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THE PRODUCTIVITY-INFLATION NEXUS IN CANADA
1963-1979

by

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CONTENTS

ABSTRACT

During recent years the Canadian economy has been simultaneously subjected to increasing rates of inflation and declining growth in labour productivity. Virtually all analysis of the macroeconomic relationship between the two phenomena has been based on the premise that there is a unidirectional flow of causation from productivity growth (assumed to be exogenous) to inflation.

In this paper we have attempted to identify the macroeconomic relationship between labour productivity growth and inflation. Specifically, we utilized both a reduced-form, bivariate Granger technique and structural models to test the hypothesis that the result of increased productivity growth is a one-for-one reduction in inflation against the alternative hypothesis that, because of a feedback relationship, inflation may itself have had a negative effect on productivity growth in Canada over the 1963-79 period. In the bivariate case we observed the existence of bidirectional causality and this allowed us to reject the hypothesis that the payoff to increased productivity growth is a unit-proportional reduction in inflation. Rather, the implied multiplier is 2.24. A variety of structural models also displayed a feedback relationship. Anticipated inflation was shown to figure more importantly than unanticipated inflation in its negative effect on

productivity growth, but our measures of uncertainty about inflation appeared to have had no incremental influence. Depending on how one proxies inflation expectations in the model, a 'permanent' one percentage point increase in inflation leads to a reduction in productivity growth of .08 to .34 percentage points. This is sufficient to explain a substantial portion of the recent slowdown in productivity growth. The long-run inflation multiplier associated with an increase in productivity growth lies in the range of -.75 to -1.33.

RÉSUMÉ

Au cours des dernières années, l'économie canadienne a fait face simultanément à une aggravation de plus en plus marquée de l'inflation et à un ralentissement de la croissance de la productivité du travail. Presque toutes les analyses des relations macroéconomiques entre ces deux phénomènes se sont fondées sur la prémisse qu'il existe un lien de causalité univoque entre l'accroissement de la productivité (qu'on considère comme exogène) et l'inflation.

Dans cette étude, nous avons tenté d'identifier la relation macroéconomique existant entre l'accroissement de la productivité et l'inflation. Nous avons utilisé à la fois la technique de Granger, modèle de forme réduite à deux variables, et les modèles structurels en vue de comparer les deux hypothèses suivantes : la première, qui veut qu'une accélération de la croissance de la productivité entraîne une réduction du taux d'inflation, et la seconde qui veut que par rétroaction l'inflation ait eu au Canada, entre 1963 et 1979, un effet négatif sur l'accroissement de la productivité. Dans le modèle à deux variables, nous avons observé que la relation de cause à effet était biunivoque. Cela nous a amenés à rejeter l'hypothèse selon laquelle une accélération de la croissance de la productivité aurait eu pour conséquence une réduction équivalente du taux d'inflation. Le multiplicateur

implicite a plutôt été de 2,24. Un grand nombre de modèles structurels ont révélé l'existence de l'effet de rétroaction. Nous avons montré que l'effet négatif que produit l'inflation anticipée sur la croissance de la productivité est plus important que celui qui est causé par l'inflation non anticipée, mais les incertitudes au sujet de l'inflation semblent n'avoir eu en soi aucune incidence sur l'accroissement de la productivité. Selon la manière dont les anticipations inflationnistes sont représentées dans le modèle, une augmentation constante de 1 point de pourcentage du taux d'inflation provoque un ralentissement de l'accroissement de la productivité de l'ordre de 0,08 à 0,34 point de pourcentage. Cette constatation suffit à expliquer en très grande partie le récent ralentissement de la croissance de la productivité. Le multiplicateur à long terme du taux d'inflation lié à un accroissement de la productivité se situe entre -0,75 et -1,33.

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1 INTRODUCTION

The macroeconomic relationship between labour productivity (output per man-hour) and inflation is important to the understanding of the stagflationary malaise that has gripped the U.S. and Canadian economies during the past decade. Virtually all analysis of this relationship has been based on the premise that there is a simple, unidirectional line of causation running from productivity growth (assumed to be exogenous) to inflation. This belief is exemplified by the rule-of-thumb or neoclassical condition that equates price inflation with the difference between wage inflation and productivity growth.

Recently, numerous arguments have been put forward as to why increases in price inflation can conversely have a negative effect on productivity growth. Most of these arguments are based on the concept that inflation induces an increasingly severe tax burden on the private sector because of a non-neutral tax structure. In addition, an observed correlation of inflation with the variance of inflation and with the dispersion of relative prices leads to arguments that inflation reduces investment and causes economic inefficiencies by increasing the probability of entrepreneurial error.

In this paper we examine the time-series relationship between productivity growth and inflation. To do this we test the hypothesis that an increase in productivity growth leads to a unit-proportional reduction in inflation, or whether the response might be more than one-for-one because of a feedback relationship. We proceed as follows. In Section 2 we provide a brief review of previous research relating inflation and productivity growth. In Section 3 the mechanisms by which inflation can reduce productivity growth are outlined. The dynamics of the inflation-productivity growth relationship are explored in Section 4 using reduced forms, and in Section 5 we examine simple structural models in order to increase the power of the tests. In Section 6 some conclusions are offered.

2 PREVIOUS EMPIRICAL RESEARCH

A negative correlation between productivity growth and industry price inflation has been demonstrated by Lydall (1968) for 54 Australian manufacturing industries; by Kendrick (1973) for 21 U.S. manufacturing industries over the period 1948 to 1969; by Klein (1980) for about 500 U.S. industries over the period 1965 to 1972; and by Kendrick and Grossman (1980) for 30 U.S. industries over the period 1948 to 1976. Moreover, Kendrick and Grossman found the absolute value of the correlation coefficient to be higher during the latter third of their sample (pp. 67, 74, 80). At the macroeconomic level, regression analysis using aggregate price measures has also indicated a negative correlation between productivity growth and inflation (Productivity Perspective, American Productivity Center Inc., cited in Zell, 1979).

More recently, Freund and Manchester (1980) hypothesized a model of wage determination (similar to ones espoused by Malkiel, 1979, p. 293 and Lewis, 1980, p. 559) which allows a direct test of the unit elasticity presumption, given the implicit assumption of unidirectional causation from productivity growth to inflation. In this model a closed economy, or one with fixed terms of trade, with productivity growth of x percent per year is in dynamic equilibrium when workers, cognizant of this growth, bargain for similar real wage increases. Subsequently, if productivity growth declines to x-n percent per annum, but workers are slow to recognize this fact and continue to demand the same real wage increases, inflation must accelerate to reduce the *ex post* real wage increase to x-n percent. Until workers recognize and accept a new, lower rate of real wage increase, inflation will spiral up, reaching a higher long-run rate where dynamic equilibrium is eventually re-established. The Freund and Manchester model yields a reduced-form equation of wage inflation in the private business sector which, when estimated, shows productivity growth to have no significant effect on wage inflation, and the equilibrium long-run elasticity of price inflation with respect to productivity growth in the United States to be 4.4.[1] Freund and Manchester also cite the testimony of Michael Evans before the Joint Economic Committee of the U.S. Congress in which Evans states that a multiplier of about two is likely (Evans, 1979).

While there has been some effort devoted to an examination of the response of inflation to productivity growth, empirical work on the impact of inflation on productivity growth is virtually non-existent. In what follows we attempt to remedy this deficiency. Specifically, we test for the existence of a multiplier relationship by allowing inflation to feed back onto productivity growth.

3 MECHANISMS THROUGH WHICH INFLATION CAN REDUCE PRODUCTIVITY GROWTH

There are a number of ways in which an increased rate of inflation may adversely affect productivity growth. First, inflation may affect the desire or ability of labour to do productive work. It may result in disincentives to labour directly or it may result in a need on the part of business managers to allocate a greater proportion of their labour force to 'unproductive' lines of work. For example, in an inflationary climate business managers are forced to allocate a greater portion of their workforce to such 'unproductive' work as readjusting prices, monitoring factor and rival product price increases, recontracting, hiring forecasting services, and conducting market surveys to determine how resistant consumers are to nominal price increases. Leijonhufvud (1977) has pointed out that in times of inflation the payoff for devoting effort to 'real' activities declines relative to that for playing the inflation game correctly, thereby reducing the relative reward and hence the effort devoted to socially productive hard work. In addition, reliance on private economic contracting will decline and more effort will be devoted to forming political coalitions in order to avoid the distributional consequences of inflation. Both of these factors suggest labour productivity will suffer during an inflationary period.

Second, inflation may also affect labour productivity by causing an inefficient mix of factor inputs. Inefficient factor combinations, and hence lower productivity, can result if relative factor prices change faster than factor inputs can be adjusted. If factors are mixed in inefficient proportions, inflation can lower the intensity with which a particular factor, be it capital or labour, is used. Inflation can also result in inefficiencies in factor mixes by lowering the information content of price signals, thus decreasing the reliability of absolute price movements to reflect relative price changes accurately. Even in a period of steady inflation the information content of price changes is reduced. Hence, even if firms correctly anticipate that inflation will average x percent over the relevant time horizon, it does not necessarily follow that they will also correctly anticipate the rates of change of any particular price. With less information on which to base their decisions, business managers will make more errors and hence will more often choose sub-optimal factor input mixes and sub-optimal types of capital (particularly a relative abundance of short-lived capital). Moreover, there is an increase in the optimal expenditure of time and resources on search activities and on what Jaffee and Kleiman (1977) have termed 'protective outlays', that is, efforts to get out of nominal and into real assets. In addition, inflation shortens optimal contract length and planning horizons thereby increasing contracting costs. Both Weil (1979) and Hayes and Abernathy (1980) have hypothesized that a shorter management planning horizon has affected labour productivity growth adversely.

Increasing uncertainty about inflation can decrease productivity by inducing firms to increase their inventories of 'unproductive' buffer stocks and to reduce their expenditures on long-term basic research (Mansfield, 1980, p. 871). Klein (1976) has argued that a higher rate of inflation tends to be associated with a higher variance of inflation, a greater dispersion of inflation expectations (Jaffee and Kleiman, 1977) and increasing uncertainty about the longer run mean rate of inflation.[2] Vining and Elwertowski (1976) have found that the increasing variance of the price level is not independent of the increasing dispersion of relative prices,[3] while Parks (1978) has argued that relative price variability is especially sensitive to the unanticipated component of inflation. Amihud (1981) found that from 1964 to 1975 inflation stimulated U.S. man-hours employed (controlling for inflation uncertainty), but did not affect real output, clearly pointing to reduced labour productivity. Most recently, Blejer and Leiderman (1980) have shown that each of real output, unemployment and employment (see also Levi and Makin, 1980) are adversely affected by relative price variability. Most importantly, they found the negative coefficient in the real output equation to be about twice the magnitude of its counterpart in the employment equation. Klein also claimed that it is not price variability per se that has led to increasing uncertainty, but a lack of understanding of the process that generates movements in the price level. He suggested that during the 1960s and early 1970s there was a generally poor understanding of the source of the prevailing inflation.

Gordon and Halpern (1976) have pointed out that one of the consequences of the increased uncertainty about inflation is a reduction in the real spread between monetary and non-monetary assets. Thus, fixed investment is likely to suffer at the expense of liquidity as required rates of return rise, optimal net investment falls and replacement investment is deferred (Nelson, 1976b).[4]

Finally, because of non-neutral tax laws, inflation reduces after-tax profits[5] and this in turn causes a decline in capital accumulation. Inflation interacts with the tax system in a number of ways to alter the expected after-tax real rate of return on fixed investment. On the one hand, debt-financed investment is more attractive in an inflationary environment because nominal interest payments are tax deductible. On the other hand, fixed-asset investments are less attractive because allowable depreciation is based on historical costs. Cross (1980) claims that for fixed assets with lifetimes exceeding one year, the net effect of inflation on required marginal rates of return is positive. His results are suspect, however, since he overlooked the fact that <u>nominal</u> capital gains and inventory profits are taxed, and hence that inflation increases the effective rate of taxation and further reduces after-tax rates of return.

There is now ample evidence of both a theoretical and an empirical nature that inflation has reduced after-tax profits in Canada as well as elsewhere.[6] This is probably the result of tax laws as well as the historical inability of many entrepreneurs to see through the veil of inflation and protect themselves to the maximum degree possible. In Britain, the Sandilands Committee (1975) reported that about one-third of even the larger British firms did not use any form of inflation accounting systems. Kopcke (1978) reported that in the United States at the end of 1976, only one-quarter of total inventories were covered by the last-in first-out (LIFO) inventory accounting method, despite its acknowledged advantage to firms in times of inflation. It is therefore not surprising that real equity prices and returns do not seem to be invariant to inflation.[7]

A good statement of this mechanism has recently been provided by the U.S. Joint Economic Committee: "Thus under presently required accounting practices, a rise in the inflation rate raises real corporate tax liability, lowers real after-tax profits, and therefore reduces the real after-tax rate of return on fixed investment. This means that there is a direct adverse link between the rate of inflation and the level of capital spending, and this traps the economy in a vicious circle. Low investment and sluggish productivity help to raise the inflation rate and the higher inflation rate helps to keep investment and productivity depressed." (U.S. Congress, Joint Economic Committee, 1978, p. 141.)[8]

4 A REDUCED-FORM BIVARIATE MODEL

In this section we explore the dynamic relationship between productivity growth and inflation using a technique pioneered by Granger (1969) and Sims (1972). This technique is generally referred to as testing for exogeneity or for Granger-causality. In practice, a variable X is said to 'Granger-cause' Y if the past history of X is of significant value in reducing the variance of a least-squares autoregressive prediction of Y. Sims (1977) has demonstrated that if X is exogenous to Y in the usual econometric sense, then Y does not Granger-cause X.

While the Granger-Sims technique is a useful device for exploring the dynamic relationship between two variables, it is not very powerful either as a test of causality or of exogeneity. Because the Granger-Sims technique relies on correlation analysis, it lacks power as a test of causation since correlation does not necessarily imply causation.[9] In particular, Granger-causality does not coincide with what Zellner (1979) regards as a more acceptable concept, namely, "predictability according to a law or set of laws", unless it has associated with it an explicit structural model (i.e., a set of laws). Nevertheless, intertemporal correlation patterns are important and useful in the identification of relationships that are causal according to Zellner's definition.

Consider the following structural model:

$$p_t = C_{11}(L)\, q_t + C_{12}\,(L)\, z_t$$

$$q_t = C_{21}(L)\, p_t + C_{22}\,(L)\, v_t \qquad (1)$$

where

p_t represents the rate of inflation,

q_t represents the growth in labour productivity,

z_t represents other possible influences on inflation such as monetary or wage growth or demand pressure,

v_t represents other possible influences on labour productivity growth, for example cyclical economic activity or the growth of capital intensity, and

L represents the lag operator such that

$$L^m x_t = x_{t-m}$$

and

$$C_{ij}(L) = c_{0ij} + c_{1ij}L + \ldots + c_{nij}L^n$$

We assume equations (1) are structural in the sense that the C_{ij} terms are policy invariant.

The Granger-Sims technique operates on a bivariate reduced form which can be expressed as:

$$p_t = B_{11}(L)\ p_t + B_{12}(L)\ q_t + u_{1t}$$

$$q_t = B_{21}(L)\ p_t + B_{22}(L)\ q_t + u_{2t} \qquad (2)$$

where u_1 and u_2 are independent (i.e., u_{1t} and u_{2s} are not correlated for all t and s, Sims, 1977) and the $B_{ij}(L)$ polynomials are now defined exclusive of the contemporaneous term b_{0ij}. Equations (2) can be derived from equations (1) providing z_t and v_t are strictly exogenous (i.e., the equations for p_t and q_t can be characterized as a recursive 'block' in a more elaborate model), and providing that z_t and v_t can be represented as invertible moving average processes.

Equations (2) can be used to identify the dynamic relationship between inflation and productivity growth in the following manner. If $B_{12}(L) = B_{21}(L) = 0$, then inflation and productivity growth are said to be temporally independent. Of course, this result does not indicate that p and q are also contemporaneously independent since it does not imply that $c_{011} = c_{021} = 0$ in equations (1).

If, on the other hand, neither $B_{12}(L)$ nor $B_{21}(L)$ are zero, this indicates that there is a dynamic relationship between inflation and productivity growth that includes feedback. In this case we have identified a relationship in which inflation

Granger-causes productivity growth which in turn feeds back onto inflation. Again, nothing concrete can be inferred about the contemporaneous nature of the relationship. Finally, if $B_{12}(L) = 0$ but $B_{21}(L) \neq 0$, there is a one-way dynamic relationship from inflation to productivity growth; conversely, if $B_{21}(L) = 0$ but $B_{12}(L) \neq 0$, there is a one-way dynamic relationship from productivity growth to inflation.

The assumption that u_1 and u_2 are independent is critical to the interpretation of the test results. Specifically, if u_1 and u_2 are not independent, then a control relationship between productivity growth and inflation may not exist even if $B_{12}(L)$ and $B_{21}(L)$ differ from zero. The reason is that the influence of any excluded variables may not be adequately captured by a distributed lag on past values of the left-hand variable. As a consequence, the observed relationship between inflation and productivity growth may not be causal in the sense that if inflation could be controlled then productivity growth could also be controlled. In the empirical work that follows we examine the assumption of independence by constructing a cross-correlogram between u_1 and u_2.

We explored the relationship between inflation and productivity growth for the period 1963 Q2 to 1979 Q4. Productivity growth (q) was measured as the quarterly percent change in the ratio of seasonally adjusted Real Domestic Product (RDP) (Statistics Canada Catalogue no. 61-213) to estimated total man-hours worked (the product of total employment and average weekly hours worked). Employment data were obtained from the Labour Force Survey (Statistics Canada Catalogue no. 71-001). Data on the hours of employment per worker were obtained from the Large Establishment Survey (Statistics Canada Catalogue no. 72-002). Construction, mining and manufacturing were presumed to be representative in terms of average weekly hours worked.[10] Inflation (p) was measured as the quarterly percent change in the ratio of seasonally adjusted[11] Gross Domestic Product to Real Domestic Product. Both the productivity growth and inflation series appeared to be covariance stationary -- a necessary condition for the application of Granger-Sims techniques -- as neither the mean nor the variance of either series showed any indication of having a secular trend.

In choosing the lengths of the lags in equations (2) we followed the method suggested by Hsiao (1979). This procedure involved first regressing each variable on its own lagged values and choosing the lag length that minimized Akaike's (1969) Final Prediction Error (FPE).[12] The minimum FPE occurred with eight lags for inflation and one lag for productivity growth. The second step involved including lagged values of inflation in the productivity growth equation and vice versa, and again minimizing the FPE. The number of lags on productivity growth in the inflation equation was found to be six, while the number of lags on inflation in the productivity growth equation was two. Finally, lagged values of the dependent variable in each growth equation were again allowed to vary in order to confirm the choice of lag length. No change in the order of lags was deemed necessary.

Once the orders of the lag lengths were determined, equations (2) were estimated using Wymer's (1968) Full Information Maximum Likelihood (FIML) program. FIML estimation provides efficient parameter estimates. The results are as follows (asymptotic t-ratios are given in parentheses):

$$\underset{(2.2)}{p = .68} + \underset{(1.8)}{.20p(-1)} + \underset{(3.4)}{.38p(-2)} + \underset{(2.7)}{.35p(-3)} + \underset{(2.3)}{.29p(-4)} - \underset{(1.3)}{.16p(-5)}$$

$$- \underset{(0.6)}{.07p(-6)} + \underset{(0.8)}{.10p(-7)} - \underset{(3.1)}{.36p(-8)} + \underset{(0.6)}{.07q(-1)} + \underset{(0.6)}{.07q(-2)}$$

$$+ \underset{(1.1)}{.13q(-3)} - \underset{(2.9)}{.35q(-4)} + \underset{(0.4)}{.05q(-5)} - \underset{(2.8)}{.36q(-6)}$$

sum of coefficients on inflation = .75 (6.4)

sum of coefficients on productivity growth = −.39 (1.2)

Quasi-R^2 = .64

$$\underset{(5.3)}{q = .91} - \underset{(0.7)}{.07p(-1)} - \underset{(1.8)}{.17p(-2)} - \underset{(0.5)}{.06q(-1)}$$

sum of coefficients on inflation = −.24 (2.5)

sum of coefficients on productivity growth = −.06 (0.5)

Quasi-R^2 = .09 (MODEL 1)

NOTE: Quasi-R^2 is calculated as one minus the ratio of the variance of the structural residual to the variance of the left-hand variable. Thus, its value lies in the interval $[-\infty, 1]$.

These estimates indicate a two-way multiplier relationship between inflation and productivity growth. When a two-way relationship is taken as the maintained hypothesis and tested against alternative one-way relationships, each alternative can be rejected in favour of the two-way relationship.[13] The results of these likelihood ratio tests are reported in Table 1.

TABLE 1

TESTS OF MAINTAINED HYPOTHESIS

Alternative hypotheses	Value of likelihood ratio	χ^2 Critical value (.05)	Result
$q \rightarrow p;\ p \not\rightarrow q$	6.3	6.0	Reject
$q \not\rightarrow p;\ p \rightarrow q$	15.5	12.6	Reject

The economic implications of these results are clear. In the long run, a one percentage point 'permanent' positive shock to productivity growth results in a 1.46 percentage point increase in productivity growth and a 2.24 percentage point drop in inflation. A permanent one percentage point positive shock to inflation translates into an eventual 6.05 percentage point increase in inflation and a 1.38 percentage point reduction in productivity growth. Adjustment is virtually complete after 17 years with most of the response occurring during the first 3 years.

A permanent one percentage point increase in inflation is associated with a greater than one percentage point drop in productivity growth and a permanent one percentage point increase in productivity growth is associated with a greater than one percentage point decrease in inflation. It is noteworthy that while large in size, our estimate of the response of inflation to a change in productivity growth is much smaller than that calculated by Freund and Manchester (1980) on the basis of a unidirectional relationship from productivity growth to inflation.

As mentioned above, there remains the possibility that the estimated relationship between inflation and productivity growth is not causal in a control sense but is instead the sole product of a neglected third causal factor. To explore for this possibility we examined the cross-correlogram of the residuals from the estimated equations. The results were mixed: Haugh's (1976) test of the independence of two time series yielded a chi-square value that was not significant at the 5 percent level - an indication that the hypothesis of intertemporal independence cannot be rejected. However, there were significant individual correlations at lags of 11 quarters and 13 quarters (as measured against the two standard deviation benchmark of $2/\sqrt{n}$). Thus, there is some indication that a bivariate reduced form does not adequately characterize the relationship between inflation and productivity growth and that a further refinement of the relationship would therefore be useful. The 'marginal' character of some of the likelihood ratio test results suggests that conducting tests to explore the robustness of these results would be desirable.

5 A STRUCTURAL REPRESENTATION

In order to refine our model further, we decided to expand the set of probable determinants of inflation and productivity growth. A popular representation of the inflation process is the wage-markup-adjusted-for-market-conditions model. In this model, price inflation (p) is determined by its relationship with wage inflation (w), productivity growth (q), excess demand in the domestic market (dev), and U.S. inflation (pus). U.S. inflation is included because the Canadian economy is a small, 'open' economy.

Wage inflation is measured as the rate of change in the seasonally adjusted average weekly wage of the industrial composite plus the community services, government and agriculture sectors, and includes loss due to strikes (Statistics Canada Catalogue nos. 72-005 and 72-008). Fluctuations in domestic excess demand are proxied by deviations in Real Domestic Product (RDP) about its trend.[14] The rate of U.S. inflation is measured by the U.S. implicit GNP deflator (Survey of Current Business 7,1).

Numerous factors have been put forward as possible determinants of productivity growth. Of these, the growth in capital intensity (kl) seems to be the most popular. Capital intensity is measured as the ratio of fixed capital to labour, where fixed capital includes the stock of machinery and equipment and non-residential construction. Fixed capital is obviously the principal substitute for labour in production as well as the primary vehicle for embodied technical progress.

It is also well known that cyclical variations are reflected in productivity growth, probably because there are longer delays in factor input adjustment than are required for output adjustment. Consequently, the deviation of RDP about trend is included as an additional determinant of productivity growth. And finally, our hypothesis about inflation feedback dictates that inflation also be included in the productivity growth equation.

FIML estimation of these relationships yielded the following results:

$$p = -\underset{(0.8)}{.24} - \underset{(1.5)}{.17q} - \underset{(2.6)}{.27q(-1)} - \underset{(0.0)}{.00q(-2)} - \underset{(0.6)}{.06q(-3)} - \underset{(1.0)}{.10q(-4)}$$

$$+ \underset{(2.6)}{.38w} - \underset{(0.2)}{.03w(-1)} + \underset{(1.5)}{.24w(-2)} - \underset{(2.4)}{.36w(-3)} + \underset{(0.9)}{.13w(-4)}$$

$$+ \underset{(2.8)}{.37dev} - \underset{(2.9)}{.54dev(-1)} + \underset{(3.3)}{.61dev(-2)} - \underset{(3.8)}{.45dev(-3)} + \underset{(7.0)}{1.05pus}$$

Quasi-R^2 = .75

$$q = \underset{(6.9)}{.36} - \underset{(0.3)}{.01p} + \underset{(0.4)}{.01p(-1)} - \underset{(3.0)}{.11p(-2)} - \underset{(3.6)}{.14p(-3)} - \underset{(0.7)}{.03p(-4)}$$

$$+ \underset{(0.5)}{.02p(-5)} - \underset{(1.6)}{.06p(-6)} + \underset{(24.3)}{.97kl} + \underset{(18.1)}{.82dev} - \underset{(20.0)}{.92dev(-1)}$$

Quasi-R^2 = .92 (MODEL 2)

The sum of the current and lag coefficients together with their appropriate asymptotic t-ratios are as follows:

response of p to q	−.60 (2.4)	response of q to p	−.31 (9.5)
response of p to w	.37 (2.8)	response of q to kl	.96 (24.3)
response of p to dev	−.01 (0.2)	response of q to dev	−.10 (4.5)
response of p to pus	1.05 (7.0)		

The results clearly indicate a relationship running from productivity growth to inflation and back to productivity growth, confirming our earlier findings. The direct response of inflation to a one percentage point improvement in productivity growth is a decline of .60 percentage points, which is within two standard deviations of a unit decline. The long-run multiplier (including feedback) is −.75. If we examine the other side of the coin, we find that the direct response of productivity growth to a one percentage point increase in inflation is −.31 percentage points which, because of feedback, eventually translates (within approximately 6 years) into a 1.23 percentage point increase in inflation and a .38 percentage point decline in the growth rate of productivity.[15] The long-run pre-1973 rate of productivity growth was 2.9 percent per annum and the 1976-79 rate was only .7 percent per annum; thus, the recent slowdown amounts to about 2.2 percentage points. The annual rate of inflation has likewise increased from about 3 percent to at least 9 to 10 percent. According to Model 2 an increase in inflation of this magnitude would result in a decline in productivity growth of about 2 percentage points. In other words, the increase in inflation through the past decade is sufficient to explain virtually the entire measured slowdown in labour productivity growth!

Inflation in Canada responds positively to domestic wage inflation, to U.S. inflation and to contemporaneous excess demand. However, a shock to excess demand does not produce a sustained inflationary response but does induce volatility in the rate of inflation: the coefficients on dev in the inflation equation are large, significant, and of alternating signs, while the sum of the coefficients is small and insignificant. Productivity growth responds positively to increasing capital intensity and positively, on impact, to variations in demand. Over the longer term, a demand shock results in a statistically significant, albeit small, negative response from productivity growth.

Alternative versions of Model 2 were tested using likelihood ratio tests. The results, which are reported in Table 2, were mixed. The hypothesis that inflation does <u>not</u> cause a decline in productivity growth can be decisively rejected. However, the hypothesis that productivity growth has no effect on inflation cannot be rejected, even though the sum of the coefficients on productivity growth in the inflation equation is not significantly different from minus one. The reason for this unusual result appears to be multicollinearity between the lagged values of productivity growth and those of the excess demand variable. Hence, the coefficients on lagged productivity growth in the inflation equation are ill determined, and there is not enough variance in the data to distinguish among models in which productivity growth is a significant determinant of inflation, models in which excess demand fluctuations are a significant determinant of inflation, and models which incorporate both of these relationships.

TABLE 2

TESTS OF ALTERNATIVE VERSIONS OF MODEL 2

Alternative hypotheses	Value of likelihood ratio	χ^2 Critical value (.05)	Result
$q \rightarrow p;\ p \not\rightarrow q$	59.96	14.1	Reject
$q \not\rightarrow p;\ p \rightarrow q$	9.52	11.1	Cannot reject

Examination of the cross-correlogram of the residuals from Model 2 revealed no significant correlations. Haugh's S-statistic was calculated to be 11.2, compared to a .05 critical value of 27.6. Thus, independence cannot be rejected and there is no indication that excluded influences are distorting our interpretation of the test results.

We now turn our investigation towards an identification of the characteristics of inflation that lead to the negative response in productivity growth. Three separate aspects of inflation were tested: anticipated inflation, unanticipated inflation and uncertainty about inflation. We posit that anticipations of inflation (pe) are adequately characterized by one-step-ahead forecasts based on an eight-quarter autoregressive representation of the realized inflation process.[16] Further, since we based the autoregressive representation on seven years of previous experience, the parameters of the autoregressive model vary through time. This procedure of proxying anticipations is similar to that used by Kennedy and Lynch (1979). Unanticipated inflation (pu) is then defined residually as the difference between realized and anticipated inflation. Because anticipations of inflation are formed recursively, they can be treated as exogenous for purposes of estimation. The results of allowing anticipated and unanticipated inflation to influence productivity separately are presented below:

$$p = -\underset{(0.8)}{.23} - \underset{(1.4)}{.17q} - \underset{(2.5)}{.26q(-1)} - \underset{(0.1)}{.01q(-2)} - \underset{(0.6)}{.06q(-3)} - \underset{(1.2)}{.12q(-4)}$$

$$+ \underset{(2.6)}{.38w} - \underset{(0.2)}{.03w(-1)} + \underset{(1.5)}{.24w(-2)} - \underset{(2.3)}{.35w(-3)} + \underset{(1.0)}{.14w(-4)}$$

$$+ \underset{(2.8)}{.37dev} - \underset{(2.9)}{.55dev(-1)} + \underset{(3.5)}{.64dev(-2)} - \underset{(3.9)}{.46dev(-3)} + \underset{(6.7)}{1.03\ pus}$$

Quasi-R^2 = .75

$$q = \underset{(5.3)}{.27} - \underset{(3.1)}{.12pe} - \underset{(3.8)}{.13pe(-1)} - \underset{(1.3)}{.05pu} + \underset{(23.7)}{.97kl}$$

$$+ \underset{(19.0)}{.86\ dev} - \underset{(20.4)}{.94\ dev(-1)}$$

Quasi-R^2 = .92 (MODEL 3)

pu = p-pe

The sums of the coefficients are as follows:

response of p to q	-.63 (2.5)	response of q to pe	-.24 (8.3)
response of p to w	.39 (2.9)	response of q to pu	-.05 (1.3)
response of p to dev	-.01 (0.1)	response of q to dev	-.08 (3.5)
response of p to pus	1.03 (6.7)	response of q to kl	.97 (23.7)

These results are virtually identical to those from Model 2. They suggest that of any inflation-induced decline in productivity growth, 83 percent can be attributed to inflation that is anticipated, while the remaining 17 percent can be attributed to unanticipated inflation. The greater adverse impact of anticipated inflation is in accordance with the results of Blejer and Leiderman (1980) which show that unanticipated inflation stimulates both real output and employment, while anticipated inflation inhibits real output while still stimulating employment. The long-run response of productivity growth to a one percent increase in inflation that is perfectly foreseen is a decline of .29 percentage points, whereas an unforeseen increase results in a decline in productivity growth of .06 percentage points. The long-run anticipated (unanticipated) inflation multiplier associated with an increase in productivity growth is -.74 (-.65).

We simulated a perfectly foreseen increase in inflation by adding 1.0 to the constant term of the inflation equation and assuming that pe = p. An unforeseen increase in inflation was simulated by adding 1.0 to the constant term of the inflation equation, leaving pu = p - pe, and by assuming that pe remained unchanged in spite of the increase in realized inflation. A more 'realistic' simulation in which the increase in inflation is initially unforeseen but is eventually incorporated into expectations would produce results that lie between those of the two extremes cited above.[17]

Table 3 gives the 'causality' results:

TABLE 3

TESTS OF ALTERNATIVE VERSIONS OF MODEL 3

Alternative hypotheses	Value of likelihood ratio	χ^2 Critical value (.05)	Result
$q \rightarrow p$; $pe \not\rightarrow q$	36.4	6.0	Reject
$q \rightarrow p$; $pu \not\rightarrow q$	1.2	3.8	Cannot reject
$q \not\rightarrow p$; $pe, pu \rightarrow q$	9.5	11.1	Cannot reject

Feedback is again observed from (anticipated) inflation to productivity growth, and again the coefficients on productivity growth in the inflation equation are ill determined, their sum being neither significantly different from zero nor from negative one. A likelihood ratio test of the restriction that the sum of the coefficients on productivity growth in the inflation equation equal negative one results in an χ^2 value of 1.8, as compared to the .05 critical value of 3.8. The sums of the remaining coefficient groups with this constraint imposed are:

response of p to q	-1.0 (constrained)	response of q to pe	-.25 (8.7)
response of p to w	.42 (3.2)	response of q to pu	-.07 (1.7)
response of p to dev	.02 (0.4)	response of q to dev	-.08 (3.4)
response of p to pus	.92 (6.3)	response of q to kl	.96 (23.6)

The long-run productivity multiplier associated with a perfectly foreseen (unforeseen) increase in inflation is -.33 (-.08). The long-run inflation multiplier associated with an increase in productivity growth is -1.33 if changes in inflation are perfectly foreseen and -1.08 if they are not. Adjustment is virtually complete within two to three years.

It has been hypothesized that in addition to inflation per se, uncertainty about inflation also asserts a negative influence on productivity growth. To investigate this possibility we constructed two alternative measures of inflation uncertainty: (i) the square of the ratio of unexpected to expected inflation, and (ii) the square of the difference between actual inflation and an eight-quarter moving average of actual inflation. Likelihood ratio tests indicated that neither of these measures contributed significantly to the explanation of productivity growth.

A popular alternative to the above representation of the price determination process suggests that, in addition to productivity growth, the rate of growth of the money supply is a dominant driving force behind inflation.[18] When monetary growth is included in an equation describing inflation, it is usual to expect the sum of its coefficients to equal unity, based on a hypothesis of long-run neutrality. However, if inflation induces a permanent decline in productivity growth, a sum of unity implies money is not neutral in the long run. In this case a one percentage point decline in monetary growth would eventually reduce inflation by more than one percentage point. Moreover, if the velocity of the circulation of money is unaffected, real output must adjust.

The results of estimating this alternative model of the inflation-productivity growth relationship -- with monetary growth (m) measured by the seasonally adjusted rate of growth of M1 (Bank of Canada Review Table 14, Cansim series B1609) -- are as follows:

$$p = \underset{(0.3)}{.12} - \underset{(1.8)}{.24q} - \underset{(1.1)}{.15q(-1)} - \underset{(1.1)}{.14q(-2)} + \underset{(0.3)}{.04q(-3)} - \underset{(2.6)}{.36q(-4)}$$

$$+ \underset{(0.1)}{.00m} + \underset{(2.2)}{.17m(-1)} + \underset{(0.7)}{.05m(-2)} + \underset{(3.2)}{.23m(-3)} + \underset{(0.2)}{.02m(-4)}$$

$$+ \underset{(0.3)}{.02m(-5)} + \underset{(2.6)}{.18m(-6)} + \underset{(0.1)}{.01m(-7)} + \underset{(3.4)}{.26m(-8)}$$

Quasi-R^2 = .53

$$q = \underset{(5.0)}{.30} - \underset{(3.2)}{.14pe} - \underset{(3.7)}{.12pe(-1)} - \underset{(1.6)}{.07pu} + \underset{(23.4)}{.96kl}$$

$$+ \underset{(19.0)}{.85dev} - \underset{(20.4)}{.93dev(-1)}$$

Quasi-R^2 = .91

pu = p-pe (MODEL 4)

The coefficient sums are as follows:

response of p to q	-.86 (2.9)	response of q to pe	-.26 (7.6)
response of p to m	.94 (6.4)	response of q to pu	-.07 (1.6)
		response of q to kl	.96 (23.4)
		response of q to dev	-.08 (3.7)

The relevant likelihood ratio tests used to determine 'causality' are given in Table 4.

TABLE 4

TESTS OF ALTERNATIVE VERSIONS OF MODEL 4

Alternative hypotheses	Value of likelihood ratio	χ^2 Critical value (.05)	Result
$q \rightarrow p$; $pe \not\rightarrow q$	34.1	6.0	Reject
$q \rightarrow p$; $pu \not\rightarrow q$	2.1	3.8	Cannot reject
$q \not\rightarrow p$; $pe, pu \rightarrow q$	9.6	11.1	Cannot reject

Once again feedback is seen to exist and once again the response of p to q is ill determined, being neither significantly different from zero nor from negative one. Again the cross-correlogram revealed no significant correlations among the residuals, and Haugh's S-statistic is 11.8 (with 17 degrees of freedom).

As one can see, the results of this model are broadly similar to those of Model 3 in terms of 'fit' and reasonableness. The partial response of inflation to an acceleration in the money supply is not significantly different from unity. This result is virtually identical to the findings of von Furstenberg and White (1980), except that we interpret it as an implication that monetary growth is non-neutral because of the negative effect of inflation on productivity growth. The partial response of inflation to productivity growth is near negative one in size, but, because it is not well determined, the hypothesis that it is zero cannot be rejected. The long-run response of inflation to a one percentage point increase in productivity growth is -1.11 percentage points if changes in inflation are perfectly foreseen and -.91 percentage points if they are not.

The partial response of productivity growth to a one percentage point increase in anticipated (unanticipated) inflation is a decline of .26 (.07) percentage points. In the long run, a perfectly foreseen (unforeseen) increase in inflation of one percentage point induces a reduction in productivity growth of .34 (.08) percentage points.

It has been suggested that the observed relationship between productivity growth and inflation is spurious because the effects of the energy sector are neglected. The argument proceeds as follows. First, it is put forth that energy price inflation is a significant cause of general price inflation. Further, it is also argued that the change in the relative price of energy results in a change in the proportions in which energy, capital and labour are combined in the production process and that these variations in factor proportions influence the growth of labour productivity.[19] Therefore, according to this hypothesis, rising energy costs cause both general price inflation and diminished labour productivity. Thus, since energy is excluded from explicit consideration in the preceding empirical analysis, the observed correlation between inflation and productivity growth is spurious: it does not imply a causal relationship.[20]

If this hypothesis were correct, then one would expect that including energy price inflation (e) as a determinant of general price inflation and including the growth of the energy to labour ratio (el) in the productivity equation, would lead to significant coefficients on both of these variables and would result in the coefficients on inflation in the productivity equation becoming insignificant. The energy price and value data were constructed from Statistics Canada Input-Output Tables (Statistics Canada Catalogue nos. 15-201E and 15-202E); see Masson, Muller and Simard (1980) for complete details. Constraints on data availability reduced the sample period to 1963 Q2 to 1978 Q4. The results are as follows:

$$\begin{aligned} p = &- \underset{(2.2)}{.74} - \underset{(1.4)}{.14q} - \underset{(3.3)}{.32q(-1)} + \underset{(1.0)}{.10q(-2)} + \underset{(0.6)}{.06q(-3)} - \underset{(0.1)}{.01q(-4)} \\ &+ \underset{(3.8)}{.51w} - \underset{(0.4)}{.06w(-1)} + \underset{(2.2)}{.31w(-2)} - \underset{(1.8)}{.24w(-3)} + \underset{(0.8)}{.09w(-4)} \\ &+ \underset{(3.7)}{.45dev} - \underset{(4.2)}{.74dev(-1)} + \underset{(3.8)}{.64dev(-2)} - \underset{(3.8)}{.39dev(-3)} + \underset{(5.8)}{.93pus} \\ &+ \underset{(0.3)}{.01e} + \underset{(0.5)}{.02e(-1)} + \underset{(0.3)}{.01e(-2)} - \underset{(1.0)}{.04e(-3)} - \underset{(0.9)}{.03e(-4)} \end{aligned}$$

Quasi-R^2 = .81

$$\begin{aligned} q = &\underset{(4.8)}{.34} + \underset{(0.5)}{.02p} + \underset{(0.6)}{.03p(-1)} - \underset{(2.8)}{.12p(-2)} - \underset{(3.4)}{.15p(-3)} - \underset{(1.1)}{.04p(-4)} \\ &+ \underset{(0.4)}{.01p(-5)} - \underset{(1.0)}{.04p(-6)} + \underset{(23.5)}{.94kl} + \underset{(17.1)}{.80dev} - \underset{(18.1)}{.90dev(-1)} \\ &+ \underset{(0.3)}{.00el} + \underset{(0.0)}{.00el(-1)} - \underset{(0.3)}{.01el(-2)} + \underset{(0.8)}{.02el(-3)} + \underset{(0.8)}{.01el(-4)} \end{aligned}$$

Quasi-R^2 = .93 (MODEL 5)

The sums of the current and lag coefficients are:

response of p to q	-.32 (1.1)	response of q to p	-.29 (9.0)
response of p to w	.62 (4.1)	response of q to kl	.94 (23.5)
response of p to dev	-.03 (0.5)	response of q to dev	-.10 (3.7)
response of p to pus	.93 (5.8)	response of q to el	.03 (0.4)
response of p to pe	-.03 (0.7)		

A likelihood ratio test of the significance of the coefficients of e and el yields a value of 5.9, compared to a 5 percent critical value of 18.3. This is a clear rejection of the hypothesis that the observed relationship between inflation and productivity growth results solely because each are in turn related to energy price inflation.

Finally, three additional caveats to the interpretation of our results are worth noting. First, it is possible that our results are due to the existence of what has recently been labelled the underground or 'subterranean' economy.[21] If the prevalence of these extra-legal activities is an increasing function of the realized rate of inflation, then an increase in that rate would appear to 'cause' a reduction in output and perhaps in labour productivity from levels that would have otherwise prevailed. However, it is virtually impossible to test this hypothesis formally owing to a lack of adequate data on the magnitude of this 'subterranean' economy.

Second, Terborgh (1979) has pointed out a divergence between U.S. labour productivity data for manufacturing as derived from deflated current dollar statistics from the Bureau of Economic Analysis and those derived from the Federal Reserve Board's index of industrial production which involve more actual counting of physical output. This divergence is apparently an increasing function of realized inflation (or of shifts in relative prices), and it is therefore possible that implicit price deflators are systematically overestimating the 'true' price level in inflationary times and that this bias increases with inflation.[22] If the same holds true for Canada, our findings may simply be the product of the way in which the data are constructed. Once again there is no apparent way to evaluate the validity of this hypothesis.

Third, we used average hours worked per employee in the construction, mining and manufacturing sectors as representative of the economy-wide average. There was a shift of labour into the service sector, particularly in the 1960s, and since this sector traditionally has lower average hours worked, we have underestimated productivity in the 1960s and hence underestimated the decline in productivity. This would imply that our estimate of the response of productivity growth to inflation may well be biased towards zero.

6 FINAL REMARKS

In this paper we have attempted to identify the macroeconomic relationship between productivity growth and inflation using both reduced-form and structural models. Specifically, we tested the hypothesis that the result of increased productivity growth is a one-for-one reduction in inflation, against the alternative hypothesis that because of a feedback relationship between the two, the response might be more than one-for-one.

Using a bivariate reduced-form approach we were able to reject the unit elasticity hypothesis. Because of significant feedback, the implied multiplier associated with a one percentage point increase in productivity growth is a 2.24 percentage point decline in inflation. However, significant cross-correlation of the residuals indicated the presence of specification error.

We then turned to a variety of structural models and again found a feedback relationship. Moreover, while we found anticipated inflation to figure more importantly than unanticipated inflation in the explanation of the fluctuations in productivity growth, we found uncertainty about inflation to have no role in explaining productivity growth. The long-run response of productivity growth to a 'permanent' one percentage point increase in inflation varied from a decline of .08 percentage points when expectations were assumed not to adapt, to a decline of .34 percentage points when expectations were assumed to adapt fully. We estimated that an exogenously induced one percentage point decline in inflation would eventually multiply into a decline in inflation of between 1.23 and 1.33 percentage points because of its feedback onto productivity growth. The long-run inflation multiplier associated with an increase in productivity growth was calculated to range between -.75 and -1.33, depending on the particular specification of the model. It is worth pointing out that while these estimates clearly indicate that the recent decline in productivity growth has contributed to rising inflation, they also suggest that the effects have not been large enough to conclude that this interaction is the sole cause of the current high levels of inflation. However, the increased inflation rates of the 1970s are sufficient to explain virtually the entire recent slowdown in productivity growth.

FOOTNOTES

1. A brief description of the Freund and Manchester model is as follows:

Let p = the rate of price inflation (as measured by the CPI),

w = the rate of wage inflation,

q = the rate of labour productivity growth, and

u = the rate of unemployment.

Then p = w-q if we assume that prices are set according to unit labour cost, and

$$w_t = ap_{t-1} + bq_{t-1} + cu_t + d \qquad (*)$$

Substituting out for w and lagged p, we have

$$p_t = -q_t + (b-a) \sum_{j=1}^{n} a^{j-1} q_{t-1} + cu_t + d$$

Now if productivity growth is shocked for n + 1 periods by an amount X, then

$$\Delta p_{tn} = [-1 + (b-a) \sum_{j=1}^{n} a^{j-1}] X_n$$

and, as $n \rightarrow \infty$, and assuming $a < 1$

$$\Delta p_t/X = -1 + (b-a)/(1-a)$$

Freund and Manchester estimated equation (*) in order to derive estimates of a and b. For the U.S. private business sector the results were:

$$w(t) = \underset{(5.15)}{6.30} + \underset{(6.84)}{0.81}\, p_{t-1} + \underset{(0.88)}{0.17}\, q_{t-1} - \underset{(2.97)}{0.62}\, u_t$$

$R^2 = 0.74$ D.W. = 2.23 1953 to 1979

Thus, the equilibrium long-run elasticity of inflation with respect to productivity growth is:

$$-1 + ((.17 - .81)/(1 - .81)) = 4.4$$

When we duplicated this equation for Canada our results were extremely sensitive to the choice of price index used to measure inflation and significant autocorrelation was in evidence. In addition, an intercept shift for the period 1976 Q1 to 1978 Q4 (the period of controls administered by the Anti-Inflation Board) was required. When first-order serial correlation was allowed for, the coefficient on the unemployment rate became insignificant and the term was dropped. With these modifications, the implied multiplier is 1.57 using the Consumer Price Index, 1.18 with the GNE deflator and .98 using the ratio of GDP to RDP i.e., the GDP deflator. Estimated multipliers were significantly larger when no autocorrelation correction was applied.

2. Vining and Elwertowski (1976), Touche Ross and Company (1976), Liebling (1980), Malkiel (1979), and Mullineaux (1980) among others, have put forward similar arguments. Moreover, Okun (1971) and Gordon (1971) showed that for seventeen industrialized nations the correlation between average inflation rates and the standard deviation of these rates was .78 for the 1951 to 1968 period, .90 from 1951 to 1960, and .40 (not significant) from 1960 to 1968. Gordon and Halpern (1976) found the correlation to be .91 for thirty-three nations over the 1952-72 period. Logue and Willett (1976) extended the sample to forty-one countries -- including both developed and developing nations. They also extended the sample period to include the years 1948 to 1970. They found that the positive relationship seems to have declined in the latter half of the period relative to the earlier years, but that it remains significant for the over-all sample. Upon disaggregating the sample into such broad categories as highly industrialized countries, Latin America etc., they found the correlation to be robust for all groups except the highly industrialized nations. They then

disaggregated by average rate of inflation and found that the correlation was apparent only when inflation exceeded a rate of about 4 percent per annum. Jaffee and Kleiman (1977) undertook a similar analysis for seventeen OECD nations and sixteen Latin American countries over the 1951-71 period, and found the relationship to be robust, except for the latter group, over the 1961-71 period. Foster (1978), using a different variability measure, showed a significant relationship that was robust to variations in time period and country choice. Vining and Elwertowski (1976) presented evidence that the distribution of individual price changes is skewed, and that this skewness is especially pronounced in periods of high inflation.

3. Cukierman and Wachtel (1979) have recently disputed Vining and Elwertowski's interpretation by claiming that both the increased variation of the general price level and the increased dispersion of relative prices are caused by the increased variance of aggregate and relative excess demand shocks.

4. Able (1980), in his recently completed dissertation, demonstrated that an investment equation that incorporates the assumptions that all variances and covariances associated with input and output prices are proportional to output prices, and in which uncertainty is treated as a cost of

production, significantly outperforms a traditional Jorgensonian investment function in predicting the sluggish investment spending of the 1975-78 period.

5. Pointing to the inflation-wrought increase in real U.S. effective corporate tax rates and the consequent reduction in investment, Gordon (1980, p. 109) has recently written: "Through this and other channels, inflation may be partly responsible for the decline in the growth of productivity ... during the latter part of the 1970s, although recent studies indicate that the slowdown in investment explains only part of the productivity story." Those who have studied the time, regional and industrial patterns of productivity growth almost universally recognize the significant role played by investment spending and capital intensity in determining that growth. For Canada see Postner (1971), Davenport (1979), Auer (1979), Rao (1979) and Bilkes (1980). For the United States see, for example, McCarthy (1978), Bennett (1979), Siegel (1979), Clark (1978), Nadiri (1980), Kendrick (1976), Norsworthy et al (1979), Denison (1979), and Klotz et al (1980). However, Thurow (1979) argues that increased investment will cause an increase in the size of the construction sector (which traditionally exhibits low productivity growth) thereby lowering aggregate productivity growth, while Zohar (cited in Friedland, 1980) claims investment spending is effective in increasing productivity

in only four of Canada's nineteen two-digit manufacturing industries.

6. For Canada see Pesando (1980), Bélanger and McIlveen (1980) and Touche Ross and Company (1976). For the United States see Tideman and Tucker (1976), Terborgh (1974), Kopcke (1978, 1980), Haberler (1979), Corcoran (1977, 1979), Okun (1975), Holland and Myers (1979, 1980), Tatom and Turley (1978), Tatom (1979), Flemming (1976), Richardson (1979), Nowotny (1980), Hart (1980), and a series of papers by Feldstein and his collaborators, most recently, Feldstein (1980).

7. See Jones (1980), Jaffe and Mandelker (1976), Bodie (1976) and Nelson (1976a).

8. Ruttan (1979) has hypothesized a "dialectical interaction between inflation and productivity" (p. 896). Kendrick (1980) has recently written: "The relationship between inflation and productivity is, of course, an inverse one. While inflation impairs productivity growth, so does a retardation of the latter variable accelerate inflation through stronger cost push."(p. 18). Okun (1980) has recently stated: "There are ample grounds for the suspicion ... that various aspects of our chronic inflation may account for some of the puzzle of the productivity slowdown." (p. 168). Denison (1979) has also argued that inflation has

impaired the efficiency of markets by causing information to become outdated more quickly and by increasing the variance of individual price changes. Similar thoughts have recently been expressed by the Council of Economic Advisers, (1981, pp. 33-34) and Wallich (1981). Evans (1980) alluded to the possibility of a vicious circle emanating from negative rates of return on saving through inadequate investment to lower productivity and higher inflation, or to dollar depreciation and back to higher prices and lower investment. Nordhaus (1980) has expressed doubts that the negative effects of inflation are large; however, he uses purely static allocative arguments, whereas productivity growth is in large part a question of dynamics.

9. On a more practical level, it is also known that under certain circumstances Granger-Sims techniques may give misleading results. For example, Gelb and Selody (1978) and Jacobs, Leamer and Ward (1979) have shown that when data are measured with error, Granger-Sims techniques can indicate the presence of Granger-causality when, in fact, it is absent. Alternatively, Sims (1977) has shown that if Y is perfectly controlled by X, a Granger-Sims technique may lead to the conclusion that X and Y are independent when in fact they are causally related in a very significant way. Jacobs, Leamer and Ward also argued that since Granger-Sims techniques operate on reduced forms, the parameters of which are complex

expressions of structural parameters, they are not useful in testing the more powerful hypothesis that a structural parameter or group of structural parameters are near zero. A reduced-form parameter near zero need not imply insignificant structural parameters. According to Jacobs, Leamer and Ward this is a particularly serious drawback of the technique since errors in model specification which bias zero coefficients away from zero are common in economics. Finally, one-way Granger-causality is only a necessary condition and not sufficient in itself for exogeneity in the usual econometric sense. In particular, because it operates on reduced forms, the technique is not useful in isolating contemporaneous exogeneity. On the other hand, Sims (1977) has argued that although there are certain conditions under which the Granger-Sims technique can be inaccurate, these conditions are not likely to be found in typical economic data.

10. The consequences of using an alternative measure of productivity are presented in Appendix A. Generally, the magnitude of the effect of a change in productivity growth on inflation appears to be sensitive to the choice of productivity measure, whereas the effect of a variation in inflation on productivity growth proves to be very robust.

11. Real Domestic Product, Gross Domestic Product and employment

series were seasonally adjusted at source, whereas the data on man-hours were seasonally adjusted at the Bank of Canada using the X-11 seasonal adjustment package.

12. Akaike's criterion is

$$FPE = \sum_{i=1}^{T} ((Y_i - y_i)^2/T) \cdot (T+K+1)/(T-K-1)$$

where Y_i represents the fitted values and y_i represents the actual values in an OLS regression with T observations and K+1 coefficients. Geweke and Meese (1979) discuss alternative methods of determining lag length.

13. These results were confirmed by a modified Pierce-Haugh (1977) test in which the residuals from the univariate autoregressive specifications are cross-correlated. The pattern of cross-correlations indicated a two-way relationship. The Haugh S-statistic had a value of 58.8 which exceeds the critical χ^2 with 41 degrees of freedom (55.8). Thus we reject independence.

14. We experimented with various measures of excess demand, including deviations of RDP around an exponential trend,

around an exponential trend through peaks, and around an exponential trend that shifts in 1973 Q2. The results reported in the text use the latter measure of dev (results using other measures are reported in Appendix B). The rationale for allowing the trend in RDP to differ after 1973 is that the rise in oil prices after 1973 rendered a portion of the capital stock obsolete (see footnote 19). The direct response of productivity growth to expected inflation varies between -.10 and -.24, that of productivity growth to unexpected inflation varies between .04 and -.12, and that of price inflation to wage inflation varies between .64 and .88. The only large variation occurs in the case of the direct response of inflation to productivity growth, which varies between -1.99 and -.61.

15. It may be thought that these figures underestimate the response of productivity growth to inflation since, after all, one of the mechanisms through which inflation affects productivity is via capital accumulation, and the rate of change of the capital-labour ratio enters as a separate explanatory variable in the productivity growth equation. However, a simple (OLS estimation and arbitrarily fixed lag lengths) bivariate Granger-causality test of inflation (p) and the rate of capital deepening (kl) indicated that these two variables are intertemporally independent.

16. It should be pointed out that a one-step-ahead forecast is a very narrow concept of anticipations. There are many arguments that suggest that the term 'anticipations of inflation' refers to expectations over a time horizon longer than one period ahead or to expectations more subjective than a mechanical rule.

17. See Appendix C for a description of three intermediate simulations.

18. The two versions of the inflation equation are not necessarily inconsistent. The first version assumes wages and other 'real' factors are the exogenous driving force behind inflation and that monetary growth accommodates. The second version assumes monetary growth is the main exogenous source of inflation and that price inflation drives wage inflation.

19. For U.S. evidence regarding the importance of energy in the determination of productivity growth see, for example, Norsworthy et al (1979), Siegel (1979), a series of papers by Robert Rasche and John Tatom, e.g., Tatom (1979), and a series of papers by Jorgenson et al, e.g., Hudson and Jorgenson (1978) and Jorgenson. For Canada see Bilkes (1980). For contrary evidence see Berndt (1980).

20. Gregory (1980, p. 91) suggests that possibly the only way to reverse Berndt's conclusion that energy price inflation has had a negligible impact on productivity growth would be to model the direct effect of energy price inflation on aggregate inflation and the subsequent effect of aggregate inflation on productivity growth. This approach is similar to that used in our Model 5.

21. For the United States, see Porter (1979) and the references cited therein; for Canada see Wong and Rose (1980).

22. This hypothesis was, however, explicitly rejected for the U.S. construction industry in Stokes (1979).

APPENDIX A

An alternative measure of productivity

Alternative versions of the inflation-productivity growth relationship were estimated using productivity measured as the output per man-hour in the private business sector (excluding agriculture and non-commercial business). This narrower definition allows us to avoid those sectors where productivity measures are suspect (particularly the government sector). In the presentation of the following results, the reported coefficient is the sum of the individual coefficients on the contemporaneous and lagged values of the variables. The order of the lag polynomial is given in parentheses following each variable, while the t-ratio for the sum of the coefficients is in parentheses below. In all cases at least one individual coefficient of the lag polynomial is significant, and hence an insignificant t-ratio for a sum is generally indicative of an oscillating pattern of lag coefficients.

Alternative A1:

$$p = -\underset{(1.4)}{.47} + \underset{(3.1)}{.43}w(4) + \underset{(0.9)}{.04}dev(4) - \underset{(2.2)}{.52}q(4) + \underset{(6.4)}{1.08}pus \qquad \text{Quasi-}R^2 = .72$$

$$q = \underset{(1.5)}{.32} - \underset{(2.6)}{.25}p(4) + \underset{(3.8)}{.91}kl(3) - \underset{(1.7)}{.08}dev(2) \qquad \text{Quasi-}R^2 = .69$$

Alternative A2:

$$p = -.33 + 1.10m(8) - .65q(4)$$
$$\quad (1.1) \quad (8.0) \quad (2.9)$$

Quasi-R^2=.57

$$q = .38 - .18pe(1) + .09pu(0) + .68kl(0) - .10dev(1)$$
$$(2.4) \quad (1.8) \quad (0.8) \quad (6.3) \quad (2.4)$$

Quasi-R^2=.68

In the above alternatives, deviations are measured by fluctuations of output around its trend. As is discussed in the text, this trend line is allowed to change in 1973 Q2. As a test of the robustness of our results to this measure, a version of the relationship was estimated using an alternative measure of dev. Here, dev was measured as deviations in output around trend output based on a Cobb-Douglas production function with the actual capital stock, the average employment rate and trended average weekly hours as factor inputs.

Alternative A3:

$$p = .22 + .38w(4) + .14dev(4) - 1.19q(4) + .99pus$$
$$(0.5) \quad (2.1) \quad (1.9) \quad (3.3) \quad (5.0)$$

Quasi-R^2=.48

$$q = .07 - .19p(4) + 1.03kl(3) - .09dev(2)$$
$$(0.3) \quad (1.8) \quad (3.8) \quad (1.6)$$

Quasi-R^2=.61

APPENDIX B

Alternative measures of fluctuations in output

Alternative versions of the inflation-productivity growth relationship were estimated using various measures of fluctuations in output. The first alternative measures dev as fluctuations in RDP about its sample trend. In the second approach, dev is measured as fluctuations in RDP about an exponential trend through sample peaks. The quarters of peak output used were 1969 Q1 and 1974 Q1. The third alternative measures dev as fluctuations in RDP about an exponential trend through peaks that break in 1974 Q1. Here, the high output quarters were taken to be 1962 Q2, 1969 Q1 and 1974 Q1. The first version of the inflation-productivity growth relationship was:

$$p = a_0 + \sum_{i=0}^{6} a_1(i)\, w + \sum_{i=0}^{4} a_2(i)dev + \sum_{i=0}^{4} a_3(i)q$$

$$q = b_0 + \sum_{i=0}^{2} b_1(i)pe + \sum_{i=0}^{1} b_2(i)pu + \sum_{i=0}^{5} b_3(i)kl + \sum_{i=0}^{4} b_4(i)dev \tag{B.1}$$

and produced the following results:

Table B1

p equation:	Sum of coefficients (t-ratios) for alternative:		
	1	2	3
variable			
constant	1.31 (3.0)	-.44 (0.8)	1.14 (3.0)
w	.64 (2.2)	.88 (4.5)	.64 (4.0)
dev	.05 (0.2)	-.14 (0.7)	.16 (1.0)
q	-1.99 (4.8)	-.61 (1.2)	-1.28 (4.5)
Quasi-R^2	.51	.63	.61
q equation:			
variable			
constant	.22 (2.3)	-.06 (0.5)	.04 (0.4)
pe	-.12 (3.1)	-.10 (3.8)	-.24 (7.6)
pu	-.12 (1.4)	.04 (0.6)	.01 (0.1)
kl	.86 (9.2)	1.08 (10.2)	.96 (13.2)
dev	-.02 (1.2)	-.04 (2.9)	-.08 (3.7)
Quasi-R^2	.92	.96	.96

The second version of the relationship is:

$$p = a_0 + \sum_{i=0}^{8} a_1(i)\, m + \sum_{i=0}^{4} a_2(i) q$$

$$q = b_0 + \sum_{i=0}^{1} b_1(i) pe + b_2 pu + b_3 kl + \sum_{i=0}^{1} b_4(i) dev \qquad (B.2)$$

This version produced the following results:

Table B2

p equation:	Sum of coefficients (t-ratios) for alternative: 1		2		3	
variable						
constant	.01	(0.1)	.10	(0.3)	.31	(0.9)
m	.96	(6.5)	.93	(6.3)	.87	(6.0)
q	-.75	(2.5)	-.81	(2.7)	-.98	(3.4)
Quasi-R^2	.53		.53		.52	

q equation:	1		2		3	
variable						
constant	.06	(1.1)	.05	(0.9)	-.02	(0.3)
pe	-.07	(2.2)	-.10	(3.5)	-.21	(6.6)
pu	-.03	(1.0)	-.07	(2.0)	-.08	(2.1)
kl	.96	(27.2)	.98	(28.8)	.97	(27.0)
dev	-.03	(2.7)	-.03	(3.7)	-.09	(5.4)
Quasi-R^2	.94		.95		.93	

APPENDIX C

Alternative simulation rules about inflation expectations

There are an infinite number of intermediate assumptions about inflation expectations that lie between the extremes of perfect foresight and continual ignorance. Moreover, as all simulations are necessarily hypothetical, it is impossible to know what the true adjustment path would have been. In this Appendix we highlight three intermediate models of inflation expectations.

First, we assumed that our constructed anticipations series was an accurate reflection of 'true' anticipations. This assumption was useful because it allowed us to sidestep the problem of a lack of a measure of expected inflation. We then modelled this 'true' anticipations series with a distributed lag on past inflation and productivity growth. The rationale for fitting a function with time-invariant parameters to a series that is constructed with explicit time-varying parameters is that this simpler model is an adequate 'as if' representation of the more complex 'true' behavioural model. We experimented with various lag lengths, imposed the constraint that the sum of the coefficients on lagged realized inflation is unity, and finally settled on the following equation:

$$pe = \underset{(1.2)}{.13} + \underset{(2.5)}{.24}\, p(-1) + \underset{(4.9)}{.42}\, p(-2) + \underset{(3.4)}{.34}\, p(-3) - \underset{(2.2)}{.25}\, q(-1)$$

$$R^2 = .71 \qquad S.E.E. = .75 \qquad D.W. = 1.73 \qquad (C.1)$$

We added this equation to Model 3 and undertook our shocks. At first a shock to inflation was entirely unexpected and had only a minor effect on productivity growth. But agents gradually adapted their anticipations of inflation and, by the sixth quarter, inflation was inhibiting productivity growth. After three years the adjustment was virtually complete. At this point, realized inflation was 1.19 percentage points higher than before the shock, expected inflation was 1.27 percentage points higher and productivity growth was .31 percentage points lower. The reason for the divergence between anticipated and realized inflation is that the feedback effect of productivity growth on anticipated inflation is slightly larger than that for realized inflation. After a permanent increase in productivity growth, it was not until the twentieth quarter that anticipated inflation stabilized and equilibrium was re-established. Long-run elasticities for realized, anticipated and unanticipated inflation were -.79, -1.09, and .31, respectively. Productivity growth was eventually 1.25 percentage points higher than its control solution value.

In an alternative specification of inflation expectations, it was assumed that expectations take the same structural form as the realized inflation process:

$$pe = -.23 + .38w - .03w(-1) + .24w(-2) - .35w(-3) + .14w(-4) - .17q - .26q(-1) - .01q(-2) - .06q(-3) - .12q(-4) + .37dev - .55dev(-1) + .64dev(-2) - .46dev(-3) + 1.03\ pus \qquad (C.2)$$

With this equation substituted into Model 3, we again shocked inflation and productivity growth. After a one percentage point increase in realized and anticipated inflation, equilibrium was re-established in three years. By this time realized inflation was 1.19 percentage points higher, anticipated inflation 1.31 percentage points higher, and productivity growth was .31 percentage points lower. A one percentage point increase in productivity growth was eventually multiplied into a 1.29 percentage point increase in productivity growth, with inflation dropping by .58 percentage points after one year, and eventually by .81 percentage points.

One final specification of inflation expectations was performed so that, once shocked, the system would be restored to equilibrium with no change in unanticipated inflation. This was accomplished using:

$$pe = .5p(-1) + (.5)^2 p(-2) + (.5)^3 p(-3) + (.5)^4 p(-4) + (.5)^4 p(-5) \quad (C.3)$$

A shock to realized inflation led to virtually complete adjustment in about 25 quarters. In the long run, inflation increased by about 1.18 percentage points and productivity growth declined by .29 percentage points. It took about one year after the start of the productivity growth shock for inflation to complete one-half of its adjustment. Inflation was eventually reduced by .74 percentage points.

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