variables of interest.

A. Patterns of Aggregate Price Uncertainty

The most striking similarity in the behavior of our price uncertainty measures across countries is the "spike" in the series that comes with the rapid increase in energy (and other raw materials) prices in the 1973-74 period. The inflation caused

Figure 1*



*Here and in figures 2-4, the hatchmark labeled for a given year denotes the first quarter of that year. The scale of the vertical axis is the actual uncertainty statistic multiplied by 10^6.

Figure 2

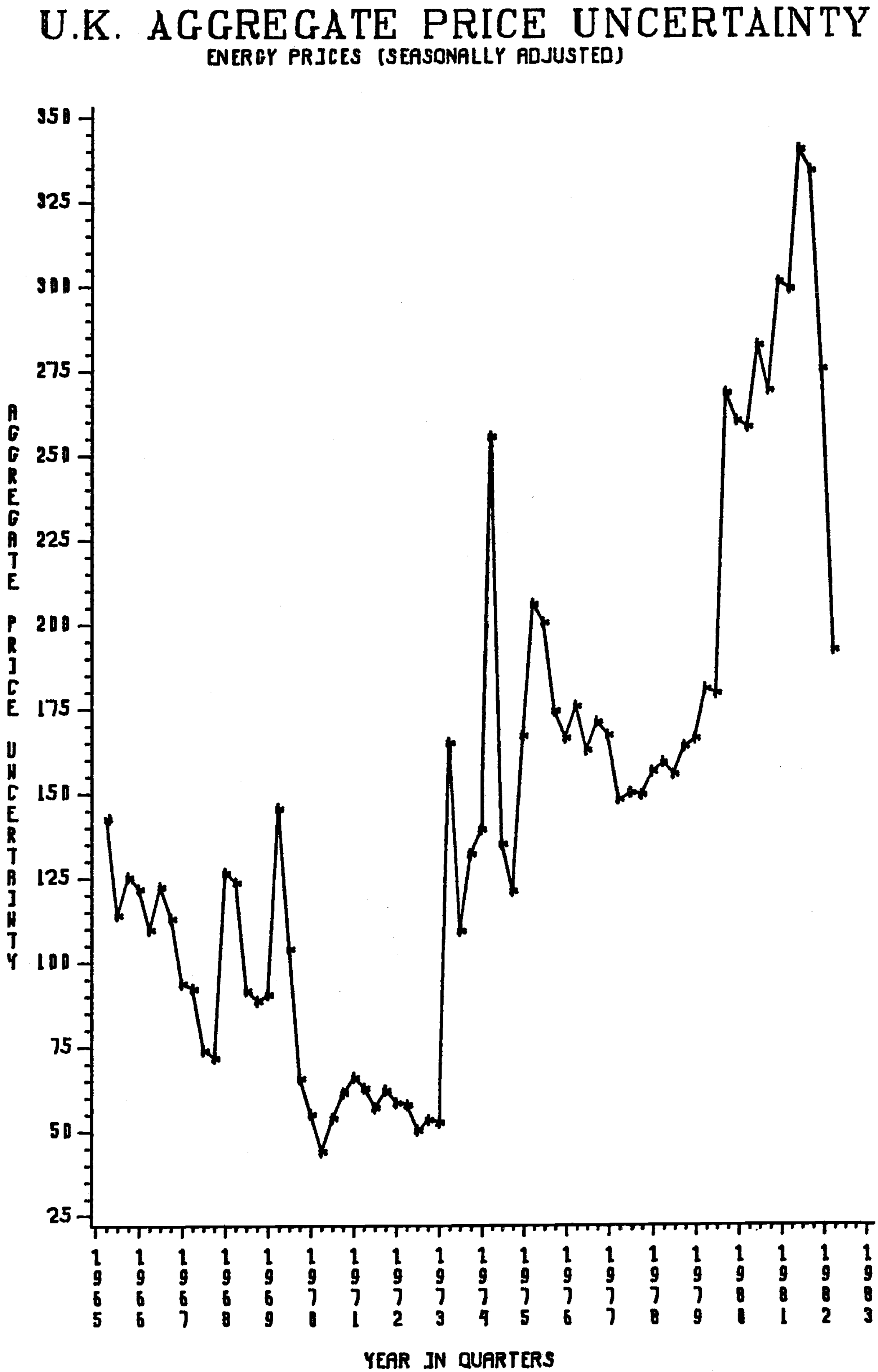
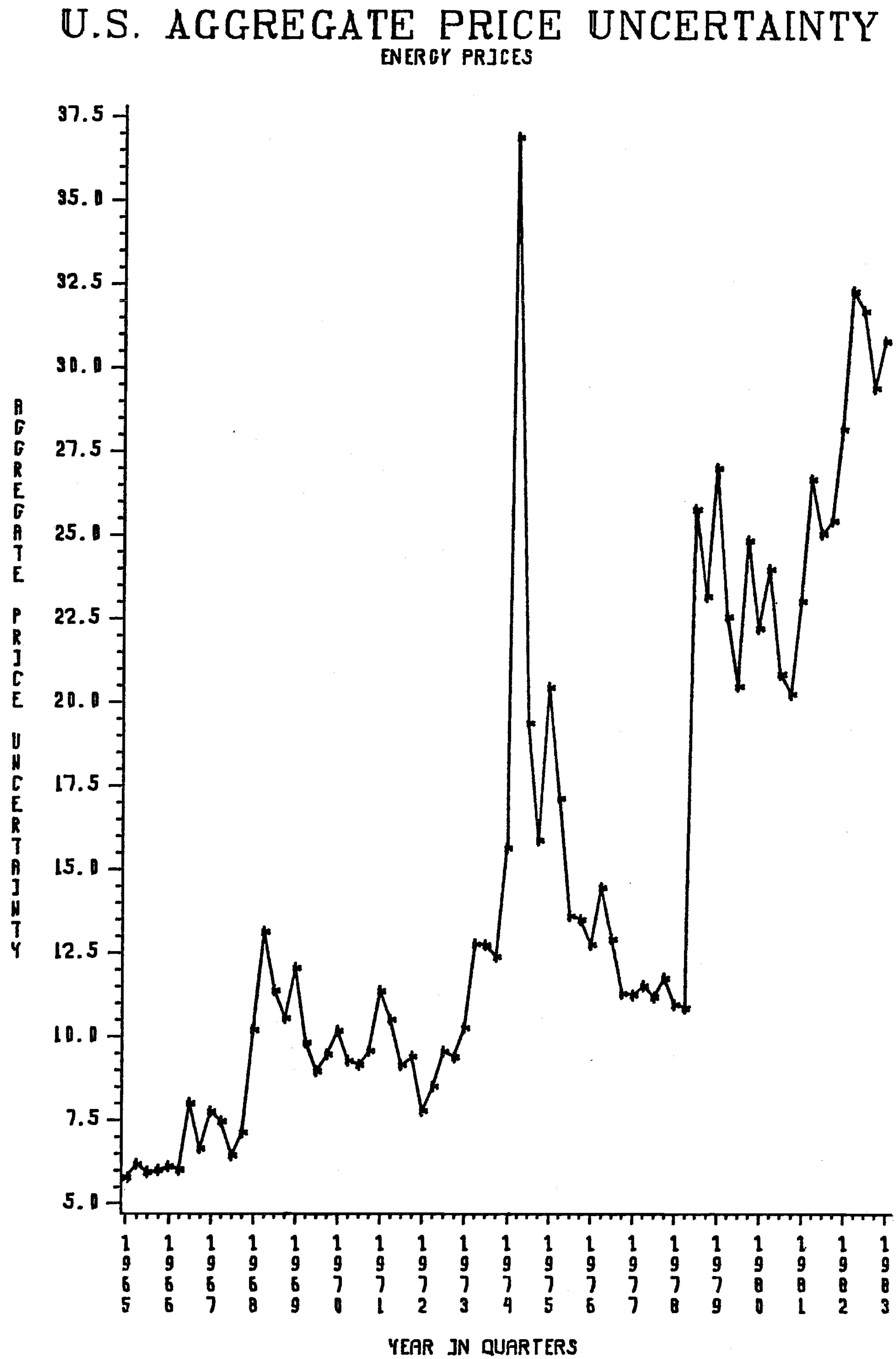
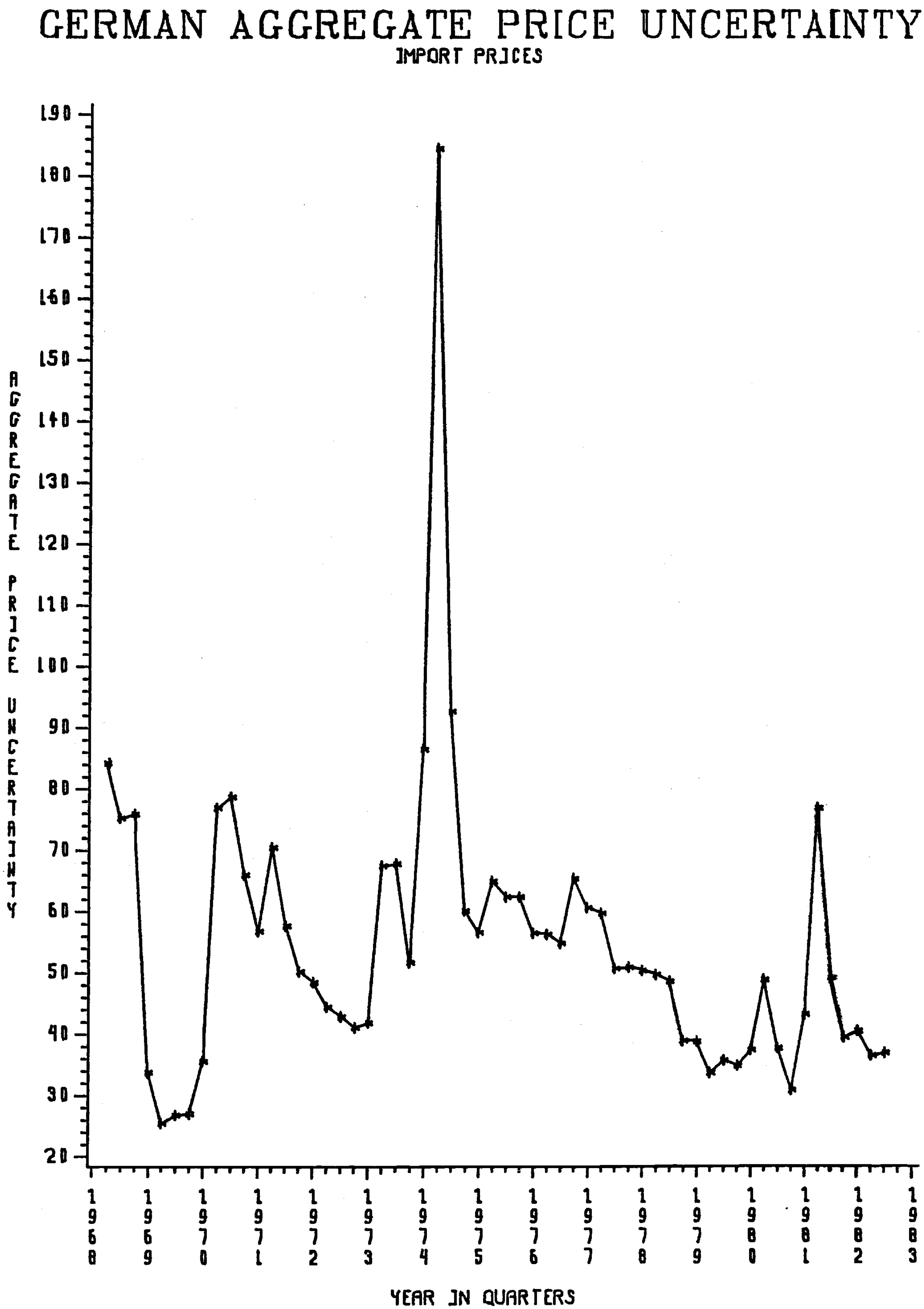

U.K. AGGREGATE PRICE UNCERTAINTY
ENERGY PRICES (SEASONALLY ADJUSTED)
AGGREGATE PRICE UNCERTAINTY
350
325
300
275
250
225
200
175
150
125
100
75
50
25
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
YEAR IN QUARTERS

Figure 3



U.S. AGGREGATE PRICE UNCERTAINTY
ENERGY PRICES
AGGREGATE PRICE UNCERTAINTY
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
YEAR IN QUARTERS

Figure 4


GERMAN AGGREGATE PRICE UNCERTAINTY
IMPORT PRICES
AGGREGATE PRICE UNCERTAINTY
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
YEAR IN QUARTERS

by the supply shocks of the mid-1970s clearly increased aggregate price uncertainty in all four countries.

A feature common to the experience of Canada, the United Kingdom and the United States, but not to West Germany, is another sharp rise in price uncertainty later in the 1970s, although the timing of this second peak in the series differs across the three countries.

In the United States the second sharp increase in price uncertainty comes in 1978 and coincides with a renewed upward trend in the inflation rate. Uncertainty then remains high even when the inflation rate declines in 1982. In the United Kingdom the second period of rapidly rising price uncertainty also coincided with an acceleration in the rate of inflation. In contrast to the United States, price uncertainty in the United Kingdom declined near the end of the period as the inflation rate fell sharply. In Canada the second jump in price uncertainty began in 1976, before there was an acceleration in the inflation rate, but this upward trend in price uncertainty sharpened as the inflation rate accelerated over the 1979-82 period.

Price uncertainty in West Germany followed a course after 1975 that was quite different from that in other countries. Once the immediate effects of the supply shock dissipated, price uncertainty fell to levels similar to those of the 1968-72 period. This is concident with a period of low stable inflation rates in West Germany. (During the 1976-82 period the West German inflation rate was in each year within the range of 3.4% to 4.8%.)

To summarize, the supply shocks of the mid-1970s appear to have increased aggregate price uncertainty in all four of the countries in our sample. Over the rest of the 1970s and early 1980s in the countries where inflation again accelerated there was a second period when aggregate price uncertainty increased rapidly. In West Germany where aggregate price uncertainty declined to pre-1970 level and remained there, the inflation rate had also declined and remained stable throughout the rest of the period. On the surface then our evidence on the behavior of price uncertainty is consistent with the view that more rapid and variable rates of change in the price level will create increased price uncertainty. The next section examines this view in more detail.

B. Relationships Between Price Uncertainty and the Level and Variability of Inflation

Table 1 shows correlation coefficients, for each of the four countries, between the price uncertainty measures based on the energy (U_E) and import (U_I) supply shock variables and measures of the inflation rate and of inflation variability.[11] The inflation rate is, as above, simply the change in the log of the aggregate price level (p_t). In any one period, we observe only one outcome from the distribution of the inflation rate and this alone is not enough to measure changes in inflation variability over time. As a proxy for a time-varying $\sigma^2_{\Delta p,t}$, we construct a moving variance of actual inflation rates, $\hat{\sigma}^2_{\Delta p,t}$. At each point in time we have computed a variance using observations from the past 8 period (quarters).

The correlation coefficients in Table 1 show a positive association between aggregate price uncertainty and both the level and variability of the inflation rate for Canada, the United Kingdom

Table 1

Correlation Coefficients Among $U_E, U_I, \Delta p$, and $\hat{\sigma}^2_{\Delta p,t}$

(t statistics in parentheses)

	$U_E \cdot \Delta p_t$	$U_I \cdot \Delta p_t$	$U_E \cdot \hat{\sigma}^2_{\Delta p,t}$	$U_I \cdot \hat{\sigma}^2_{\Delta p,t}$
Canada	0.578* (5.83)	0.550* (5.43)	0.198** (1.67)	0.373* (3.32)
United Kingdom	0.354* (3.10)	0.316* (2.73)	0.544* (5.31)	0.546* (5.33)
United States	0.532* (5.26)	0.518* (5.06)	0.382* (3.46)	0.415* (3.82)
West Germany	--	0.168 (1.28)	--	0.104 (0.79)

*--indicates significance at the .05 level

**--indicates significance at the .10 level and the United States. For West Germany, there is no significant correlation between aggregate price uncertainty and either the level or variability of the inflation rate.

To examine further the relationship between price uncertainty and the level and varibility of the inflation rate in Canada, the United Kingdom and the United States, we compute subperiod averages for these variables and compare movements in them between subperiods. The two subperiods are 1965:2-1972:4 and 1973:1 to the end of the sample period for each country. The same comparison cannot be made with West Germany since the data began several years later. What we did find by breaking the available West German data (1968:2-1982:4) into various subperiods is that there is very little variation across subperiods in inflation uncertainty, the mean inflation rate or the moving variance of inflation.

Table 2 shows subperiod averages of U_E, U_I, $\hat{\sigma}_{\Delta p}$ and Δp, as well as their ratios between subperiods ($U_{E,2}/U_{E,1}$, for example, where 2 and 1 denote the later and earlier subperiods, respectively). The data are consistent with a positive association between aggregate price uncertainty and both the level and variability of the inflation rate. In each of the three countries the data indicate that aggregate price uncertainty, the level of the inflation rate and the variability of inflation all rose between the first and second subperiod. Notice also that if we look across the three countries the data also suggest a positive relationship among price uncertainty, the level of the inflation rate and the variability of inflation. The United Kingdom has the highest inflation rate in each subperiod and also the most variable inflation rate and the highest level of price uncertainty. Canada is second in each of these respects in each subperiod, and the United States is third.

For the second subperiod, data are available to add West Germany to this cross-country comparison. West Germany does not conform to the pattern of the other three countries. West Germany had the lowest average inflation rate among the four countries and 3rd in inflation variability, but ranked 2nd in the level of price uncertainty.

VI. Comparison With Other Measures of Uncertainty

There have been a number of previous studies on the relationships among aggregate price uncertainty, inflation variability, and the level of inflation. In this section we compare our results with previous findings.[12]

A. Cross-Country Evidence

John Taylor (1981) examined a sample of 7 countries and found that a measure of inflation forecast uncertainty was positively related to both inflation variability and the level of inflation. Our measures of uncertainty for Canada, the United Kingdom, and the United States exhibit this pattern. West Germany is somewhat of an outlier from this pattern.

Other studies of price uncertainty focus on individual countries. None of these consider Canada or West Germany. We discuss studies of the United States and United Kingdom in turn.

B. The United States

Two approaches have been taken previously in looking at the relationship between price uncertainty and the variability and

Table 2

Subperiod Comparisons of U_E, U_I, $\hat{\sigma}^2_{\Delta p,t}$, and Δp[a]

		U_E	U_I	$\hat{\sigma}^2_{\Delta p}$	Δp
Canada	1st subperiod	21.497	19.738	0.0000208	0.01032
	2nd subperiod	51.010	50.763	0.0000429	0.02421
	ratio	2.37	2.57	2.06	2.34
United Kingdom	1st subperiod	86.975	82.318	0.0000443	0.01419
	2nd subperiod	194.382	183.387	0.0001718	0.03370
	ratio	2.23	2.23	3.88	2.37
United States	1st subperiod	8.805	8.928	0.0000062	0.01031
	2nd subperiod	19.593	16.031	0.0000180	0.01812
	ratio	2.23	1.80	2.91	1.76
West Germany	2nd subperiod		55.050	0.0000394	0.01175

[a]The first subperiod is 1965:2-1972:4. The second subperiod begins in 1973:1 for each country. End points for the second subperiod are

Canada - 1982:3
United Kingdom - 1982:2
United States - 1983:1
West Germany - 1982:4

level of inflation.

Cukierman and Wachtel (1979) use the variance across survey respondents from the Livingston and Survey Research Corporation surveys of inflationary expectations as measures of inflation uncertainty. They find that the variance of expected inflation is positively related to the variance of inflation. Stanley Fisher (1981) finds a positive relationship between this variance within the cross-section of forecasters (in both surveys) and the actual inflation rate. Our results are consistent with this evidence from survey data.

The second approach is that of Robert Engle (1983). Engle assumes that the error term from an inflation forecasting equation follows an autoregressive conditional heteroschedastic (ARCH) process. Such a process captures the assumed tendency of shocks to inflation to bunch up. Uncertainty is measured as the conditional variance of the error term from the forecast equation at each point in time.

Engle's results differ from the results that use survey data in two respects.

First, Engle finds much less of an increase in price uncertainty in the 1970s than is indicated by the cross-sectional variance of forecasts in the surveys. Engle concludes that the increased inflation and more variable inflation of the 1970s was for the most part predictable. Second, Engle finds no significant relationship between his measure of inflation uncertainty and the (lagged) level of the inflation rate. He points out that this is in contradiction to Friedman's view that the higher inflation of the 1970s led to more inflation uncertainty and a rise in the natural rate of unemployment.

In terms of the estimated increase in the respective measures of price uncertainty, Engle's estimate is substantially lower than ours. Comparing averages over the subperiods we used in Table 2, with the second subperiod shortened to 1973:1-1979:4 (the end point for Engle's estimates), Engle's measure of inflation uncertainty (GNP deflator) rose 16.5 percent between subperiods. Our measure (energy price supply shock variable) rose by 85.0. Our results also differ from Engle's in that we do find a significant positive relationship between price uncertainty and the level of the inflation rate.

To get at the source of the differences between Engle's results and ours, we have reestimated our model using the ARCH procedure.[13] The resulting estimates of price uncertainty are shown in Figure 5, for the energy measure of the supply shock. The correlation coefficient between this price uncertainty measure and the level of the inflation rate is lower than for the measure based on the rolling regression approach, 0.33 compared to 0.53, but still significant. For the import measure of the supply shock the correlation between the ARCH uncertainty measure and the rate of inflation is insignificant (0.07), while using the rolling regression technique there is a significant correlation (0.52).

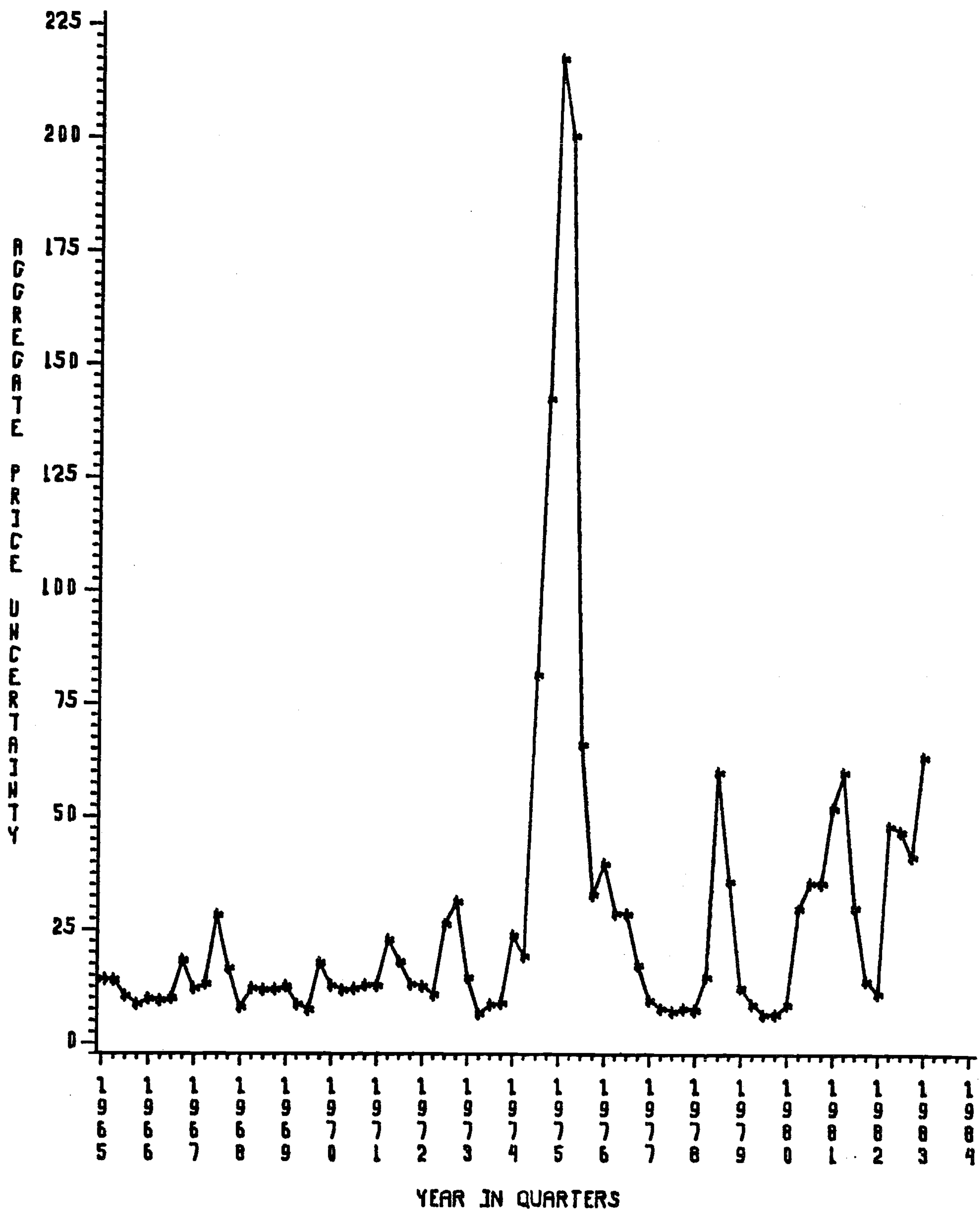
For the United States then, ARCH estimates of aggregate price uncertainty are less closely related to the level of inflation than are the estimates derived from the rolling regression approach, even when the same model is used in both approaches.

Still, the discrepancies between our results and Engle's should not be overstated. If we extend our sample period back to the late 1940s and early 1950s, we find, as did Engle, that price

Figure 5

U.S. AGGREGATE PRICE UNCERTAINTY

ENERGY PRICE - ARCH



uncertainty during this earlier period was substantially greater than in any later period, including the mid-1970s. The behavior of the price level in the 1970s was much more predictable than over the 1947-53 period. Second, while our measure of uncertainty shows a larger increase on the 1970s than Engle's (86% compared to 16%). Our estimate of the increase in uncertainty is much closer to Engle's than to the much larger rise evidenced in the survey based measures [see the Tables in Engle (1983, p. 296) and Cukierman and Wachtel (1979, p. 604)]. Finally, if one correlates Engle's measure of inflation uncertainty with the current, rather than the lagged inflation rate, there is a positive significant realtionship (correlation coefficient = 0.354) between the two variables.

C. The United Kingdom

Engle (1982) applies the ARCH technique to estimate inflation uncertainty for the United Kingdom over the 1958-1977 period. He finds that inflation uncertainty increased substantially in the 1970s as the rate of inflation accelerated. This is in accord with our results using the rolling regression technique. However, when we test for ARCH effects using our model over the 1965:2-1982:2 period, we find no evidence of such.[14]

Our estimates, therefore, imply that the pattern of price uncertainty in the United Kingdom (as measured by our model) is not well characterized by the ARCH specification. A possible reason for our failure to find ARCH effects in the United Kingdom is that our model includes a supply shock variable while Engle's does not. In Engle's model, the full effect of supply shocks will be measured in the error term. In our model, the auto-correlated part will be attributed to the lagged energy (or import) price variable. In this regard it is worth noting that one interpretation of the ARCH model advanced by Engle (1982, p. 990), is that "The ARCH specification might then be picking up the effect of variables omitted form the estimated model."

VII. Price Uncertainty and Real Output

Here we apply our estimates to test the hypothesis, suggested by Marshall, Keynes, Friedman and Okun, among others, that an increase in aggregate price uncertainty will lower the level of real output.[15] For this purpose we estimate the output equation implied by the model presented in Section II, with the addition of price uncertainty as a determinant of the "natural" rate of real output.

As in earlier versions of this model [Lucas (1973), Cukierman and Wachtel (1979), and Froyen and Waud (1983)], real output can be broken into two parts: the natural rate of output ($y_{n,t}$) and a cyclical component ($y_{c,t}$)

$$y_t = y_{n,t} + y_{c,t}$$

In the model, with the addition of aggregate price uncertainty, the specification for the natural rate becomes

$$y_{n,t} = g_0 + g_3\phi(t) + g_4K_t + \gamma_1(U_t - \bar{U}) \qquad (15)$$

$$\gamma_1 < 1$$

The natural rate of output depends on the systematic movement in the relative price of energy or, alternatively, imports ($\phi(t)$), the capital stock (K_t), and on the level of aggregate price uncertainty (U_t) relative to some long-run norm ($\bar{U}$).

The cyclical component of output depends on the behavior of the demand ($\Delta x_t - \delta$) and supply shocks (μ_t) in the model, as follows[16]

$$y_{c,t} = \frac{-g_2\theta}{1-g_2\theta} (\Delta x-\delta) \tag{16}$$

$$+ \frac{g_3}{1-g_2\theta} \mu_t$$

Prior to estimating an equation for real output, we make the same adjustments that were made to the price equation in Section IV; namely, we allow for an output adjustment lag by including the lagged deviation of output from trend as a explanatory variable and we use a linear time trend to proxy for the systematic movements in the relative price of energy as well as for growth in the capital stock. Additionally, examination of the data suggested that Δx contained a statistically significant upward trend in several countries, instead of having a constant mean (δ) specified in equation (4). To allow for this we respecify the aggregate demand shock as the detrended change in the log of nominal income $\Delta\tilde{x}$ (i.e., $\Delta x_t = \delta_0 + \delta_1 t + \omega_t$, $\Delta\tilde{x}_t$ being the estimate of the residual ω_t). The trend growth in Δx_t can be shown to have no effect on output in our model since such growth will be anticipated by rational economic agents.

With these modifications, equations (15) and (16) imply the following specification for detrended real output ($\tilde{y}_t$)

$$\tilde{y}_t = \gamma_0 + \gamma_1 U_t + \gamma_2 \Delta\tilde{x} + \gamma_3 \tilde{\mu}_t \tag{17}$$

$$+ \gamma_4 \tilde{y}_{t-1} + \nu_t$$

where $-\gamma_1 \bar{U}$ from (15) is incorporated in the constant term γ_0, with the coefficients on the other variables remain as given by (15) and (16), and where $\tilde{\mu}_t$ is the detrended supply shock.[17]

Estimates of Equation (17) for each of the four countries in our study are given in Table 3. The sample period is that for which we have estimates of price uncertainty in each country as shown in the first column of the table. Part A contains estimates where the supply shock and price uncertainty measure are both based on the energy price measure of the supply shock. Part B is based on the import measure. For each country, equation (17) was initially estimated by ordinary least squares. Where Durbin's (1970) h statistic showed evidence of autocorrelation, (at the 5% level of significance) the equation was reestimated using the modified "three pass least squares" procedure suggested by Wallis (1967). For these estimates the value of the first-order autocorrelation coefficient (ρ) is shown in the table.

For either the estimates based on the energy or import price measures of the supply shock, the price uncertainty variable is significant with a negative sign for Canada and the United Kingdom. With either measure of the supply shock for the United States, the price uncertainty variable has the expected negative sign but is not significant. For Germany, where there are only estimates for the import measure of the supply shock, the price uncertainty measure is also insignificant, though with a negative sign.[18]

There have been a number of previous studies of the relationship between either output or employment and the level of price uncertainty to which our results may be compared. There are no previous studies of the relationship between output and aggregate price uncertainty for Canada of which we are aware. The same is true for West Germany.[19] For the United Kingdom, the results here are consistent

Table 3

Output and Aggregate Price Uncertainty

A. Energy Price Specification

	Constant	Δx_t	μ_t	y_{t-1}	U^a	$\bar{R}^2$	ρ
Canada (1965:2-1982:3)	0.00793* (3.674)	0.76110* (10.959)	-0.01691 (-1.463)	0.88440 (24.66)	-0.00024* (-4.563)	0.979	0.18
United Kingdom (1965:2-1982:2)	0.00599* (2.097)	0.55265* (8.005)	-0.00407 (-0.321)	0.80088* (16.820)	-0.000044* (-2.479)	0.886	----
United States (1965:2-1983:1)	0.00018 (0.921)	0.84656* (21.923)	-0.0183* (-2.092)	0.90127* (31.665)	-0.00011 (-1.046)	0.992	0.58

B. Import Price Specification

	Constant	Δx_t	μ_t	y_{t-1}	U^a	$\bar{R}^2$	ρ
Canada (1965:2-1982:3)	0.00825* (4.969)	0.72083* (10.555)	-0.03726* (-2.364)	0.89848* (32.34)	-0.00025* (-6.396)	.979	.10
United Kingdom (1965:2-1982:2)	0.00606* (2.309)	0.55183* (7.833)	-0.00573 (-0.408)	.79556* (15.395)	-0.000047* (-2.776)	.888	----
United States (1965:2-1983:1)	0.00063 (0.312)	0.85615* (0.220)	-0.01816* (-3.428)	0.91520* (44.317)	-0.00018 (-1.307)	.993	.46
West Germany (1968:2-1982:4)	0.00150 (0.483)	0.75447* (10.564)	-0.01471 (-0.661)	0.82900* (14.002)	-0.000021 (-0.425)	0.933	0.43

[a]The uncertainty measures here are scaled upwards by the same factor (10^6) as in Figures 1-4. This accounts for the small absolute value of the coefficients on U.

with those of our earlier study, Froyen and Waud (1984), which used a moving variance of the inflation rate to measure aggregate price uncertainty and found significant negative output effects for that variable.

Our results are not consistent with those of several studies for the United States that have found significant negative effects on output or employment for measures of price uncertainty. These previous studies [Levi and Makin (1980), Mullineaux (1980), Makin (1982)] used the standard deviation across inflation forecasts from the Livingston survey as a proxy for inflation uncertainty.[20]

Our model differs from the models in these studies in that ours includes a supply shock variable. For the United States this variable was significant and the estimate of the coefficient on the price uncertainty measure, especially for the equation using the energy price measure, was sensitive to this variable. When it is dropped from the equation, the price uncertainty measure has a negative coefficient, significant at the 10 percent level ($t = 1.90$).[21]

The other important difference between our estimates and those of previous studies for the United States is the sample period. Levi and Makin (1980), Mullineaux (1980) and Makin (1982) estimate equations for sample period beginning in the late 1940s or in the 1950s and extending to the mid-1970s. Our period begins much later (1965:2) and extends to 1983:1.[22]

The disparity between our results and those of earlier studies for the United States, using survey data, suggests the usefulness of examining whether estimates using such survey measures, extended to a later period and controlling for supply shocks, would continue to show significant negative output effects for inflation uncertainty.

VIII. Conclusion

In Canada, the United Kingdom, and the United States, our measures show an increase in aggregate uncertainty during the period of supply shocks, 1973-74. After a decline in 1975-76, price uncertainty rose again as inflation accelerated in these countries later in the decade of the 1970s. Looking both across these countries or at the pattern of price uncertainty for each country through time, our results indicate that there was a positive association between the level of aggregate price uncertainty and both the level and variability of the inflation rate. These results suggest that the higher and more variable inflation of the 1970s did increase uncertainty about the aggregate price level.

In West Germany aggregate price uncertainty also rose sharply with the oil price shock in 1974. The rise was temporary, however, and price uncertainty quickly declined back to, and at times below, pre-1974 levels. The low and stable inflation rate in West Germany during the post-1974 period may explain this rapid decline in price uncertainty. The lack of much variability in the inflation rate may also explain why, in contrast to the other three countries, we could detect no significant relationship between the level of price uncertainty and either the level or moving variance of the inflation rate in West Germany.

Estimates of the effect of inflation uncertainty on the level of real output differed across countries. For Canada and the United Kingdom, we did find evidence of a significant negative output effect for increases in aggregate price uncertainty. For West Germany and the United States our measures of aggregate price uncertainty did not have significant estimated output effects.

Footnotes

[1]See, for example, the discussion in Fischer and Modigliani (1978) and Fischer (1981).

[2]For a more detailed derivation of this model, see the Appendix to Froyen and Waud (1983).

[3]This assumption simplifies the analysis considerably since with it no detailed specification of the elements of aggregate demand is required. Since this assumption results in the assumed exogeneity of nominal income, its validity is crucial to the consistent estimation of the model. For our measures of price uncertainty, the exogeneity of nominal income is not, however, crucial because the forecast equations we estimate contain only lagged values of both aggregate demand and supply shocks. These values are predetermined in any case. For the income equations estimated in Section VII, the exogeneity of Δx_t is important. Specification tests in Froyen and Waud (1984) provide support for this assumption for the United Kingdom. Nelson's (1979) (1981) results provide support for this assumption for the United States.

[4]There is a different p_t^* in each market. We supress the v subscript here to make clear that this is an expectation of the aggregate price level.

[5]In deriving (6) we also assume that a proportional increase in product price and the prices of each of the two variable factors of production leaves desired output supply unchanged. It can be shown that this assumption implies $g_1 = -(g_2 + g_3)$ in equation 1.

[6]Equation (8) assumes that energy prices are fully indexed to the aggregate price level (the coefficient on p_t is one). We have also examined the case where energy prices are only partially indexed (the coefficient on p_t in (8) is between zero and one). In this latter case aggregate demand management policy can, by changing p_t, affect the real price of energy. The potential role of monetary policy in this case is analyzed by Blinder (1981). The implications of partial indexing of energy prices for our price prediction equation are discussed in Section IV.C.

[7]See the Appendix to Froyen and Waud (1983), equation (vi).

[8]Over the latter part of the sample period there is evidence of an upward trend in Δx in Canada, the United Kingdom, and the United States. Such a deterministic part of the aggregate demand shock would be predictable to economic agents. This trend will also be picked up in our estimates by the time variable in equation (14).

[9]Estimates of equation (14) for our whole sample period, for each of the four countries, are given in Appendix 1. These whole period estimates are not used to calculate our price uncertainty measure. These equations are estimated only to examine whether our price prediction equation provides a reasonable characterization of price behavior over this period. The equations seem to fit the data quite well.

[10]For Canada and the U.S. the energy price measure is the producer (or wholesale) price index for fuels, related products and electricity. For the United Kingdom the energy price series is the index of "Basic Materials and Fuel Used in Manufacturing Industry". In each case the relative price of energy is computed by deflating each index by the GNP deflator. For each country the relative price of imports is measured as the index of import prices deflated by the GNP deflator. For all variables other than energy prices, data are from the IMF, International Financial Statistics computer tape. Energy price data are from: the Bank of Canada, Statistical Review (Canada); entral Statistical Office, Monthly Digest of Statistics (U.K.); Bureau of Labor Statistics, Producer Prices and Price Indices (U.S.).

[11]Fischer (1981, p. 29) points out that a procedure such as ours implies no link between expected inflation and aggregate price uncertainty. Tests of the relationship between the level of the inflation rate and the level of price uncertainty are therefore implicitly tests of whether a higher inflation rate meant that more of the change in the price level was unexpected.

[12]There is also a considerable literature on the related question of whether higher inflation is, in general, accompanied by more variability in the inflation rate. See, for example, the survey in Taylor (1981). The discussion here is confined to previous studies which focused explicitly on price level and inflation uncertainty.

[13]For this estimation we have followed the iterative procedure outlined in Engle (1982, pp. 996-98) with the exception that at

each iteration three scoring steps for the α coefficient are made. Overall three iterations are run (3 estimates of $\hat{\beta}_s$). The order of the ARCH model (p) is two for the estimate using the energy measure of the supply shock and 1 with the import measure.

[14]Up to 8 lags were used in tests for ARCH effects. The test is described in Engle (1982, p. 1000).

[15]Marshall and Keynes clearly suggest a relationship between output and aggregate price uncertainty. Friedman and Okun proposed the relationship between price <u>variability</u> and output or employment. Such price variability affects output in Friedman's view, for example, partly through the creation of price uncertainty, but perhaps by broader channels as well. Tests of Friedman's hypotheses such as those by Levi and Makin (1980), Mullineaux (1980) and Makin (1982) have all employed measures of price uncertainty, relying on the close relationship between variability and uncertainty.

[16]With the modification of the model in Section IV to allow for only partial indexing of energy (or import) prices, the coefficient on x_{t-1} in the <u>price</u> equation will be less than one and, therefore, x_{t-1} will have a nonzero coefficient on the output equation. In our estimates of the price equation for the whole sample period (Appendix 1), the coefficient on x_{t-1} was significantly different from one in only one case (Canada using the energy price measure of the supply shock). In this case, when x_{t-1} was entered in the output equation its coefficient was insignificant. Consequently, the output equations estimated in this section are for the fully-indexed case when x_{t-1} is not included.

[17]The trend in the supply variable, $\phi(t)$, will affect only the trend in real output and, therefore, is not included in (17). The supply shock is entered as a single variable in (17), rather than as separate variables measuring anticipated ($\lambda\mu_{t-1}$) and unanticipated (ε_t) components (see equation 10). Since, in the model, the anticipated and unanticipated component have somewhat different effects on price and output (see (6)), it would be preferable to enter them as separate variables. Previous attempts to measure these separate effects, however, did not prove fruitful (see Froyen and Waud (1983, note 18) and Froyen and Waud (1984, p. 61)).

[18]Since our measures of price uncertainty, using the rolling regression procedure, are generated solely on the basis of lagged observations on squared residuals and the independent variables in the model (see equation (12)), the coefficient estimates for (17) will be consistent. The standard errors for the coefficients will not, however, reflect the fact that the uncertainty variable is generated rather than being directly observed. For a discussion of these issues, see Pagan (1984, pp. 241-42).

[19]Buck and Gahlen (1984) examine the relationship between relative price variability and both output and employment for West Germany for 1953-77. They find that increased relative price variability lowers output and employment. For a similar finding for the United States, see Blejer and Leiderman (1980).

[20]Mullineaux (1980) also used a moving standard deviation of the inflation rate as a measure of uncertainty. With that measure, his results, concerning the negative output effects of inflation uncertainty were mixed.

[21]For the specification using the import price measure of the supply shock, the coefficient on price uncertainty remained insignificant even when the supply shock variable itself was dropped from the equation.

[22]In Froyen and Waud (1983) we found that a moving variance of the inflation rate had a significant negative effect on real output in the United States over the 1957-68 period, but not over the 1969-80 period. A measure of the variability of either energy or import prices did have a negative significant output effect over this later period suggesting the importance of supply shocks.

References

Blejer, Marjo I. and Leiderman, Leonardo, "On the Real Effects of Inflation and Relative-Price Variability: Some Empirical Evidence," Review of Economics and Statistics, 62 (November 1980), 539-44.

Blinder, Alan S., "Monetary Accommodations of Supply Shocks Under Rational Expectations," Journal of Money, Credit and Banking, 13 (November 1981), 425-38.

Buck, Andrew J. and Gahlen, Bernhard, "The Real Effects of Price Variability in the Federal Republic of Germany, 1953-77," Economic Letters, 15 (1984), 79-85.

Cukierman, Alex and Wachtel, Paul, "Differential Inflationary Expectations and the Variability of the Rate of Inflation," American Economic Review, 69 (September 1979), 595-610.

Durbin, J., "Testing for Serial Correlation in Least Squares Regression When Some of the Regressors Are Lagged Dependent Variables," Econometrica, 38 (May 1970), 410-21.

Engle, Robert F., "Autoregressive Conditional Heteroscedasticity With Estimates of the Variance of United Kingdom Inflations," Econometrica, 50 (July 1982), 987-1007.

Engle, Robert, "Estimates of the Variance of U.S. Inflation Based on the ARCH Model," Journal of Money, Credit and Banking, 15 (August 1983), 286-301.

Fischer, Stanley, "Toward an Understanding of the Costs of Inflation," Carnegie-Rochester Conference Series on Public Policy 15 (1981), 5-42.

Fischer, Stanley and Modigliani, Franco, "Toward an Understanding of the Real Effects and Costs of Inflation," Weltwirtschafticher Archiv, Bank 114, (1978), 810-33.

Friedman, Milton, "Inflation and Unemployment," Journal of Political Economy, 85 (June 1977), 451-72.

Froyen, Richard T. and Waud, Roger N., "Demand Variability, Supply Shocks, and the Output-Inflation Tradeoff," NBER Working Paper No. 1081, (February 1983).

__________ and __________, "The Changing Relationship Between Aggregate Price and Output: The British Experience," Economica, 51 (February 1984), 53-67.

Goldberger, Arthur S. "Best Linear Unbiased Prediction in the Generalized Linear Regression Model," Journal of the American Statistical Association, 57 (June 1962), 369-75.

Keynes, John M., Tract on Monetary Reform. New York: Harcourt Brace and Company, 1924.

Levi, Maurice P. and Makin, John M., "Inflation Uncertainty and the Phillips Curve: Some Empirical Evidence," American Economic Review, 70 (December 1980), 1022-27.

Lucas, Robert E., Jr., "Some International Evidence on Output-Inflation Tradeoffs," American Economic Review, 63 (June 1973), 326-34.

__________, "An Equilibrium Model of the Business Cycle," Journal of Political Economy 83 (December 1975), 1113-44.

Makin, John H., "Anticipated Money, Inflation Uncertainty and Real Economic Activity," Review of Economics and Statistics, 64 (February 1982), 126-34.

Marshall, Alfred, "Answers To Questions on the Subject of Currency and Prices Circulated by the Royal Commission on the Depression of Trade and Industry," in Official Papers by Alfred Marshall. London: Macmillan, 1926.

Mullineaux, Donald J., "Unemployment, Industrial Production and Inflation Uncertainty in the United States," Review of Economics and Statistics, 62 (May 1980), 163-69.

Nelson, Charles, "Recursive Structure in U.S. Income, Prices, and Output," Journal of Political Economy, 87 (November 1979), 1307-27.

__________, "Adjustment Lags Versus Information Lags," Journal of of Money, Credit, and Banking, 13 (February 1981), 1-11.

Okun, Arthur, Prices and Quantities. Washington: The Brookings Institution, 1981.

Pagan, Adrian, "Econometric Issues in the Analysis of Regressions with Generated Regressors," International Economic Review, 25 (February 1984), 221-247.

Sargent, Thomas, "The Persistence of Aggregate Employment and the Neutrality of Money," unpublished manuscript, University of Minnesota, 1977.

Taylor, John, "On the Relationship Between the Variability of Inflation and the Average Inflation Rate," Carnegie-Rochester Conference Series on Public Policy 15 (August 1981), 57-85.

Theil, Henri, Principles of Econometrics. New York: John Wiley, 1971.

Wallis, Kenneth F., "Lagged Dependent Variables and Serially Correlated Errors: A Reappraisal of Three-Pass Least Squares," *Review of Economics and Statistics*, 49 (November 1967), 555-67.

Appendix 1
Whole Period Estimates of the Price Prediction Equation

Table 1

Whole Period (1957:2-end[b]) Estimates of the Price Prediction Equation[a]

A. Energy Price Measure of the Supply Shock

	Constant	t	x_{t-1}	$y_{c,t-1}$	μ_{t-1}	R^2	ρ
CANADA	-2.3013 (-35.691)	-0.0094 (-18.021)	0.9397 (38.185)	-0.7867 (-17.4434)	0.0613 (3.520)	0.9998	0.183
U.K.	-1.4637 (-27.07)	-0.0054 (-14.78)	0.9805 (67.238)	-0.8903 (-16.446)	0.06853 (4.938)	0.9996	-0.0097
U.S.	-1.528 (-17.911)	-0.0081 (-20.4632)	0.9820 (44.433)	-0.9135 (-33.5033)	0.01338 (1.710)	0.9999	0.499

[a] t statistics are in parentheses

[b] The end points for the sample period are
Canada - 1982:3 United States - 1983:1
United Kingdom - 1982:2 West Germany - 1982:4

B. Import Price Measure of the Supply Shock[c]

	Constant	t	x_{t-1}	$y_{c,t-1}$	μ_{t-1}	R^2	ρ
CANADA	-2.5545 (-29.502)	-0.01149 (-44.8521)	1.0166 (101.575)	-0.9055 (-33.2182)	0.0269 (1.4724)	0.9998	0.237
U.K.	-1.4472 (-31.759)	-0.0052 (-14.887)	0.9736 (71.382)	-0.9471 (-17.892)	0.0791 (6.010)	0.9997	-0.061
U.S.	-1.5215 (-27.0327)	-0.0080 (-31.864)	0.976 (71.7590)	-0.9092 (-52.3241)	0.02668 (4.223)	0.9999	0.374
West Germany	-2.1021 (-18.352)	-0.00838 (-21.888)	0.9971 (52.520)	-0.8671 (-25.925)	0.02808 (2.605)	0.9994	-0.285

[c] The starting point of the sample period for West Germany is 1960:2