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Abstract

This paper analyzes the short-run dynamic process of inflation in Canada and examines whether a systematic variation in the relationship between inflation and output can be detected over time. In the theoretical literature, different models of price-setting behaviour predict that the slope of the Phillips curve will be a function of macroeconomic conditions, implying a time-varying sacrifice ratio. Evidence for four different types of asymmetry is presented in the context of short-run Phillips curves estimated in a state-space framework. The results suggest that there is significant time variation in the trade-off in Canada, but that it is difficult to distinguish definitively among the possible models generating the non-linearity.

Résumé

Les auteurs analysent le processus dynamique d’inflation à court terme au Canada et cherchent à établir si une variation systématique de la relation entre l’inflation et la production peut être détectée sur longue période. Les divers modèles théoriques décrivant le processus d’établissement des prix prédisent que la pente de la courbe de Phillips est fonction de la situation macroéconomique, ce qui laisse supposer un ratio de sacrifice variable dans le temps. Les auteurs présentent les résultats qu’ils obtiennent à l’égard de quatre types d’asymétrie différents en estimant des courbes de Phillips à court terme dans un cadre espace d’états. Selon ces résultats, la relation d’arbitrage varie beaucoup dans le temps au Canada, mais il est difficile de déterminer avec certitude lequel des modèles envisagés pourrait être à l’origine de la non-linéarité.

1. Introduction

Since the beginning of the 1990s, several countries have experienced low inflation. At the same time, several central banks have explicitly committed themselves to low-inflation targets. This recent experience has raised questions concerning the output losses associated with disinflation and also the issue of the economic adjustment in an environment characterized by low inflation. A standard approach in the literature is to use linear Phillips curves to assess the loss of output throughout the disinflation period. In this approach, the short-run trade-off between output and inflation is assumed to be constant over time, and the change in inflation relative to expected inflation to be simply proportional to the deviation of output from potential—the output gap. In particular, the size of the effect of the output gap on inflation relative to expectation is assumed not to vary with the initial level of inflation, the sign of the output gap, or other economic indicators. However, a strand of the theoretical literature allows for an output-inflation trade-off that depends on the initial state of the economy, and recently some studies have found empirical evidence for a variety of different possible non-linearities in the Phillips curve. From a policy perspective, the source of any non-linearity in the Phillips curve is important, since different theoretical motivations for non-linearity have quite different policy implications.

This study analyzes the dynamic process of inflation in Canada and examines whether a systematic variation in the relationship between inflation and output over time can be detected. It also attempts to identify the source of the time variation in the relationship. The tests are designed to identify, within the short-run Phillips curve framework, those variables that affect the output-inflation trade-off. In contrast to most other studies, this methodology allows testing of different types of non-linearity at the same time.

The first section of the paper surveys the literature and describes the models that imply a time-varying sacrifice ratio. The second section provides a detailed presentation of the estimation technique and variables that can be associated with different models of non-linear behaviour. A discussion of the results obtained for Canada follows. The final section presents concluding remarks.

2. Literature survey

The shape of the short-run Phillips curve is a long-standing issue in macroeconomics that has recently attracted renewed attention. A common assumption is that expectations can be modelled as a simple weighted average of past inflation rates, which gives rise to the accelerationist version of the Phillips curve.[1] It is now recognized that expectations formation may be sensitive to the monetary policy regime, among other things, so that constant parameter weights on past inflation may be inappropriate. This has led to the search for proxies for

1. For empirical examples for Canada, see Cozier and Wilkinson (1990) and Duguay (1994).

expectations, such as survey measures of inflation expectations, and to the separation of expectational dynamics from the structural dynamics that are due to costly adjustment of prices.

Several theoretical models of price-setting behaviour predict that the slope of the Phillips curve will be a function of macroeconomic conditions. The policy implications of a sacrifice ratio that is a function of the level of inflation are quite different from those of a ratio that is a function of the sign of the output gap. This section describes briefly five different approaches that may give rise to an asymmetric relationship between output and inflation or to time variation in an otherwise linear relationship.

The first model, the *capacity constraint model*, supposes that some firms find it difficult to increase their capacity to produce in the short run. Thus, when an economy experiences strong aggregate demand, the impact on inflation will be greater when more firms run up against capacity constraints. This model implies that inflation becomes increasingly sensitive to excess demand. In this particular framework, the short-run Phillips curve has a convex shape. This is consistent with the early empirical work on the Phillips curve, including Phillips (1958), which assumed that the relationship was non-linear and predicted that excess demand would increase inflation more than excess supply would reduce it. A simplified version of the model allows for a higher sacrifice ratio in periods of excess supply than in periods of excess demand.

In the capacity constraint model, the costs of a disinflation are independent of the initial level of inflation, as in the simple linear model. However, the capacity constraint model has important implications for the conduct of monetary policy aimed at controlling inflation.[2] In particular, a convex Phillips curve directly implies that, the more stable output is, the higher will be the level of output in the economy, on average. Given the lags in the effects of monetary policy, this provides an incentive for pre-emptive monetary responses to inflationary pressure. This conclusion is generally based on a comparison of policies for controlling inflation under linear and non-linear Phillips curves. A pre-emptive tightening in response to inflationary pressures helps to prevent the economy from moving too far up the Phillips curve where inflation begins to rise more rapidly, thereby avoiding the need for a larger negative output gap in the future to reverse this large rise in inflation.

The second model, the *misperception* or *signal extraction model*, was proposed by Lucas (1972; 1973). In this model, a relationship between output and inflation arises because agents are unable to distinguish precisely between aggregate and relative price shocks, since these shocks are not directly observable and must be inferred from the behaviour of individual prices. Output decisions are based on estimated relative price movements. The relationship between output and inflation in this model depends on the variance of inflation. The more (less) volatile the aggregate prices, the less (more) a given price change will be attributed to a change in relative prices, and

2. See Macklem (1997) for a full discussion of this model and its implications for monetary policy.

thus the smaller (larger) will be the output response. In this case, the short-run Phillips curve could be linear, but its slope will vary positively with the volatility of inflation.

A third model, the *costly adjustment model*, implies a relationship between output and inflation that varies with the level of inflation. For example, Ball, Mankiw, and Romer (1988) show that, in the presence of menu costs, not all firms will change their prices in response to a particular demand shock. However, the more firms that decide to change their prices, the more responsive will be the aggregate price level to demand shocks. In their model, firms increase the frequency and size of price adjustment as inflation rises so aggregate demand shocks will have less effect on output and more effect on the price level. Ball and Mankiw (1994) discuss another implication of menu costs. In the presence of trend inflation, prices should be more flexible upwards than downwards because some firms are able to obtain relative price declines from trend inflation without changing their own prices and incurring real costs. The model could thus imply a convex Phillips curve that becomes linear as inflation approaches zero.

Another example relates to the duration of contracts. The process of negotiating wages and benefits between firms and workers is costly. It therefore could be optimal, in an environment characterized by low inflation, to negotiate longer contracts on average in order to lower the costs faced by the firms. In this case, when a shock occurs, even though prices and wages are fully flexible in the long run, the existence of the contracts makes it difficult to adjust quickly. The implication from the costly adjustment model is that the Phillips curve is steeper—and possibly convex—at higher rates of inflation than at lower rates.

In the costly adjustment model, the impact of the output gap on the deviation of actual from expected inflation is a function of the average level of inflation. In this case, monetary authorities may find it more costly to achieve lower inflation when current inflation is low than when it is relatively high. This means that the benefits of lower inflation have to be greater in order to justify a disinflation when inflation is already low. By the same token, it also implies that inflation control may be easier at low rates of inflation, since the inflationary consequences of excess demand shocks take longer to materialize, giving the monetary authority more time to react. A monetary policy that reacts more slowly allows more information to be gathered about the state of excess demand.

Another model that can motivate an asymmetric relationship between output and inflation is the *downward nominal wage rigidity model*. Stiglitz (1986) and Fisher (1989) give excellent overviews of the type of theoretical models that can generate wage rigidity. In these models, workers are more reluctant to accept a decrease in their nominal wages than a decrease in their real wages because of money illusion, institutional, or behavioural factors. Therefore, in an environment characterized by a low rate of inflation, relative wages could adjust more slowly, leading to allocation inefficiencies. Provided that full adjustment to individual demand shocks eventually occurs, this model has two implications for the shape of the short-run Phillips curve.

First, it implies that the effects of nominal wage floors are more likely to be important at low rates of inflation, since the higher the average level of inflation, the less likely it is that a nominal wage cut will be required for a given decline in real wages. Second, if the rigidity applies only to downward wage adjustment, then at low rates of inflation excess supply might have less effect on inflation than excess demand, leading to an asymmetry with respect to the output gap. Recently Akerlof, Dickens, and Perry (1996) proposed a model in which downward nominal wage rigidity also leads to a long-run trade-off between inflation and output.[3] The empirical section of this paper limits its focus to models of short-run trade-offs.

Finally, the *monopolistically competitive model* refers to the strategic pricing behaviour of firms in monopolistically competitive or oligopolistic markets (see Stiglitz 1984, for example). In such an environment, producers might be inclined to lower prices quickly to avoid being undercut by rivals. However, they might be reluctant to raise prices, even in the face of generally rising prices, hoping to keep out potential new competitors. This last model is consistent with a concave short-run Phillips curve. In periods of excess demand, this type of relationship between output and inflation gives the monetary authority more time to react and gather more information about the state of the economy.

The shapes of the Phillips curve implied by the models described above are presented in Appendix 1. The six graphs plot the difference between actual and expected inflation ($\pi - \pi^e$) on the vertical axis against the output gap, *Y*, on the horizontal axis. Figure 1 depicts a linear short-run Phillips curve. When the output gap is negative (the economy is in excess supply), inflation will tend to decline below expected inflation. On the other hand, when the output gap is positive (the economy is in excess demand), inflation will be pushed above the expected level. With a linear formulation of the Phillips curve, the deviation between actual and expected is proportional to the output gap. Figure 2 depicts the non-linear short-run Phillips curve implied by the capacity constraint model. In Figures 3 and 4, the slope of the short-run Phillips curve can be linear but will be a function of, respectively, the level and the variability of inflation. Figure 5 illustrates the downward nominal wage rigidity model where excess supply has smaller effect on inflation than excess demand. Finally, Figure 6 presents a short-run Phillips curve consistent with a concave Phillips curve implied by the monopolistically competitive model.

A number of different directions have been pursued to estimate the short-run trade-off between output and inflation. One strand of the literature looks for evidence that nominal demand shocks have different effects on output in different countries and links the differences across countries to variables suggested by a particular model. Another branch of the literature looks for evidence of a non-linear Phillips curve using either single-country or multicountry data. Most studies do not attempt to test for more than one type of non-linearity at the same time but the

3. Fortin and Prud'homme (1984) also discuss the issue of nominal wage rigidity and the hypothesis of a non-linear Phillips curve.

results reported in the literature can support the different models described above.[4] The goal in this paper is to test for a variety of possible sources of non-linearity in the short-run trade-off between output and inflation.

3. The state-space framework

This section presents evidence for the different types of asymmetry from estimates of reduced-form Phillips curves.[5] This framework has been used extensively by researchers to quantify the effects of asymmetry or non-linearity in terms that are useful for policy-makers. This has typically involved allowing the parameter measuring the short-run output-inflation trade-off to vary with the size or sign of the output gap or with the level of inflation. The analysis in this paper is similar in this respect, but the estimated models also test for different types of asymmetry or non-linearity. The short-run output-inflation trade-off is treated as an unobserved state variable that can be forecast using different types of conditioning information. Because the state variable is unobserved, the uncertainty surrounding estimates of the trade-off parameter and its variation over time is also quantified.

The estimation framework consists of three parts. The first part is the basic Phillips curve equation, which is treated as the observation equation of a state-space model:

$$\pi_t = a \bullet \pi_t^e + (1-a) \bullet \pi_{t-1} + \beta_t \bullet Y_t + \delta \bullet Z_t + \varepsilon_t , \tag{1}$$

where π is the inflation rate, π^e is the expected inflation rate, Y is the output gap, Z_t is a set of variables representing other influences such as supply shocks, and ε is a random shock.

The second part specifies the form of the transition equation for the trade-off parameter β_t. The transition equation specifies the dynamics of the state variable and the set of conditioning information that should be useful in predicting its value. The general form of the transition equation is

$$\beta_t = \alpha + \rho \bullet \beta_{t-1} + \gamma \bullet X_{t-1} + \mu_t , \tag{2}$$

where X_{t-1} represents the conditioning information set. The inclusion of the error term μ_t means that parameter variation is allowed that cannot be explained by the elements of X_{t-1}. It may be that none of the theories examined explain all the variation in β_t. It may also be that some of the estimated movements in β_t are the result of misspecification of the measurement equation.

4. For a more detailed survey of the empirical literature, see Dupasquier and Ricketts (1998).
5. Dupasquier and Ricketts (1998) implement a different test to detect the presence of an asymmetry consistent with the monopolistically competitive model (or the concave Phillips curve). The results obtained do not favour this hypothesis.

The third part of the estimated model specifies the variables that enter the information set and their relationship to the state variable. The variables entering the information set depend on the model that generates the non-linearity or asymmetry. The capacity constraint model would imply that the sign or magnitude of the output gap should be positively related to the level of the trade-off parameter,[6] while the costly adjustment model would imply that some measure of the average level of inflation should be a useful predictor. For the misperception model, a measure of the conditional volatility of inflation should enter the information set. Finally, the downward nominal wage rigidity model can be tested using dummy variables for periods of low nominal wage growth.

3.1 Data and information sets

The short-run Phillips curve is estimated for inflation that is defined as the growth rate (at annual rates) of the total consumer price index excluding the impact of the GST, QST, and tobacco tax as measured by Statistics Canada.

The measurement equation requires specification of proxies for inflation expectations and the output gap, and as well the variables in Z_t. Inflation expectations and the output gap are unobservable and hence results will be, to a certain extent, dependent upon the effect of errors introduced by the choice of proxies. One way of attempting to control for these effects is to determine the robustness of the results to different proxies. Two measures of the output gap are used for this purpose. The first is based on the extended multivariate filter (EMVF), which is published regularly in the *Monetary Policy Report* and used in the context of the Bank of Canada's Quarterly Projection Model.[7] The other estimate of potential output is derived from a structural VAR including output, inflation, and real interest rates.[8] These measures of the output gap are relatively close until 1980, but there is greater volatility in the EMVF gap measure than in the SVAR measure, and also more excess supply at the end of the sample (see Figure 1).

To proxy inflation expectations, a three-state Markov switching model (MSM) is estimated, using the one-period-ahead predictions as the measure for expectations (see Figure 2). Each of the three states is described by a different long-run mean and autoregressive process, so that inflation expectations are generated differently in each state.[9] The predictions of the MSM are not based solely on the current behaviour of inflation. They also take into account the changing nature of the inflation process over time. In this sense, they have something of a forward-looking element because they adjust for the possibility of future changes in process. This introduces an additional

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6. As shown by Clark, Laxton, and Rose (1995), the average output gap must be negative if there is an asymmetry consistent with the capacity constraint model. To identify this mean shift, an additional parameter is introduced both in the measurement and the transition equation.
7. For more details on this approach to generate potential output, see Butler (1996).
8. This measure of the output gap, using the same data, is presented in St-Amant and van Norden (1997).
9. See Ricketts and Rose (1995) for an application of the Markov switching model to Canadian inflation data.

degree of uncertainty in inflation forecasts because the current inflation state is never known with certainty.

Since the costly adjustment model predicts that the trade-off parameter will differ according to the mean rate of inflation, this measure of inflation expectations can also be used, in the transition equation, as a proxy for periods when the long-run mean of inflation appeared to be different. Dupasquier and Ricketts (1998) use the state probabilities of the MSM to test for the costly adjustment model. However, if the slope coefficient were to change continuously as the level of expected inflation varies, the state probabilities should be capable of predicting some of the variation but the estimates would not be precise. Using the measure of inflation expectations generates more precise estimates.

Another useful output from the MSM is a measure of the conditional volatility of inflation. Because the volatility of shocks to inflation is allowed to differ across states, and because there is always some uncertainty about the inflation state, the conditional volatility measure will vary within and across states. As one can observe from Figure 3, the conditional volatility tends to vary positively with the level of inflation. The conditional volatilities from the MSMs reflect uncertainty about the size of shocks to inflation in each state as well as uncertainty about the state itself. If both these factors influence actual inflation uncertainty for individuals, then this measure can proxy the inflation uncertainty predicted by the misperception model to have an effect on the output-inflation trade-off.

The dummy variable to capture the effect of wage resistance is created following a procedure proposed by Fortin (1997) and takes the value one in those periods when average nominal wage growth was under 4 per cent.[10] Two different wage measures are used to construct the dummy variables. The first one is based on total labour compensation data as used in the Bank of Canada's Quarterly Projection Model, while the second one, which most closely matches that used by Fortin, is based on average hourly earnings data.[11]

Finally, previous empirical work on the short-run dynamics of inflation suggests that it is important to take into account supply shocks. Temporary movements in the real exchange rate, changes in the world price of oil and indirect taxes have all been found to have an impact on the dynamic process of inflation in Canada.[12] These variables are included in Z: *Dinfimp*, the first difference of imported inflation as measured by an eight-quarter moving average of the change in the nominal exchange rate plus the quarterly rate of change of the U.S. CPI; *Grpoil*, the rate of

10. Fortin creates his dummy variable from annual data on average hourly earnings in manufacturing. In this paper, quarterly data are used. Because the variables here are based on quarterly data, they are not consistently equal to one in years when Fortin's variable is one. They also identify some quarters of wage resistance in the 1960s.
11. Total labour compensation is defined as wages, salaries, and supplementary labour income per person hour.
12. See, for example, Duguay (1994).

change of the price of oil relative to the U.S. GDP deflator; and *Dtxcpi*, the first difference of the effective indirect tax rate.[13]

3.2 Estimation results

The state-space model parameters are estimated using maximum likelihood (ML). The unobserved state variable is estimated using a Kalman filter that is initialized with values obtained from a linear ordinary least-squares (OLS) regression of the observation equation. Appendix 2 provides details of the estimation and filtering procedure.

The estimation results are presented in Tables 1 and 2 for the period 1964 to 1994. This period is used to avoid end-of-sample problems associated with the extended multivariate filter.[14] Tables 1A and 1B correspond to estimations of the four individual models described previously using the EMVF or SVAR measures of the output gap respectively. Each column corresponds to a different model that may explain non-linearities in the output-inflation trade-off. The first set of parameters presented in the tables refers to the variables included in the transition equation, and the second set to the variables included in the measurement equation.[15]

In Table 1A, the results are supportive of the capacity constraint, cost adjustment, and misperception models, while the downward nominal wage rigidity model is strongly rejected by the data. For the cases where a non-linearity is identified, the measured variation in the trade-off is substantial and of economic significance. For example, if the variation is the result of capacity constraints (as estimated in Column 2 of Table 1A), the effect of excess demand on inflation is more than five times the effect of excess supply. According to the point estimates, the trade-off parameter would be only 0.08 in periods of excess supply compared with 0.41 during periods of excess demand. These values are less than the point estimates reported by Laxton, Rose, and Tetlow (1993) and Fillion and Léonard (1997), but the relative increase in the trade-off parameter is generally comparable. Figure 4 shows the predicted value of the trade-off parameter together with its 90 per cent confidence region based on full sample information for this model. The measure of the uncertainty about the value of the output-inflation trade-off does not include the uncertainty about the parameter estimates in the transition equation. These estimates are taken as given by the Kalman filter when calculating the conditional variance of the trade-off parameter. Taking into account the parameter uncertainty would increase the uncertainty about the value of the trade-off. The graph shows evidence of significant variation over the period examined.

If the variation in the trade-off parameter is due to changes in the average level of inflation, the magnitude of the variation, while still important, is smaller than those observed with positive

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13. The number of lags for the supply shock variables is determined by the common general-to-specific approach.
14. See St-Amant and van Norden (1997) for more details on shortcomings associated with mechanical filters.
15. In some models, the constant and the standard error are constrained to be zero. This is the case when the estimation procedures encounter difficulties to converge. In these cases, since only the systematic variation is estimated, no confidence intervals are reported for the slope of the Phillips curve, as in Figures 5 and 6.

output gaps. When inflation is at low or moderate levels, the point estimate is 0.12, and rises to about 0.27 when inflation is high. Thus the slope of the Phillips curve is a little more than twice as high when inflation is high as when inflation is low. This result is very close to the one obtained with the misperception model where the point estimate varies from about 0.11 in periods of low and moderate inflation to 0.29 in high-inflation periods. Figures 5 and 6 show the predicted value of the trade-off parameter for these two models respectively. One can easily see that the movements of the two estimated parameters are quite close over the historical period examined. This result is not surprising since the volatility of inflation is very closely related to the average level of inflation in Canada as shown in Figure 3.

Compared with results presented in Dupasquier and Ricketts (1998), who did not control for supply shocks, the inclusion of the supply-shock variables to the measurement equation generally lowers the standard error of the residuals both in the Phillips curve equation and the transition equation for the parameter β_t. In fact, the estimated standard error of the random shocks in the transition equation is not significantly different from zero in three of the four cases reported in Table 1A. The supply-shock variables also increase the precision of the estimated coefficients. The effect on the estimated values for β, the slope of the Phillips curve, is to reduce its range of variation. There are now almost no negative values of β indicating that the additional variables have eliminated the larger over- and under-predictions of inflation from the Phillips curve equation.

Somewhat different results are obtained using the SVAR measure of the output gap instead of the EMVF. As shown in Table 1B, in this case none of the asymmetries are found to be significant. And among the four models, the capacity constraint receives the least support. The SVAR estimate of the output gap assumes a unit root in inflation that is not fully consistent with the MSM expectations in the low- and moderate-inflation states and may bias the results in favour of a linear model. However, as shown in Béranger and Galati (1997), imposing the unit root in the inflation process for Canada, in the context of a well-specified SVAR, does not greatly alter the estimation of the output gap. On the other hand, the Phillips curve embedded in the extended multivariate technique to measure potential output is assumed to be non-linear. This may also play a role and bias the results in favour of the capacity constraint model when this measure is used. Thus, the fact that the estimate of the output gap can influence the results means that it is very difficult to be certain about the nature of a non-linearity.

With respect to the downward nominal wage rigidity model, the dummy introduced in the transition equation allows for a flatter Phillips curve in periods of nominal wage resistance. The estimated coefficients are not found to be statistically significant, suggesting that resistance to nominal wage cuts does not seem to affect the slope of the short-run Phillips curve.[16] As

16. Using different ways of entering the wage dummy variable in the transition equation leads to the same conclusions regarding the significance of the effect on the trade-off parameter.

mentioned previously, two different measures are used to construct this dummy variable. The results presented in the tables are those with the variable based on total labour compensation.[17] They can be somewhat different for the dummy variable based on average hourly earnings. In this case, the estimates support a flatter Phillips curve in periods of nominal wage resistance. However, this evidence does not seem very robust. For example, if an asymmetric response to demand shocks is allowed for only when nominal wage changes are low and a symmetric response when wage inflation is above 4 per cent, the estimates become insignificant.

Tables 2A and 2B present the estimation results for Phillips curves that nest more than one type of asymmetry. The tables reveal that it is difficult to draw firm conclusions regarding the source of asymmetry in the short-run Phillips curve. While significant when tested on its own, the capacity constraint model receives somewhat less support when tested against alternative models. In these last two tables, the downward nominal wage rigidity model remain systematically insignificant.

The volatility and the average level of inflation are very closely related over the historical period studied in this paper (see Figure 3). For this reason, results using the costly adjustment model and the misperception model together are not reported, since it would be impossible to disentangle their effects on the trade-off parameter. However, when comparing the variation of the trade-off due to two models at the same time—capacity constraint and costly adjustment model (as in Table 2A, Column 2), or capacity constraint and misperception model (as in Table 2A, Column 3)—the contribution to the variation of the point estimates seems very close. For example, based on estimates presented in Table 2A, the slope of the Phillips curve is about 0.12 when inflation is at low or moderate levels and rises to about 0.34 when inflation is high. It is important to distinguish sources of an asymmetry for the conduct of monetary policy. However, in this specific case, the distinction is not essential since the implications are comparable. Effectively, in the two models, the slope of the Phillips curve tends to become flatter at low rates of inflation. Therefore, monetary authorities may find it more costly to disinflate when inflation is already low. However, a flatter Phillips curve also implies that inflation control may become easier at low rates of inflation, since the adjustment to excess demand shocks is slower, giving the monetary authority more time to react. In this sense, a slower-reacting monetary policy would allow time to gather more information about the state of excess demand and therefore a better response to a given shock.

To examine the sensitivity of the results further, the models have been estimated using the SVAR output gap until 1997Q4.[18] Overall, the conclusions remain similar. One interesting point to note, though, is the results obtained for the downward nominal wage rigidity model. One would think that adding three years of low inflation to the sample would increase the significance of the

17. See Crawford and Harrison (1998) for a discussion of the proportion of wage cuts in a low-inflation environment using broader wage measures.
18. The SVAR is used only because of the end-of-sample problems associated with the EMVF.

wage dummy variable, if this model is supported by Canadian data. However, this is not the case. The results show that the dummy variable is not statistically significant, and in the case of a longer sample period, the results hold whether total labour compensation or the average hourly earnings are used to construct the dummy variable.[19]

4. Conclusions

This paper presents some evidence on the nature of the output-inflation trade-off in Canada. The literature survey identifies five models of pricing behaviour that imply a non-linearity in the short-run adjustment of prices to aggregate demand shocks. It is important, though difficult, to distinguish between these non-linearities because different types have different implications for monetary policy. Problems arise, especially in the Phillips curve framework, in the measurement of inflation expectations and the output gap. In this context, the tests lack power.

There is some empirical support for three models of asymmetry: the capacity constraint model, the costly adjustment model, and the misperception model. When the capacity constraint model seems to find more empirical support, the changes in the trade-off are of substantial economic consequence. However, in Phillips curves that nest more than one source of asymmetry, the capacity constraint model generally receives less support. There is also some evidence that the slope of the Phillips curve gets flatter at low and stable rates of inflation, but it is not possible to determine empirically whether this reflects the lower mean in inflation (as predicted by the costly adjustment model) or the lower standard deviation of inflation (as predicted by the misperception model). The dummy variable used to take into account possible effects of resistance to nominal wage cuts is not found to be consistently significant. And when using a longer sample period, adding three more years of low inflation, the dummy becomes clearly insignificant in the short-run Phillips curve framework.

Overall, the results show that it is empirically difficult to distinguish definitively among the possible models generating the non-linearity. Notwithstanding the uncertainty surrounding the estimates, it is more likely that more than one model may be at play.

In future work, it would be of interest to explore, using simulation methods for instance, how large asymmetries need to be reliably detected. At this time when an economically important shift in the sacrifice ratio is identified, the statistical significance is generally small. So a question that remains to be examined further is the ability of this type of approach to detect the presence of an asymmetry in the short-run Phillips curve.

19. The results are not shown but can be obtained from the authors.

Table 1A

Maximum Likelihood Estimates of Measurement and Transition Equations: Canada, Total CPI Less GST, QST, and Tobacco Tax
Expectations from Markov Switching Model; Potential Output – Extended Multivariate Filter

Variables	Capacity constraint model	Costly adjustment model	Misperception model	Downward nominal wage rigidity model
		Variables in the transition equation		
α (constant)	0.08 (0.05; 0.04)	—	—	0.15 (0.07; 0.01)
GAP	0.33 (0.17; 0.03)	—	—	—
Inflation expectations	—	0.03 (0.01; 0.00)	—	—
Volatility	—	—	0.07 (0.02; 0.00)	—
Wage dummy	—	—	—	0.02 (0.12; 0.45)
Standard error (μ_t)	0.11 (0.10; 0.14)	0.00 (0.01; 0.50)	0.00 (0.02; 0.50)	0.10 (0.13; 0.22)
		Variables in the measurement equation		
π_t^e	0.81 (0.15; 0.00)	0.79 (0.15; 0.00)	0.81 (0.15; 0.00)	0.81 (0.15; 0.00)
Grpoil	-0.12 (0.08; 0.06)	-0.11 (0.06; 0.03)	-0.11 (0.06; 0.02)	-0.08 (0.06; 0.08)
Grpoil(-1)	0.18 (0.06; 0.00)	0.16 (0.05; 0.00)	0.16 (0.05; 0.00)	0.19 (0.05; 0.00)
Dinfimp(-1)	0.11 (0.05; 0.03)	0.12 (0.06; 0.02)	0.12 (0.06; 0.02)	0.11 (0.06; 0.02)
Dinfimp(-2)	-0.03 (0.07; 0.29)	-0.02 (0.07; 0.39)	-0.02 (0.07; 0.41)	-0.03 (0.07; 0.35)
Dinfimp(-3)	0.07 (0.04; 0.05)	0.08 (0.05; 0.03)	0.09 (0.05; 0.03)	0.08 (0.27; 0.39)
Dtxcpi	0.38 (0.25; 0.07)	0.47 (0.25; 0.03)	0.46 (0.24; 0.03)	0.42 (0.25; 0.04)
Dtxcpi(-1)	0.02 (0.50; 0.48)	0.10 (0.26; 0.34)	0.10 (0.26; 0.35)	0.07 (0.27; 0.39)
Dtxcpi(-2)	-0.36 (0.26; 0.08)	-0.35 (0.23; 0.06)	-0.33 (0.24; 0.08)	-0.35 (0.24; 0.07)
Standard error (ε_t)	1.27 (0.10; 0.00)	1.30 (0.09; 0.00)	1.30 (0.09; 0.00)	1.29 (0.11; 0.00)
Mean likelihood	-1.68272	-1.68202	-1.67765	-1.68598
Mean(β_t)	0.20	0.16	0.16	0.15
Min(β_t)	0.03	0.04	0.07	0.12
Max(β_t)	0.46	0.36	0.39	0.28

Notes: Heteroscedasticity-consistent standard errors and p-values in parentheses.

Table 1B

Maximum Likelihood Estimates of Measurement and Transition Equations: Canada, Total CPI Less GST, QST, and Tobacco Tax
Expectations from Markov Switching Model; Potential Output – SVAR

Variables	Capacity constraint model	Costly adjustment model	Misperception model	Downward nominal wage rigidity model
		Variables in the transition equation		
α (constant)	0.07 (0.09; 0.24)	—	—	0.07 (0.09; 0.20)
GAP	0.01 (0.15; 0.47)	—	—	—
Inflation expectations	—	0.01 (0.01; 0.13)	—	—
Volatility	—	—	0.03 (0.02; 0.14)	—
Wage dummy	—	—	—	0.33 (0.25; 0.11)
Standard error (μ_t)	0.00 (0.06; 0.50)	0.00 (0.05; 0.50)	0.00 (0.02; 0.50)	0.00 (0.03; 0.50)
		Variables in the measurement equation		
π_t^e	0.71 (0.15; 0.00)	0.72 (0.15; 0.00)	0.73 (0.15; 0.00)	0.72 (0.15; 0.00)
Grpoil	-0.05 (0.06; 0.20)	-0.06 (0.06; 0.15)	-0.06 (0.06; 0.15)	-0.05 (0.06; 0.18)
Grpoil(-1)	0.20 (0.05; 0.00)	0.19 (0.05; 0.00)	0.19 (0.05; 0.00)	0.20 (0.04; 0.00)
Dinfimp(-1)	0.12 (0.07; 0.05)	0.12 (0.07; 0.04)	0.12 (0.07; 0.04)	0.12 (0.06; 0.03)
Dinfimp(-2)	-0.03 (0.07; 0.35)	-0.03 (0.07; 0.34)	-0.03 (0.07; 0.34)	-0.03 (0.07; 0.33)
Dinfimp(-3)	0.08 (0.05; 0.04)	0.08 (0.05; 0.04)	0.08 (0.05; 0.04)	0.08 (0.05; 0.04)
Dtxcpi	0.41 (0.25; 0.05)	0.40 (0.26; 0.06)	0.40 (0.25; 0.06)	0.39 (0.25; 0.06)
Dtxcpi(-1)	0.06 (0.28; 0.42)	0.04 (0.41; 0.46)	0.04 (0.23; 0.43)	0.07 (0.25; 0.40)
Dtxcpi(-2)	-0.41 (0.25; 0.05)	-0.44 (0.26; 0.05)	-0.44 (0.24; 0.03)	-0.40 (0.24; 0.05)
Standard error (ε_t)	1.35 (0.11; 0.00)	1.35 (0.11; 0.00)	1.35 (0.11; 0.00)	1.33 (0.10; 0.22)
Mean likelihood	-1.71921	-1.71762	-1.71775	-1.70586
Mean(β_t)	0.07	0.06	0.06	0.16
Min(β_t)	0.07	0.02	0.03	0.07
Max(β_t)	0.08	0.15	0.15	0.41

Notes: Heteroscedasticity-consistent standard errors and p-values in parentheses.

Table 2A

Maximum Likelihood Estimates of Measurement and Transition Equations: Canada, Total CPI Less GST, QST, and Tobacco Tax Expectations from Markov Switching Model; Potential Output – Extended Multivariate Filter

Variables	Capacity constraints & costly adjustment models	Capacity constraints & misperception models	Capacity constraints & downward nominal wage rigidity models	Costly adjustment & downward nominal wage rigidity models	Misperception & downward nominal wage rigidity models
			Variables in the transition equation		
α (constant)	-0.02 (0.06; 0.36)	-0.05 (0.06; 0.20)	0.06 (0.07; 0.19)	-0.02 (0.20; 0.47)	-0.04 (0.15; 0.38)
GAP	0.30 (0.25; 0.11)	0.26 (0.17; 0.06)	0.23 (0.15; 0.06)	—	—
Inflation expectations	0.02 (0.01; 0.04)	—	—	0.03 (0.03; 0.15)	—
Volatility	—	0.06 (0.03; 0.03)	—	—	0.07 (0.05; 0.06)
Wage dummy	—	—	0.06 (0.11; 0.27)	0.10 (0.18; 0.29)	0.10 (0.13; 0.23)
Standard error (μ_t)	0.00 (0.01; 0.49)	—	0.11 (0.10; 0.15)	—	—
			Variables in the measurement equation		
π_t^e	0.80 (0.15; 0.00)	0.81 (0.14; 0.00)	0.80 (0.15; 0.00)	0.79 (0.15; 0.00)	0.80 (0.15; 0.00)
Grpoil	-0.13 (0.07; 0.03)	-0.13 (0.07; 0.03)	-0.10 (0.07; 0.07)	-0.10 (0.06; 0.03)	-0.11 (0.06; 0.03)
Grpoil(-1)	0.16 (0.05; 0.00)	0.16 (0.05; 0.00)	0.18 (0.05; 0.00)	0.16 (0.05; 0.00)	0.16 (0.05; 0.00)
Dinfimp(-1)	0.12 (0.06; 0.02)	0.12 (0.06; 0.02)	0.10 (0.05; 0.03)	0.12 (0.05; 0.02)	0.12 (0.05; 0.01)
Dinfimp(-2)	-0.03 (0.07; 0.33)	-0.02 (0.07; 0.36)	-0.03 (0.06; 0.30)	-0.02 (0.06; 0.37)	-0.02 (0.07; 0.40)
Dinfimp(-3)	0.08 (0.04; 0.04)	0.08 (0.04; 0.03)	0.07 (0.04; 0.05)	0.08 (0.04; 0.03)	0.08 (0.05; 0.03)
Dtxcpi	0.41 (0.23; 0.04)	0.39 (0.23; 0.05)	0.38 (0.24; 0.06)	0.45 (0.25; 0.03)	0.44 (0.25; 0.04)
Dtxcpi(-1)	0.05 (0.27; 0.43)	0.05 (0.28; 0.43)	0.05 (0.24; 0.41)	0.12 (0.29; 0.34)	0.11 (0.27; 0.34)
Dtxcpi(-2)	-0.37 (0.23; 0.06)	-0.35 (0.24; 0.07)	-0.38 (0.24; 0.06)	-0.36 (0.24; 0.06)	-0.35 (0.24; 0.07)
Standard error (ε_t)	1.29 (0.09; 0.00)	1.29 (0.10; 0.00)	1.28 (0.10; 0.00)	1.29 (0.09; 0.00)	1.29 (0.09; 0.00)
Mean likelihood	-1.67332	-1.67419	-1.68770	-1.67741	-1.67421
Mean(β_t)	0.22	0.21	0.16	0.16	0.15
Min(β_t)	0.01	0.02	0.02	0.03	0.03
Max(β_t)	0.58	0.59	0.36	0.33	0.37

Notes: Heteroscedasticity-consistent standard errors and p-values in parentheses.

Table 2B

Maximum Likelihood Estimates of Measurement and Transition Equations: Canada, Total CPI Less GST, QST, and Tobacco Tax Expectations from Markov Switching Model; Potential Output – SVAR

Variables	Capacity constraints & costly adjustment models	Capacity constraints & misperception models	Capacity constraints & downward nominal wage rigidity models	Costly adjustment & downward nominal wage rigidity models	Misperception & downward nominal wage rigidity models
Variables in the transition equation					
α (constant)	—	0.12 (0.13; 0.18)	-0.01 (0.15; 0.47)	0.04 (0.25; 0.43)	0.05 (0.20; 0.40)
GAP	-0.06 (0.32; 0.42)	0.08 (0.28; 0.39)	0.08 (0.17; 0.33)	—	—
Inflation expectations	0.01 (0.01; 0.16)	—	—	0.00 (0.03; 0.45)	—
Volatility	—	-0.01 (0.06; 0.42)	—	—	0.01 (0.05; 0.44)
Wage dummy	—	—	0.24 (0.21; 0.13)	0.35 (0.32; 0.14)	0.34 (0.30; 0.13)
Standard error (μ_t)	0.00 (0.02; 0.48)	—	0.00 (0.51; 0.50)	—	—
Variables in the measurement equation					
π_t^e	0.69 (0.15; 0.00)	0.73 (0.14; 0.00)	0.70 (0.15; 0.00)	0.72 (0.15; 0.00)	0.72 (0.15; 0.00)
Grpoil	-0.04 (0.06; 0.25)	-0.06 (0.06; 0.16)	-0.06 (0.07; 0.24)	-0.05 (0.06; 0.18)	-0.05 (0.06; 0.17)
Grpoil(-1)	0.21 (0.05; 0.00)	0.19 (0.05; 0.00)	0.20 (0.05; 0.00)	0.20 (0.05; 0.00)	0.20 (0.04; 0.00)
Dinfimp(-1)	0.11 (0.07; 0.05)	0.12 (0.07; 0.04)	0.12 (0.07; 0.04)	0.12 (0.06; 0.03)	0.12 (0.06; 0.03)
Dinfimp(-2)	-0.03 (0.07; 0.33)	-0.03 (0.07; 0.36)	-0.04 (0.07; 0.31)	-0.03 (0.06; 0.32)	-0.03 (0.06; 0.32)
Dinfimp(-3)	0.08 (0.04; 0.03)	0.08 (0.05; 0.04)	0.08 (0.05; 0.06)	0.08 (0.05; 0.04)	0.08 (0.05; 0.04)
Dtxcpi	0.39 (0.27; 0.07)	0.41 (0.25; 0.05)	0.39 (0.26; 0.06)	0.38 (0.25; 0.06)	0.38 (0.25; 0.06)
Dtxcpi(-1)	0.04 (0.37; 0.46)	0.05 (0.25; 0.42)	0.07 (0.38; 0.43)	0.06 (0.31; 0.42)	0.06 (0.32; 0.43)
Dtxcpi(-2)	-0.42 (0.25; 0.05)	-0.41 (0.25; 0.05)	-0.43 (0.24; 0.04)	-0.41 (0.26; 0.05)	-0.41 (0.26; 0.05)
Standard error (ε_t)	1.35 (0.10; 0.00)	1.35 (0.11; 0.00)	1.34 (0.10; 0.00)	1.33 (0.10; 0.00)	1.34 (0.10; 0.00)
Mean likelihood	-1.71673	-1.71548	-1.71211	-1.70577	-1.70580
Mean(β_t)	0.04	0.11	0.07	0.15	0.15
Min(β_t)	-0.04	0.05	-0.01	0.05	0.06
Max(β_t)	0.13	0.18	0.31	0.42	0.42

Notes: Heteroscedasticity-consistent standard errors and p-values in parentheses.

Figure 1

Output gaps

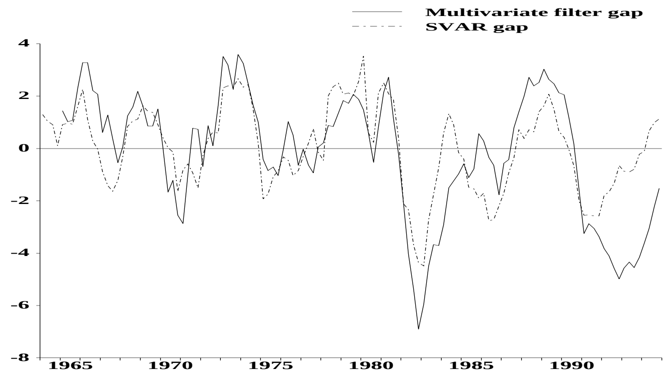


Figure 2

Inflation and inflation expectations

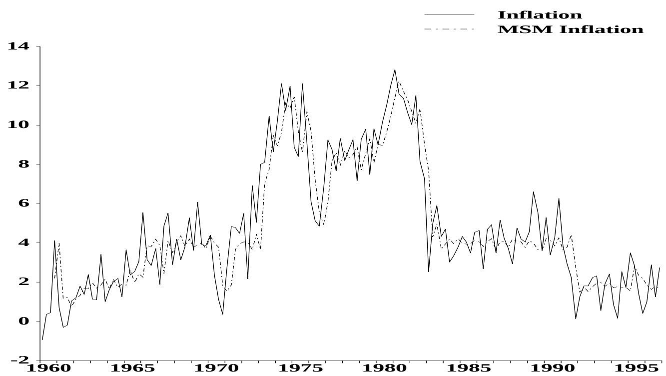


Figure 3

Conditional variance of inflation

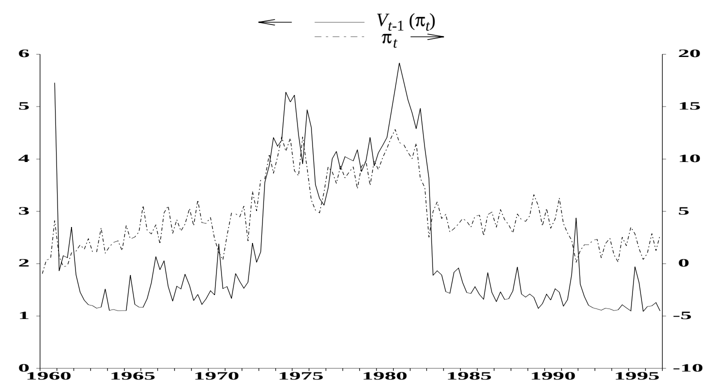


Figure 4
Output-inflation trade-off
Capacity constraint model

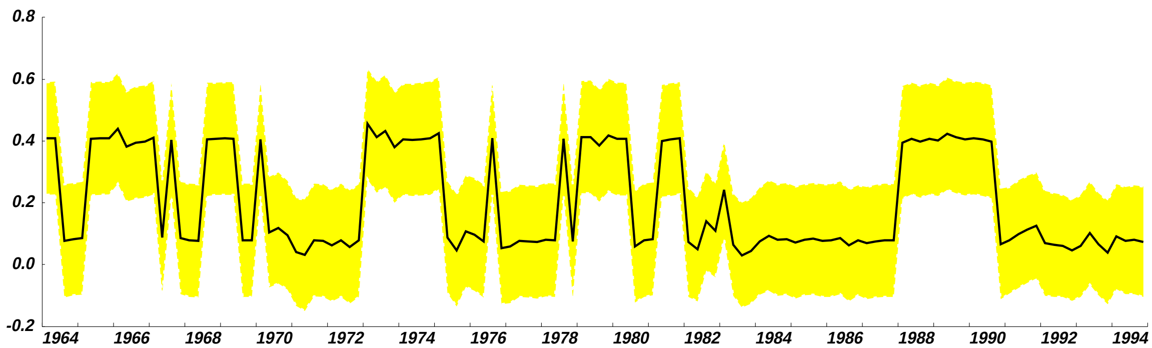


Figure 5
Output-inflation trade-off
Costly adjustment model

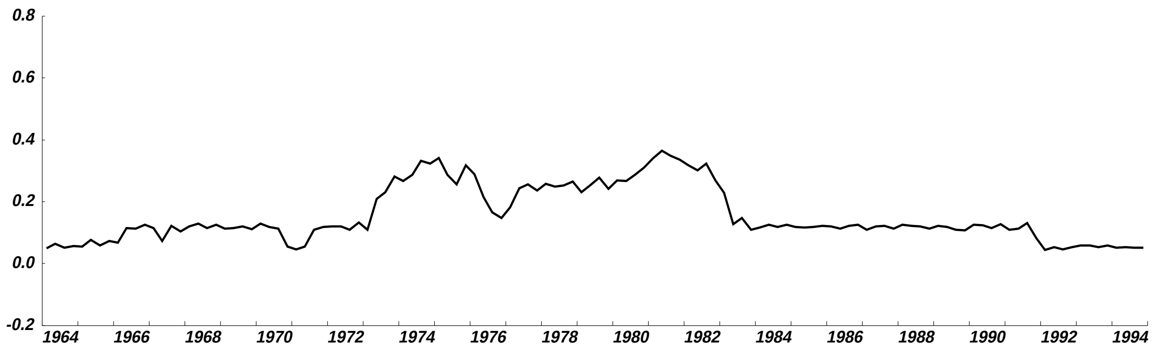
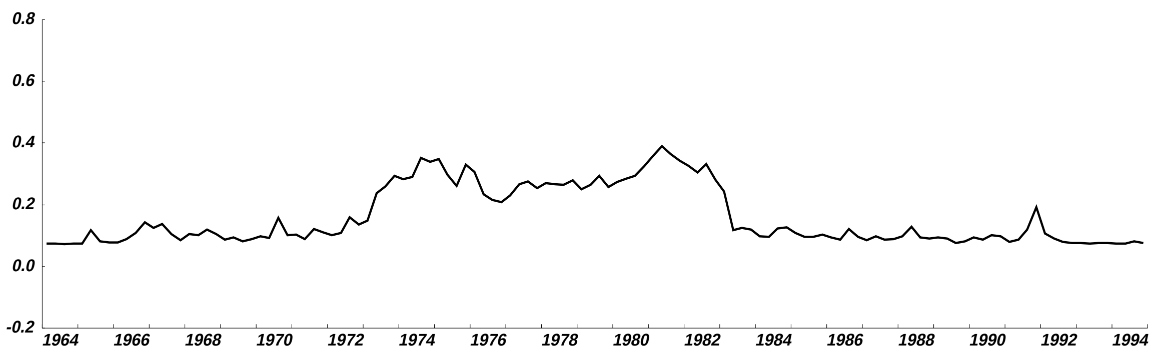


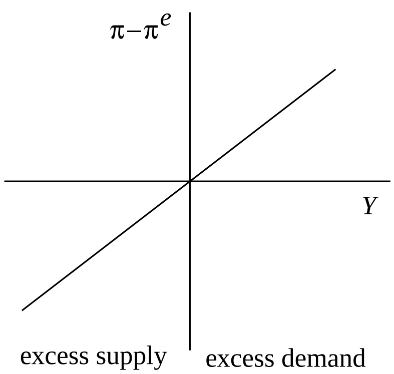
Figure 6
Output-inflation trade-off
Misperception model



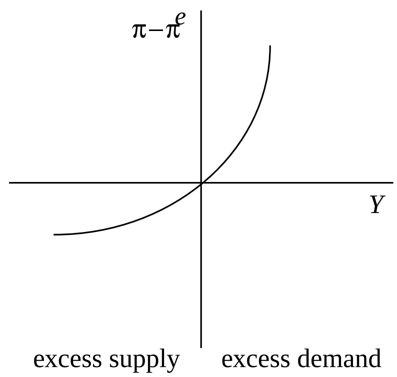
Appendix 1

Different types of output-inflation relationships

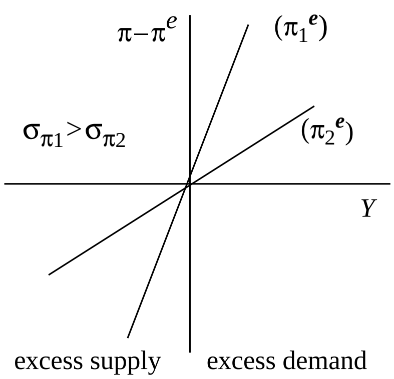
1. Linear model



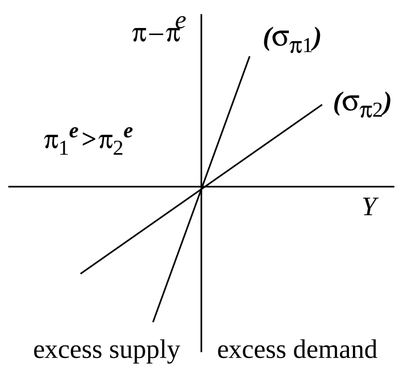
2. Capacity constraint model



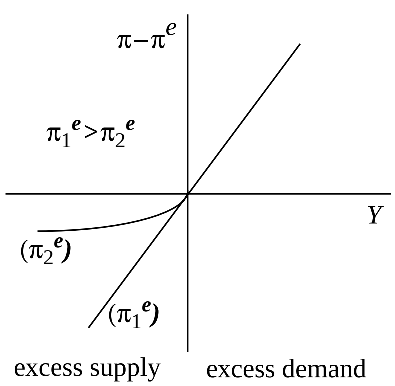
3. Costly adjustment model



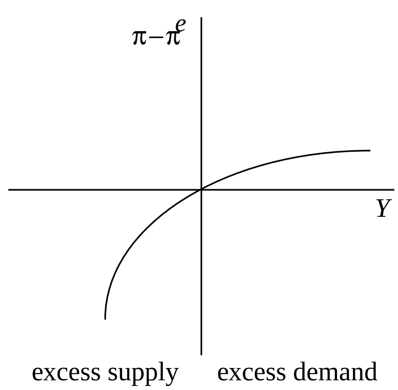
4. Misperception model



5. Downward nominal wage rigidity model



6. Monopolistically competitive model



Appendix 2

Maximum likelihood estimation of the state-space model

The parameters of the state-space model are estimated using maximum likelihood (ML). A Kalman filter generates the prediction error decomposition form of the likelihood function as in Harvey (1993). Numerical maximization is implemented with GAUSS software.

The state-space model is defined by equations (2) and (3) in the text as follows:

$$\pi_t = a \bullet \pi_t^e + (1-a) \bullet \pi_{t-1} + \beta_t \bullet GAP_t + \varepsilon_t \qquad \varepsilon_t \sim N(0, \sigma_\varepsilon^2), \tag{A2.1}$$

$$\beta_t = \alpha + \rho \bullet \beta_{t-1} + \gamma \bullet X_{t-1} + \mu_t \qquad \mu_t \sim N(0, \sigma_\mu^2). \tag{A2.2}$$

The parameters to be estimated by ML are $\{a, \alpha, \rho, \gamma, \sigma_\varepsilon, \sigma_\mu\}$. These are called the hyper parameters of the model. The Kalman filter takes these parameters as given and produces time-series estimates of β_t and ε_t. Let $\beta_{t|s}$ denote the prediction of β_t given information up to period *s*, and let $P_{t|s}$ be the associated conditional variance. Then, given starting values for the elements of the distribution of β_0, denoted by $\beta_{0|0}$ and $\mathrm{P}_{0|0}$, the Kalman filter proceeds iteratively for $t=1$ to $t=T$ as follows:

$$\beta_{t|t-1} = \alpha + \rho \bullet \beta_{t-1|t-1} + \gamma \bullet X_{t-1} \tag{A2.3}$$

$$P_{t|t-1} = \rho^2 \bullet P_{t-1|t-1} \tag{A2.4}$$

$$\varepsilon_{t|t-1} = \pi_t - a \bullet \pi_t^e - (1-a) \bullet \pi_{t-1} - \beta_{t|t-1} \bullet GAP_t \tag{A2.5}$$

$$H_t = P_{t|t} \bullet GAP_t^2 + \sigma_\varepsilon^2 \tag{A2.6}$$

$$K_{t|t-1} = P_{t|t-1} \bullet GAP_t \bullet H_t^{-1} \tag{A2.7}$$

$$\beta_{t|t} = \beta_{t|t-1} + \mathrm{K}_{t|t-1} \bullet \varepsilon_{t|t-1} \tag{A2.8}$$

$$P_{t|t} = (I - \mathrm{K}_{t|t-1} \bullet GAP_t) \bullet P_{t|t-1}. \tag{A2.9}$$

H_t in equation (A4.6) is the conditional variance of the prediction errors, $\varepsilon_{t|t-1}$. It incorporates parameter uncertainty about the slope of the Phillips curve in addition to uncertainty about the supply shocks. The prediction error decomposition form of the likelihood function for observation *t* is therefore

$$\log(l_t) = -\frac{\log(2 \bullet pi)}{2} - \frac{\log H_t}{2} - \frac{\varepsilon_{t|t-1}^2}{2H_t}. \tag{A2.10}$$

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