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An Expectations-Augmented Phillips Curve in an Open Economy

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Abstract

In this paper an expectations-augmented Phillips curve relation in an open economy is derived and estimated. As in Rotemberg´s (1982) model firms are assumed to face quadratic price adjustment costs. In addition, second-order costs of changing prices are included. Consequently the derived inflation equation incorporates not only a forward-looking component but also a backward-looking element. The model is then estimated on Swedish data. The results from this estimation shed light on the importance of inflation expectations for the development of current inflation in comparison to past inflation rates. This is, for example, of great importance to a central bank trying to achieve an inflation target. A common characteristic of inflation targeting models is that with a lower degree of persistence in inflation, a credible central bank can achieve its inflation target with relatively little loss in output.

1. Introduction

When trying to achieve an inflation target a central bank has to make analyses which help to understand how the economy works. Given the model of the econ-

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omy and the central bank's target(s) it is possible to derive an instrument rule for the central bank's operational instrument, as is shown by Svensson (1997). One thing that is of great importance for how the instrument is set and how much output will have to fluctuate to achieve an inflation target is the role of inflation expectations in the aggregate supply equation, the Phillips curve relation, in relation to past inflation rates. If only expectations about future inflation matter, then a credible central bank can achieve its target with no loss in output.

The purpose of this paper is hence to analyse and estimate the importance of expectations in the Phillips curve relation. For that purpose an aggregate supply equation for a small open economy is derived in section 3. The model has similarities with Rotemberg's (1982) model, since price stickiness arises as a consequence of quadratic price adjustment costs, and it has also similarities with Svensson's (1998) model, since it takes into account open economy aspects. The extension of the model is to include also costs of changing the speed with which prices change. Consequently the derived Phillips curve relation incorporates both a forward-looking and a backward-looking element. In section 4 an expectations-augmented Phillips curve for Sweden is estimated using survey data on households' inflation expectations as a proxy of inflation expectations. Previous work on the Swedish Phillips curve include Hansson (1993), Eika, Ericsson and Nymoen (1996), Apel and Jansson (1997), Hallsten (1998). In all of these studies a backward looking specification is used.

Section 5 concludes. To anticipate, it is found that for these data series, during this period, the data favor a forward-looking inflation specification over a purely backward-looking specification. Expectations of future prices are empirically important in explaining inflation behavior.

2. The Phillips curve

The purpose of this paper is hence to study the "price" Phillips curve for Sweden, here only referred to as the Phillips curve. Usually what is meant when referring to the Phillips curve is the link between the rate of inflation in overall prices and some measure of output. This is a modification of an underlying relationship between the rate of change of wages and unemployment, the original "wage" Phillips curve, first emphasized in Phillips (1958). If Okun's law is applied one can move from unemployment to output. Assuming that prices are a fixed mark-up over wages, it is then possible to derive a relation between inflation and output.

Over the years the Phillips curve relation has been developed. One early extension of the original Phillips curve relation was to include expectations in the specification. Initially it was assumed that agents had adaptive expectations.[1] Expected inflation was then modelled as being proportional to the most recent inflation observations. The Phillips curve hence had a backward-looking specification. The problem with this fixed autoregressive representation is that it can lead to systematic expectational errors. Lucas (1976) emphasized the shortcomings of such a model for policy evaluations. It incorporates no knowledge about how agents in the economy are assumed to behave in the future, for example how economic policy is assumed to be conducted. To be able to evaluate the consequences of different policy regimes it is necessary to consider how such regimes will affect expectations and therefore the behavior of the other agents in the economy. For this, it is necessary to assume that agents have rational expectations. With rational expectations, first introduced by Muth (1961), any systematic source of expectational errors will vanish. During the 1970s the assumption of rational expectations in a macroeconomic context was introduced by Lucas (1972), Sargent (1973) and Sargent and Wallace (1975). These models combined the assumption of rational expectations with completely flexible prices and instantaneous market clearing. Later, in the "New Keynesian" literature, rational expectations were combined with sticky prices and nominal rigidities. A Phillips curve relation can then be derived also in a rational expectations framework.

It should be noted that the original Phillips curve was an empirical relationship, with no theoretical underpinning. Over the years theoretical work has therefore been done, in an attempt to develop some microfoundations for the estimated macro economic relationship. Early contributions were made by Lucas (1973), Taylor (1980), Rotemberg (1982) and Calvo (1983). But as Nelson (1997) shows, most of the research on sticky prices has been done during the last years. He refers to around 40 papers in this research area that have been published during the 1990s. Still, most models do not derive inflation equations from an optimization problem. Another shortcoming is that in most models only the price level turns out to be sticky while the inflation rate is totally flexible. These models have been criticized by among others Fuhrer and Moore (1995) and Nelson (1997). Their objection is that these models do not capture the high degree of persistence in inflation which is usually found in inflation data. In both papers simulations are made to analyse how well models with nominal rigidities succeed in reproducing this feature of data. Roberts (1996) also criticizes the sticky-price models. The argument against these models, he claims, is that they postulate that an inflation target can be achieved with no loss in output if the central bank has full credibility so that expectations coincide with the target. Roberts refers to different studies that show that reducing inflation is costly.

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[1] In Cagan´s (1956) study of hyperinflation the mechanism of adaptive expectations was first used. In Phelps (1967) adaptive expectations were then used together with a Phillips curve.

3. A Phillips curve in a small open economy

The purpose of this section is to derive an aggregate supply curve for a small open economy. Similar to what is done in Rotemberg's (1982) model, price stickiness arises as a consequence of quadratic price adjustment costs. The model is then extended to include not only costs of changing the price level, but also costs of changing the speed with which prices are changed. Including costs of a higher-order gives a Phillips curve relation that is both forward- and backward-looking. The inflation rate then turns out to be persistent.

The model in this paper is similar to Svensson's (1998) open economy model. His model is an open-economy variant of the models of Woodford (1996) and Rotemberg-Woodford (1997). They build on Calvo's (1983) model in which a firm's opportunity to change its price arrives stochastically.

As in Svensson's paper it is hence assumed here that the economy consists of a continuum of monopolies indexed by $j \in [0,1]$. Each supplier produces one distinct good. For each good the demand function is assumed to be given by:

$$Y_t^j = Y_t \left(\frac{P_t^j}{P_t} \right)^{-\theta}, \qquad j = 1, ..., n, \tag{3.1}$$

where P_t^j is the price of good j at time t, P_t is the price index, Y_t is the total aggregate demand and $\theta > 1$ is the constant elasticity of substitution. The quantity demanded of a good hence depends on the relative price of the good. It is assumed that the monopolist takes the price level and the total aggregate demand as given.

Suppose further that the cost for each monopolist j to produce its good is given by

$$C_j(Y_t^j) = W_t V(Y_t^j), \tag{3.2}$$

where $C_j(Y_t^j)$ is the cost of monopolist j to produce the quantity Y^j at time t, $V(Y_t^j)$ is the input requirement function, which is equal for all individual suppliers and W_t is the price of inputs.

Assume for the moment no price stickiness. The monopolist's profit maximization problem is then to choose the price of its good given the behavior of consumers summarized by the demand function, equation (3.1), and given the technological constraints summarized by the cost function, equation (3.2), that is

$$\max_{P_t^j} P_t^j Y_t \left(\frac{P_t^j}{P_t} \right)^{-\theta} - W_t V(Y_t^j). \tag{3.3}$$

From the first order condition it then follows that the price chosen in period t,

P_t^{j*}, is given by

$$\begin{aligned} P_t^{j*} &= \frac{\theta}{\theta-1} W_t V'(Y_t^j) \\ &= \varsigma W_t V'(Y_t^j) \end{aligned} \tag{3.4}$$

where $*$ refers to the optimal price set in absence of adjustment costs. See appendix A for details. This is the standard result when using a constant elasticity demand function, the price is a constant mark-up, $\varsigma = \frac{\theta}{\theta-1}$, over marginal cost, with the size of the mark-up depending on the elasticity of demand. A log-linearization of the FOC around steady state gives the following expression

$$p_t^{j*} = \frac{1}{1+\omega\theta} w_t + \frac{\omega}{1+\omega\theta} y_t + \frac{\omega\theta}{1+\omega\theta} p_t \tag{3.5}$$

where small letters represent percentage deviations of the variable from its steady-state value, $x_t \equiv d \ln X_t$, and $\omega > 0$ is the elasticity of V' with respect to Y_t^j, $\frac{dV'}{V'} \frac{Y_t^j}{dY_t^j}$. Again see appendix A for details.

Assume now that some goods used in the production are foreign goods and some are domestic goods. The price of inputs can then be defined as

$$w_t \equiv (1-\gamma) p_t + \gamma p_t^{f,d} \tag{3.6}$$

where γ is the share of foreign goods in the production and $p_t^{f,d}$ is the log price of foreign goods in domestic currency. The foreign price index in domestic currency is defined as

$$p_t^{f,d} \equiv p_t^f + s_t \tag{3.7}$$

where p_t^f is the log foreign price index in foreign currency and s_t is the log exchange rate. If the log real exchange rate, q_t, is defined as

$$q_t \equiv p_t^f + s_t - p_t \equiv p_t^{f,d} - p_t. \tag{3.8}$$

the cost of inputs can be written as

$$w_t \equiv p_t + \gamma q_t \tag{3.9}$$

Substituting in this expression into equation (3.5) results in the following expression

$$p_t^{j*} = p_t + \alpha_y y_t + \alpha_q q_t \tag{3.10}$$

where $\alpha_y = \frac{\omega}{1+\omega\theta}$ and $\alpha_q = \frac{\gamma}{1+\omega\theta}$. The log of the price a firm would charge in absence of adjustment costs, p_t^{j*}, then depends on the price charged by other firms, p_t, the output gap and the real exchange rate gap.

Now assume initially that there is a fixed cost, c, of changing the price level, as in Rotemberg's (1982) model. Firms can then be assumed to minimize the costs of changing prices, weighted against the costs of being away from the price it would choose in absence of adjustment costs, the price derived above, p_t^{j*}

$$\min_{p_\tau^j} E_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} \left[\left(p_\tau^j - p_\tau^{j*} \right)^2 + c \left(p_\tau^j - p_{\tau-1}^j \right)^2 \right] \tag{3.11}$$

The first order condition to this problem is

$$p_t^j - p_t^{j*} + c \left(p_t^j - p_{t-1}^j \right) - c\delta \left(p_{t+1|t}^j - p_t^j \right) = 0 \tag{3.12}$$

where $p_{t+1|t} \equiv E_t p_{t+1}$, or, after substituting in the solution for p_t^{j*} derived above and using that all producers are the same and hence choose the same price, therefore $p_t^{j*} = p_t^*$ and $p_t^j = p_t$,

$$\pi_t = \delta \pi_{t+1|t} + \beta_y y_t + \beta_q q_t \tag{3.13}$$

where $\beta_y = \alpha_y / c$ and $\beta_q = \alpha_q / c$. [2] According to this expectations-augmented Phillips curve relation, current inflation depends on expected inflation one period ahead, the current output gap and the current real exchange rate gap. Expected future inflation rate appears since there are costs of changing the price and therefore next periods prices are important for the determining of this periods prices. Further, for $\delta = 1$, the price level is persistent while inflation is totally flexible. A δ equal to 1 is usually assumed to ensure the natural-rate hypothesis. But this is not a necessary assumption, only a sufficient assumption. The natural-rate hypothesis can still be valid even though $\delta \neq 1$, it depends on the processes of output and the real exchange rate. Further, since this inflation equation is derived only from the price setting behavior of firms and not from a complete model including also an aggregate demand equation and some reaction function for the central bank this also makes the usual assumption of $\delta = 1$ unnecessary. Once expectations are solved for one can discuss what value δ must have to ensure the natural-rate hypothesis.

In Roberts (1995) it is shown that a similar Phillips curve relation also can be derived from the Taylor and Calvo models.[3] The reason for using the Rotemberg model here is that it can be extended so that an inflation equation is derived that incorporates both a forward and a backward-looking component. As noted above models that only incorporate a forward-looking component can be criticized. If

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[2] See appendix B for details.

[3] The real exchange rate component does not appear in the Phillips curve relations derived in Roberts (1995) since he is not using an open economy framework.

Calvo's model is used, the backward-looking component has to be added to the inflation equation on an ad hoc basis after the optimization problem has been solved. This is for example done in Svensson's (1998) paper. Fuhrer and Moore on the other hand has develop a new contracting model, based on the Taylor (1980) model, in which it is assumed that agents care about relative real wages. The Phillips curve relation derived then incorporates both a forward looking and a backward-looking element. One shortcoming with the Fuhrer and Moore model is that it is not explicitly derived from an optimization problem.

The extension made here of the Rotemberg model is to include also higher-order adjustment costs in the firm's optimization problem. This suggest the existence of costs to changes in inflation, that is costs of changing the speed with which prices are changed. The question is the then if there are any natural convincing explanations for these kinds of costs. One reason for the existence of such costs could perhaps be that the cost of changing the price to some extent is related to the cost of finding out what the optimal price is. In an economy with a constant rate of inflation the uncertainty about the optimal price might then decline. If on the other hand the inflation rate varies a lot it might be more difficult to find out what the optimal price is. Higher costs are then associated with changes in the inflation rate. Another explanation could perhaps be that consumers dislike fluctuations in the inflation rate, and thereby lower their demand for goods whose price-changes vary a lot.

Others that have used a similar specifications are Pesaran (1991) and Tinsley (1993). In Pesaran (1991) a generalization of the standard rational expectations models with adjustment costs is provided. The model allows, in addition to the cost of changing the level of the decision variable, also for the cost of altering the speed with which decisions are changed. Tinsley (1993) uses a more general specification of adjustment costs.

To see how the Phillips curve relation changes when also higher order adjustment costs are included, the optimization problem of the firm is now solved with this extension. The optimization problem now looks as follows

$$\min_{p_\tau^j} E_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} \left[\left(p_\tau^j - p_\tau^{j*}\right)^2 + c_1 \left(p_\tau^j - p_{\tau-1}^j\right)^2 + c_2 \left(p_\tau^j - 2p_{\tau-1}^j + p_{\tau-2}^j\right)^2 \right] \quad (3.14)$$

$c_1 > 0$, $c_2 > 0$. The first order condition to this problem is

$$\begin{aligned} 0 \;=\; & p_t^j - p_t^{j*} + c_1 \left(p_t^j - p_{t-1}^j\right) - c_1 \delta \left(p_{t+1|t}^j - p_t^j\right) \\ & + c_2 \left(p_t^j - 2p_{t-1}^j + p_{t-2}^j\right) - 2c_2 \delta \left(p_{t+1|t}^j - 2p_t^j + p_{t-1}^j\right) \\ & + c_2 \delta^2 \left(p_{t+2|t}^j - 2p_{t+1|t}^j + p_t^j\right) \end{aligned} \quad (3.15)$$

or

$$\pi_t = -b_1\pi_{t+2|t} + b_2\pi_{t+1|t} + b_3\pi_{t-1} + b_y y_t + b_q q_t \tag{3.16}$$

see appendix C for details, where $b_y = \frac{\alpha_y}{c_1+c_2+2c_2\delta}$, $b_q = \frac{\alpha_q}{c_1+c_2+2c_2\delta}$, $b_1 = \frac{c_2\delta^2}{c_1+c_2+2c_2\delta}$, $b_2 = \frac{c_1\delta+c_2\delta^2+2c_2\delta}{c_1+c_2+2c_2\delta}$, $b_3 = \frac{c_2}{c_1+c_2+2c_2\delta}$. The inflation rate this period then depends on the expected inflation rate one and two periods ahead, where expectations are formed in the current period, the inflation rate lagged one period, current output gap and current real exchange rate gap. The specification summarized in the equation above hence includes both expected future inflation rates, a forward-looking component, and the past inflation rate, a backward-looking element.

If δ is approximated with 1 the Phillips curve relation has the following form

$$\pi_t = -b_\pi\pi_{t+2|t} + \pi_{t+1|t} + b_\pi\pi_{t-1} + b_y y_t + b_q q_t. \tag{3.17}$$

Expected inflation two periods ahead then has the same impact on current inflation as lagged inflation, but with the opposite sign.

4. Estimating an expectations-augmented Phillips curve

The purpose of this section is to test for the empirical importance of expectations in explaining inflation behavior. One way of doing the empirical study would of course be to solve for the whole model before estimating the inflation rate, assuming that agents are rational. An aggregate demand equation and an instrument rule for the central bank would then have to be added to the model. Expectations could then be solved for and the aggregate supply equation, the Phillips curve relation, could be estimated with a backward-looking specification. The expectations-augmented Phillips curve could then be backed out from these results. Because of identification problems and uncertainties, about among other things, the targets of the Swedish central bank over the estimation period, 1979-1998, this is not possible.[4] In this paper therefore, the expectations-augmented Phillips curve relation is estimated directly.

The crucial question is then what measure to use for inflation expectations. In some studies forward realizations of the inflation rate are used as measures of expected inflation.[5] If agents have rational expectations, expected inflation is

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[4] The ultimate objective for Swedish monetary policy has been price stability for many years, but an explicit target for the inflation rate was not introduced until 1995. What the target was before that is hence unclear. It is also unclear whether monetary policy was used also to stabilise output. What we do know is that the Swedish central bank has changed its target for the exchange rate during the estimation period. In 1992 Sweden moved from a fixed exchange rate regime to a regime were the exchange rate was allowed to float.

[5] This is done in McCallum (1976) and Roberts (1995).

equal to

$$\pi_{t+1|t} = \pi_{t+1} + \varepsilon_{t+1} \tag{4.1}$$

where ε_{t+1} is uncorrelated with $\pi_{t+1|t}$. If this expression is substituted into equation (3.16) above and an error term dated this period is added, it follows that

$$\pi_t = -b_1\pi_{t+2} + b_2\pi_{t+1} + b_3\pi_{t-1} + b_y y_t + b_q q_t + b_1\varepsilon_{t+2} + b_2\varepsilon_{t+1} + \varepsilon_t. \tag{4.2}$$

A problem when using actual observations as noisy measurements of past expectations is that an additional source of error is introduced and a moving-average component arises in the residual error term. Further the residual is now correlated with some of the regressors, which makes the OLS estimator biased. Using an instrumental variable technique to solve this problem could be a solution, but it is almost impossible to find an instrument that is highly correlated with the regressor but has no impact of its own on the dependent variable, here the inflation rate.

Another approach that has been used in the literature is to estimate expected inflation with a VAR.[6] But using a VAR technique gives you the same identification problems as discussed above. If the VAR specification and the forward looking specification are not identical this means that one uses two different processes to explain the development of the inflation rate. It obviously follows that at least one of these specifications is incorrect.

The approach chosen here is to use survey data on inflation expectations as a proxy for expectations.[7] The survey starts in 1979 and contains data on households' inflation expectations.[8] One advantage with this approach is that it is not necessary to make any assumptions about how expectations are formed. The disadvantage, besides that the series is short, is that it is not possible to exactly test the Phillips curve relation derived in the theoretical section above since the survey data do not match the above specification. According to the model it is expectations in this period about the inflation rate one and two periods ahead,

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[6] McCallum was the first to use the instrument variable technique. Laxton, Meredith and Rose (1994) also used this method. They followed the strategy pursued by Chadha, Masson and Meredith (1992). In Rotemberg (1994) forecasted prices are also computed, but instead of using an instrument variable technique he uses a VAR approach. He first chooses the information set on which the forecast will be based. Since his model is quite simple he includes more variables in the information set than those proposed by the model. He then specifies the VAR and runs it. The VAR specification is then used to construct expected changes in, among other things, prices.

[7] This is for example also done in Roberts (1995), (1996) and in Fisher, Mahadeva and Whitley (1996).

[8] Data comes from the Consumer Buying Expectation report, "Hushållens Inköpsplaner", published by Statistics Sweden.

$\pi_{t+2|t}$ and $\pi_{t+1|t}$ that matter for this period's inflation rate. If one period is assumed to be one quarter it implies that the quarterly inflation rate this quarter is determined by the expected quarterly inflation rate one and two quarters ahead, where expectations are formed this quarter. The survey collects information about what people this quarter expects the annual inflation rate to be one year ahead, $\pi^y_{t+4|t} = (\pi_{t+4|t} + \pi_{t+3|t} + \pi_{t+2|t} + \pi_{t+1|t})$.[9] Under very special conditions the survey measure will coincide with the model's specification.[10] The model can therefore only be used as a guideline, showing that both expected future inflation rates and past inflation rates matter for the inflation rate as of today, the exact individually impact of the expected future quarterly inflation rates can not be tested for.

4.1. The Swedish Phillips curve

The estimations start from a more general specification including four lags on all regressors. The initially estimated equation is hence of the following form

$$\pi_t = c + \alpha_\pi (L) \pi_{t-1} + \alpha_{\pi^{e,y}} (L) \pi_{t+4|t} + \alpha_y (L) y_t + \alpha_q (L) q_t + \varepsilon_t \tag{4.3}$$

where c is a constant, $\alpha_\pi (L)$, $\alpha_y (L)$, and $\alpha_q (L)$ are polynomials in the lag operator L, $L^i x_t = x_{t-i}$, $\alpha_j (L) = \alpha_0 + \alpha_1 L + \alpha_2 L^2 + \alpha_3 L^3 + \alpha_4 L^4$for $j = \pi, y, q, \pi^{e,y}$. Further π_t is the quarterly inflation rate (CPI) measured at an annual rate[11], $\pi_{t+4|t}$ is households' inflation expectation, y_t is the output gap[12], q_t is the real exchange rate gap[13]. No sum constraint on lagged inflation and expected future inflation rates is imposed.

The model was then reduced. When choosing the lag length a likelihood-ratio test was used, that indicated the progress in the modelling. The behavior of the residuals was of course also taken into account.

The estimation period is 1979-1998. During this period inflation and inflation expectations were falling. Even though one would expect all these variables to be

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[9] The survey is actually made on a monthly basis. Assuming one period is a month the correct notation is $\pi^y_{t+12|t}$. Since quarterly data are used in the estimations, data have been transformed to that frequency by taking the average of three months' expectations, that is $\pi^y_{t+4|t} = (\pi^y_{t+14|t+2} + \pi^y_{t+13|t+1} + \pi^y_{t+12|t})/3$.

[10] $(\pi_{t+4|t} + \pi_{t+3|t} + \pi_{t+2|t} + \pi_{t+1|t}) = -b_\pi \pi_{t+2|t} + \pi_{t+1|t}$ if $\pi_{t+4|t} + \pi_{t+3|t} = 0$ and $b_\pi = -1$.

[11] Seasonally adjusted, using the additive version of X11.

[12] Calculated with a HP-filter ($\lambda = 10000$), using the log of GDP, seasonally adjusted, using the additive version of X11.

[13] The real exchange rate is the geometric sum (IMF's TCW weights) of the CPI-based real exchange rates of Sweden's most important trading partners. The gap is calculated as a HP-filter ($\lambda = 10000$). Estimations were also conducted using the real exchange rate instead of its gap, which is the same as assuming that the steady state value is zero. How this affected the estimation results are comented upon below.

stationary in the long run they turn out to be non-stationary during the period of estimation. In appendix D the results from an ADF-test are shown and also graphs of the data. Despite this it is still possible to use OLS when doing the estimations. As is stated in Stock and Watson (1988) if the error term is serially uncorrelated and is uncorrelated with the regressors and if the regression equation can be written in such a way that all the coefficients of interest become coefficients on mean zero stationary variables, then the OLS estimator will be consistent. Further the t-and F-statistics for the estimated coefficients have the usual normal asymptotic distribution so the standard critical values still apply.[14] Since for example $\alpha_{\pi,1}\pi_{t-1}+\alpha_{\pi,2}\pi_{t-2}$ can be written as $(\alpha_{\pi,1}+\alpha_{\pi,2})\pi_{t-1}-\alpha_{\pi,2}\,(\pi_{t-1}-\pi_{t-2})$ and $(\pi_{t-1}-\pi_{t-2})$ is a stationary variable then $\alpha_{\pi,2}$ is a coefficient on a stationary variable. The same is true also for the coefficients on expected inflation. It is also possible to construct a stationary variable by combining lagged inflation with expected inflation, i.e. they are cointegrated.

In table 4.1 the results are reported for the reduced model. In appendix E the result of the more general model, equation (4.3), are shown for comparison.

As can be seen in the table contemporary inflation expectations have a highly significant impact on the current inflation rate. Expected inflation two periods back of the inflation rate two periods ahead has a marginal impact on the inflation rate. Concerning the impact of past inflation rates, it follows that inflation lagged four quarters has a significant impact on the current inflation rate, while inflation lagged one quarter has a marginal impact. The coefficients of the other individual lagged values are not significantly different from zero. Through a Wald test it is then tested if the coefficients on inflation expectations sum to one, which some theories predict. The null hypothesis, that they sum to one, is rejected if a significant test statistic is observed. As can be seen one cannot reject the hypothesis that price-setters place a weight of one on expected future inflation rates, the test statistic for this hypothesis takes the value 0.03 with p-value 0.87. The same is true for the test of whether the sum of the coefficients of past inflation rates sum to zero, with a p-value of 0.11. Further more, it was tested if the coefficients on both expected inflation rates and lagged inflation rates sum to one. The test statistic for this hypothesis is 2.97 and the p-value is 0.08, the hypothesis was hence weakly rejected. It was then tested if the same sum less lag three, which is not significantly different from zero, sum to one. This hypothesis was not rejected, the p-value was 0.60. Testing all the coefficients jointly hence indicated that they did not sum to one, while testing the coefficients in different subsets indicated that they sum to one.

The sign on the coefficient on the output gap is positive as expected. Quite surprisingly though the effect is not significant. The same is true for the exchange

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[14] Stock and Watson (1988), p. 165.

Table 4.1: Estimation results.

Variable	Coefficient	p-value	Standard Error
Constant	-0.56	0.43	0.71
π_{t-1}	0.20	0.07	0.11
π_{t-2}	0.15	0.19	0.11
π_{t-3}	0.14	0.21	0.11
π_{t-4}	-0.21	0.05	0.11
$\pi_t^{e,y}$	1.77	0.00	0.37
$\pi_{t-2}^{e,y}$	-0.81	0.06	0.42
y_{t-4}	0.13	0.43	0.16
q_{t-4}	-0.07	0.20	0.05
Wald test, $\sum \alpha_{\pi^{e,y}} = 1$	$\chi^2(1)$=0.03	0.87	
Wald test, $\sum \alpha_{\pi} = 0$	$\chi^2(1)$=2.59	0.11	
Wald test, $\sum \alpha_{\pi} + \sum \alpha_{\pi^{e,y}}$	$\chi^2(1)$=2.97	0.08	
LR-test of model reduction	$\chi^2(12)$=8.49	0.75	
R^2	0.90		
S.E. of regression	2.44		
AR(1)	F(1,67) = 0.16	0.69	
AR(4)	F(4,64) = 0.17	0.96	
ARCH 4	F(4,60) = 1.69	0.16	
Heteroscedastic errors	F(16,51) = 1.04	0.43	
Normality	$\chi^2(2)$=3.66	0.16	

rate gap. Choosing other lags than the fourth lag did not affect the results. Using the real exchange rate instead of its gap did not change the results in any substantial way either.

The test statistics of the estimated model show no direct signs of misspecifications and the R^2 value is high. Despite this an inflation equation including also supply shocks, as in Apel and Jansson's (1999) study, was estimated, as a comparison. The log difference of the relative price of oil[15] and the log difference of productivity[16], was added to the model. Also in this case the starting point was to include five lags of all regressors and then successively reducing it. The results of the reduced model are reported in table 4.2 while the larger model is presented in appendix E.

As can be seen in the table this did not change the results in any substantial way concerning the impact of expected and lagged inflation. Still it is the expected future inflation rates that seem to matter the most, they have a highly significant impact on current inflation rate. In this case not only contemporary inflation expectations have a significant impact, but also expected inflation three periods back of the inflation rate one period ahead, which is something that the theory derived in this paper did not predict. Concerning the impact of lagged inflation rates it follows that inflation lagged four and five quarters are significant and this time one can reject the hypothesis that the coefficients on all lagged values sum to zero with a p-value of 0.02. The hypothesis that the coefficient of the expected inflation rate and the coefficients on lagged inflation rates sum to one is not rejected, with a p-value of 0.10.

The results concerning the output gap and the exchange rate gap are on the other hand quite different compared with the results from the model without supply shocks. Both the first and the fourth lag of the output gap are in this regression significantly different from zero. The total effect of the output gap is again positive as the theory predicts. The exchange rate gap has a marginal impact on the inflation rate and the sign is also as predicted. But according to the model derived in section 2.1. it was current output gap and exchange rate that was supposed to influence current inflation rate. As it turned out data did not favor that kind of a specification. The result is therefore more in line with what follows from Taylor's staggered contracts model. In a two-period version of Taylor's (1979) model, the inflation rate is affected by both contemporary real activity and real activity lagged one period.[17]

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[15] The brent USD/barel oil price is used, converted to SEK. The relative price of oil is then defined as $100(\ln(\mathrm{OIL}_t) - \ln(\mathrm{P}_t))$.

[16] Productivity is defined as the first difference of $100((\ln(\mathrm{GDP}_t) - \ln(\mathrm{H}_t))$, where GDP is real GDP in fixed prices, and H is hours worked. Both series are seasonally adjusted with the additive version of X11.

[17] See for example Roberts (1995).

Table 4.2: Estimation results. Phillips curve with supply shocks.

Variable	Coefficient	p-value	Standard Error
Constant	-0.27	0.68	0.66
π_{t-1}	0.16	0.12	0.10
π_{t-2}	0.03	0.76	0.10
π_{t-3}	0.15	0.15	0.10
π_{t-4}	-0.23	0.02	0.10
π_{t-5}	0.29	0.01	0.11
$\pi_t^{e,y}$	1.86	0.00	0.28
$\pi_{t-3}^{e,y}$	-1.04	0.00	0.34
y_{t-1}	-0.38	0.04	0.17
y_{t-4}	0.91	0.00	0.24
q_{t-1}	0.13	0.07	0.07
roil_{t-4}	0.06	0.00	0.02
prod_{t-1}	0.83	0.00	0.23
prod_{t-2}	0.53	0.06	0.28
prod_{t-3}	0.72	0.02	0.30
prod_{t-4}	0.45	0.06	0.24
Wald test, $\sum \alpha_{\pi^{e,y}} = 1$	$\chi^2(1)$=0.45	0.50	
Wald test, $\sum \alpha_\pi = 0$	$\chi^2(1)$=5.24	0.02	
Wald test, $\sum \alpha_\pi + \sum \alpha_{\pi^{e,y}} = 1$	$\chi^2(1)$=2.76	0.10	
LR-test of model reduction	$\chi^2(15)$=11.07	0.75	
R^2	0.93		
S.E. of regression	2.09		
AR(1)	F(1,59)=0.03	0.87	
AR(4)	F(4,56)=0.66	0.62	
ARCH 4	F(4,52)=0.72	0.58	
Heteroscedastic errors	F(30,29)=0.50	0.97	
Normality	$\chi^2(2)$=0.35	0.84	

Using the actual real exchange rate instead of the gap gave slightly different results. Only contemporary expectations was significant, not lagged. Further, the fifth inflation lag was not significant, the output gap lagged four periods was marginally significant, not the first and it was the forth lag of the real exchange rate that was significant. Finally the test of whether the coefficients on lagged inflation sum to one was not rejected, with a p-value of 0.98.

4.1.1. Stability

Another important issue when estimating the Phillips curve relation is to test for the existence of regime shifts, that is, to test whether the parameters are stable during the period of estimation. According to the Lucas critique it is for example not possible to use estimated macro economic relations when doing policy experiments, if those relations actually shift in response to changes in the monetary policy regime. When estimating a Phillips curve relation to be used for policy simulations it is hence necessary to try to avoid these caveats. Much in response to this critique, an expectations-augmented Phillips curve with rationally formed expectations was initially developed. The question is then whether monetary policy affects the coefficient in the Phillips curve relation. According to the model the coefficient is a function of the elasticities, θ, $\tilde{\omega}$, the share of foreign goods in the production, γ, the discount factor, δ, and the costs of adjustments, c_1, c_2. All these factors are in this model exogenous. In reality it is of course possible that these factors change over time and among other things are affected by the way monetary policy is conducted. It is hence necessary to test if the parameters are stable during the period of estimation. Studies that have analyzed how a regime shift affects the inflation process, that is, how important the famous Lucas critique is in practice, have come to different results. In Fuhrer (1995) it is shown, using several different methods, that the Phillips curve for the United States has remained stable during the period 1960 to 1993, despite a shift in the monetary policy regime in 1979. Fuhrer argues that the shift in policy behavior perhaps was not important enough to derail the empirical performance of the Phillips curve. In economies that recover from hyperinflation, on the other hand, Sargent (1981) finds evidence of a break in the Phillips curve relation.

To examine parameter consistency the following tests are conducted; a one-step-ahead Chow test, which amounts to adding one observation at a time and testing its significance, a break-point Chow test, where all possible break points are tested against the final observation, and a forecast Chow test, which amounts to adding one and then two etc. observations and testing their significance.[18]. In

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[18] In the one-step ahead Chow test point t_0 is tested against t_0+1, then t_0+1 against t_0+2, etc. In a break-point Chow test t_0 is tested against T, then t_0+1 against T, etc. In a forcast

appendix F the results are shown. The sequences of statistics are scaled by their critical values, so that any point above unity indicates a significant break. As can be seen constancy is not rejected for either the Phillips curve relation without supply shocks or the one with supply shocks. Constancy is neither rejected using other numbers of observation for initialization.

5. Conclusions

If not only costs of changing the price level, but also costs of changing the speed with which prices are changed, are included in the firms' optimization problems it is possible to derive a Phillips curve relation that incorporates both a forward-looking component and a backward-looking component. It follows that the inflation rate this period depends on expected inflation rate one and two periods ahead, where expectations are formed in the current period, the inflation rate lagged one period, current output gap and current real exchange rate gap.

When this model is tested it turns out that for these data series, during the sample period expected future inflation rates seem to play an important role in explaining current inflation. Data favor a forward-looking inflation specification over a purely backward-looking specification. The impact of lagged inflation was small compared with the impact from expected inflation. It also turned out that not only expectations formed today but also expectations formed in a previous period are empirically important in explaining the development of the current inflation rate. This is something that is not predicted by the model derived in this paper. Further, the output gap and the real exchange rate gap turned out to have an impact on the inflation rate with a lag.

It is also interesting to note that although lagged inflation had a marginal impact on current inflation rate, the inflation rate had a high degree of persistence. The critique against the purely forward-looking models was that they did not capture the high degree of persistence in inflation which is usually found in data. But the measure used here for inflation expectations has in it self a high degree of persistence, so having a forward looking specification does not imply that the inflation rate can not be persistent.

Chow test t_0 is tested against $t_0 + 1$, then t_0 against $t_0 + 2$, etc.

APPENDIX

A. Log-linearization of the FOC

The optimization problem is

$$\max_{P_t^j} P_t^j Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} - W_t V(Y_t^j) \tag{A.1}$$

and

$$Y_t^j = Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta}. \tag{A.2}$$

The first order condition is

$$\begin{aligned} Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} - \theta P_t^j Y_t \frac{(P_t^j)^{-\theta-1}}{(P_t)^{-\theta}} + W_t V'(Y_t^j) Y_t \theta \left(\frac{P_t^j}{P_t}\right)^{-\theta} \frac{1}{P_t^j} &= 0 \\ Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} - \theta Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} + \theta Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} W_t V'(Y_t^j) \frac{1}{P_t^j} &= 0 \\ (1-\theta) Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} + (1-\theta) \frac{\theta}{1-\theta} Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} W_t V'(Y_t^j) \frac{1}{P_t^j} &= 0 \\ (1-\theta) Y_t \left(\frac{P_t^j}{P_t}\right)^{-\theta} \left[1 + \frac{\theta}{1-\theta} W_t V'(Y_t^j) \frac{1}{P_t^j}\right] &= 0 \\ 1 + \frac{\theta}{1-\theta} W_t V'(Y_t^j) \frac{1}{P_t^j} &= 0 \end{aligned} \tag{A.3}$$

$$P_t^j = \frac{\theta}{\theta-1} W_t V'(Y_t^j) \tag{A.4}$$

or

$$\begin{aligned} P_t^{j*} &= \frac{\theta}{\theta-1} W_t V'(Y_t^j) \\ &= \varsigma W_t V'(Y_t^j) \end{aligned} \tag{A.5}$$

$\varsigma = \frac{\theta}{\theta-1}$.

Now log-linearize around steady state. The steady state values are (P_0^j, W_0, Y_0^j). In what follows small letters represent percentage deviations of the variable from its steady-state value,

$$x_t \equiv \frac{X_t - X_0}{X_0} \approx d\ln X_t \equiv \ln X_t - \ln X_0. \tag{A.6}$$

The FOC is now log-linearized and a first order Taylor expansion is made around the steady state values.

$$\ln P_t^j = \ln \varsigma + \ln W_t + \ln V'(Y_t^j) \tag{A.7}$$

Define

$$f(P_t^j, W_t, Y_t^j) = -\ln P_t^j + \ln \varsigma + \ln W_t + \ln V'(Y_t^j) \tag{A.8}$$

The first order Taylor expansion around steady state gives

$$\begin{aligned} f(P_t^j, W_t, Y_t^j) &= -\ln P_0^j + \ln \varsigma + \ln W_0 + \ln V'(Y_0^j) + \\ & -\frac{\partial f(P_0^j, W_0, Y_0^j)}{\partial P_0^j}\left(P_t^j - P_0^j\right) + \frac{\partial f(P_0^j, W_0, Y_0^j)}{\partial W_0}(W_t - W_0) + \\ & +\frac{\partial f(P_0^j, W_0, Y_0^j)}{\partial Y_0^j}\left(Y_t^j - Y_0^j\right) \\ &= -\frac{\partial \ln P_0^j}{\partial P_0^j}\left(P_t^j - P_0^j\right) + \frac{\partial \ln W_0}{\partial W_t}(W_t - W_0) + \frac{1}{V'}\frac{dV'}{dY_0^j}\left(Y_t^j - Y_0^j\right) \\ &= -\frac{1}{P_0^j}\left(P_t^j - P_0^j\right) + \frac{1}{W_0}(W_t - W_0) + \frac{1}{V'}\frac{dV'}{dY_0^j}\left(Y_t^j - Y_0^j\right) \\ &= -p_t^j + w_t + \omega y_t^j \end{aligned} \tag{A.9}$$

where

$$-\ln P_0^j + \ln \varsigma + \ln W_0 + \ln V'(Y_0^j) = 0 \tag{A.10}$$

in steady state and where

$$\omega = \frac{dV'}{V'}\frac{Y_0^j}{dY_0^j} \tag{A.11}$$

and therefore

$$\frac{1}{V'}\frac{dV'}{dY_t^j}\left(Y_t^j - Y_0^j\right) = \frac{dV'}{V'}\frac{Y_0^j}{dY_0^j}\frac{1}{Y_0^j}\left(Y_t^j - Y_0^j\right) = \omega y_t^j. \tag{A.12}$$

Further, since

$$\begin{aligned} y_t^j &= d\ln Y_t^j = \ln Y_t^j - \ln Y_0^j = \ln Y_t\left(\frac{P_t^j}{P_t}\right)^{-\theta} - \ln Y_0\left(\frac{P_0^j}{P_0}\right)^{-\theta} = \\ &= \ln Y_t - \ln Y_0 - \theta\left[\ln\left(\frac{P_t^j}{P_t}\right) - \ln\left(\frac{P_0^j}{P_0}\right)\right] \\ &= y_t - \theta\left(p_t^j - p_t\right). \end{aligned}$$

the FOC can be written as

$$\begin{aligned} p_t^j &= w_t + \omega\left(y_t - \theta\left(p_t^j - p_t\right)\right) \\ p_t^j &= \frac{1}{1+\omega\theta} w_t + \frac{\omega}{1+\omega\theta} y_t + \frac{\omega\theta}{1+\omega\theta} p_t. \end{aligned} \tag{A.13}$$

B. Price setting with first-order adjustment costs

$$\min_{p_t^j} E_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} \left[\left(p_\tau^j - p_\tau^{j*}\right)^2 + c\left(p_\tau^j - p_{\tau-1}^j\right)^2\right] \tag{B.1}$$

The first order condition to this problem is

$$p_t^j - p_t^{j*} + c\left(p_t^j - p_{t-1}^j\right) - c\delta\left(p_{t+1|t}^j - p_t^j\right) = 0 \tag{B.2}$$

or

$$p_t - p_t^* + c\pi_t - c\delta\pi_{t+1|t} = 0 \tag{B.3}$$

substituting in

$$p_t^* = p_t + \alpha_y y_t + \alpha_q q_t \tag{B.4}$$

gives

$$p_t = p_t + \alpha_y y_t + \alpha_q q_t - c\pi_t + c\delta\pi_{t+1|t} \tag{B.5}$$

or

$$\pi_t = \delta\pi_{t+1|t} + \beta_y y_t + \beta_q q_t + \tag{B.6}$$

where $\beta_y = \alpha_y/c$ and $\beta_q = \alpha_q/c$.

C. Price setting with second-order adjustment costs

$$\min_{p_\tau^j} E_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} \left[\left(p_\tau^j - p_\tau^{j*}\right)^2 + c_1\left(p_\tau^j - p_{\tau-1}^j\right)^2 + c_2\left(p_\tau^j - 2p_{\tau-1}^j + p_{\tau-2}^j\right)^2\right] \tag{C.1}$$

The first order condition to this problem is

$$\begin{aligned} 0 = \; & p_t^j - p_t^{j*} + c_1\left(p_t^j - p_{t-1}^j\right) - c_1\delta\left(p_{t+1|t}^j - p_t^j\right) \\ & + c_2\left(p_t^j - 2p_{t-1}^j + p_{t-2}^j\right) - 2c_2\delta\left(p_{t+1|t}^j - 2p_t^j + p_{t-1}^j\right) \\ & + c_2\delta^2\left(p_{t+2|t}^j - 2p_{t+1|t}^j + p_t^j\right) \end{aligned} \tag{C.2}$$

Use that in equilibrium all producers choose the same price, therefore $p_t^{j*} = p_t^*$ and $p_t^j = p_t$, then

$$\begin{aligned} 0 &= p_t - p_t^* + c_1\pi_t - c_1\delta\pi_{t+1|t} + c_2\pi_t - c_2\pi_{t-1} - 2c_2\delta\pi_{t+1|t} + 2c_2\delta\pi_t \\ &\quad + c_2\delta^2\pi_{t+2|t} - c_2\delta^2\pi_{t+1|t} \\ 0 &= p_t - p_t^* + c_2\delta^2\pi_{t+2|t} - \left(c_1\delta + 2c_2\delta + c_2\delta^2\right)\delta\pi_{t+1|t} + \left(c_1 + c_2 + 2c_2\delta\right)\pi_t - c_2\pi_{t-1} \end{aligned} \tag{C.3}$$

$$\begin{aligned} \pi_t &= \frac{1}{c_1 + c_2 + 2c_2\delta}\left(p_t^* - p_t\right) - \frac{c_2\delta^2}{c_1 + c_2 + 2c_2\delta}\pi_{t+2|t} \\ &\quad + \frac{c_1\delta + 2c_2\delta + c_2\delta^2}{c_1 + c_2 + 2c_2\delta}\delta\pi_{t+1|t} + \frac{c_2}{c_1 + c_2 + 2c_2\delta}\pi_{t-1} \end{aligned} \tag{C.4}$$

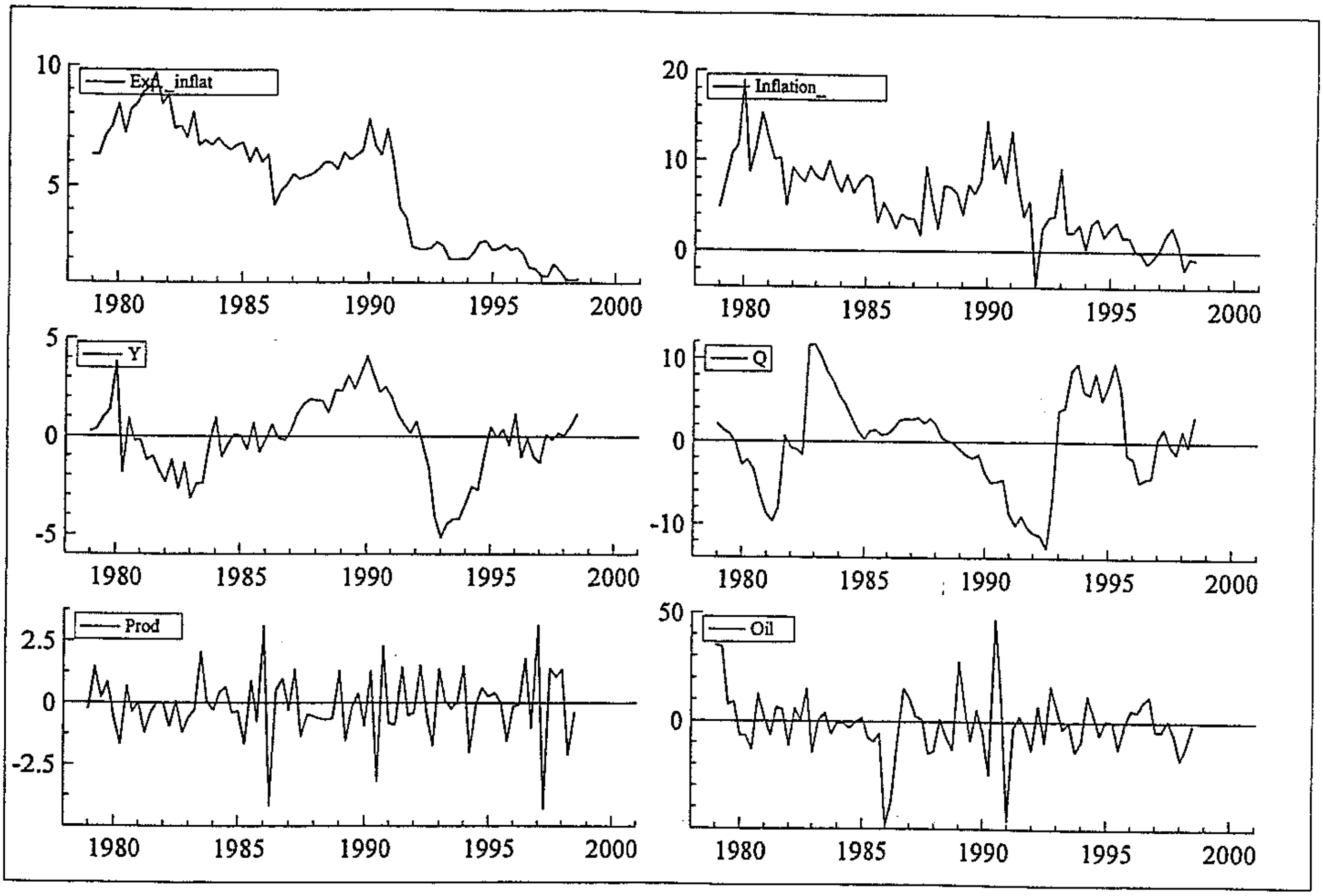
$$\begin{aligned} \pi_t &= \frac{1}{c_1 + c_2 + 2c_2\delta}\left(\alpha_y y_t + \alpha_q q_t\right) - \frac{c_2\delta^2}{c_1 + c_2 + 2c_2\delta}\pi_{t+2|t} \\ &\quad + \frac{c_1\delta + 2c_2\delta + c_2\delta^2}{c_1 + c_2 + 2c_2\delta}\delta\pi_{t+1|t} + \frac{c_2}{c_1 + c_2 + 2c_2\delta}\pi_{t-1} \end{aligned} \tag{C.5}$$

Table D.1: Augmented Dickey Fuller Test. $\triangle X_t = c + \beta_0 X_{t-1} + \sum_{i=1}^{4} \beta_i \triangle X_{t-i} + \varepsilon_t$

Variable	ADF Test statistic	β_0
π	-1.84	-0.16
$\pi^{e,y}$	-1.14	-0.04
y	-2.71*	-0.19
q	-3.25*	-0.23
oil	-5.09***	-1.33
prod	-5.35***	-2.62

*** Significantly different from zero at the 1 percent level. * Significantly different from zero at the 10 percent level. Critical values; 10 per cent -2.59, 5 per cent -2.90, 1 per cent -3.52. Other lag lengths were also tested but this did not change the results.

D. Data description



E. Estimation results for the general model

Table E.1: Estimation results.

Variable	Phillips curve, no supply shocks		Phillips curve with supply shocks	
	Coefficient, (p-value)	Std.Error	Coefficient, (p-value)	Std.Error
Constant	-0.22(0.79)	0.85	0.00(0.99)	0.77
π_{t-1}	0.19(0.14)	0.13	0.10(0.44)	0.12
π_{t-2}	0.15(0.24)	0.13	0.04(0.77)	0.12
π_{t-3}	0.15(0.23)	0.13	0.16(0.20)	0.12
π_{t-4}	-0.27(0.06)	0.14	-0.16(0.22)	0.13
π_{t-5}	0.20(0.16)	0.14	0.34(0.02)	0.14
$\pi_t^{e,y}$	1.25(0.02)	0.53	1.52(0.02)	0.64
$\pi_{t-1}^{e,y}$	1.07(0.14)	0.72	0.76(0.45)	1.01
$\pi_{t-2}^{e,y}$	-1.28(0.08)	0.72	-0.76(0.42)	0.95
$\pi_{t-3}^{e,y}$	-0.44(0.52)	0.68	-1.28(0.15)	0.88
$\pi_{t-4}^{e,y}$	0.10(0.86)	0.56	0.45(0.48)	0.63
y_t	0.15(0.64)	0.33	0.01(0.97)	0.33
y_{t-1}	-0.20(0.56)	0.35	-0.36(0.32)	0.36
y_{t-2}	-0.01(0.98)	0.36	-0.04(0.92)	0.36
y_{t-3}	-0.07(0.84)	0.35	0.12(0.72)	0.35
y_{t-4}	0.49(0.16)	0.35	1.01(0.00)	0.34
q_t	-0.05(0.74)	0.14	0.09(0.52)	0.14
q_{t-1}	0.20(0.26)	0.17	0.14(0.46)	0.19
q_{t-2}	-0.21(0.27)	0.18	-0.11(0.62)	0.22
q_{t-3}	0.28(0.13)	0.18	0.22(0.30)	0.21
q_{t-4}	-0.21(0.10)	0.12	-0.14(0.29)	0.13
oil_t			0.03(0.35)	0.03
oil_{t-1}			0.01(0.75)	0.03
oil_{t-2}			0.02(0.57)	0.03
oil_{t-3}			0.02(0.42)	0.03
oil_{t-4}			0.07(0.01)	0.03
prod_t			-0.15(0.60)	0.29
prod_{t-1}			0.57(0.13)	0.36
prod_{t-2}			0.44(0.27)	0.39
prod_{t-3}			0.64(0.10)	0.38
prod_{t-4}			0.48(0.14)	0.32

Table E.2: Estimation results.

	Phillips curve, no supply shocks	Phillips curve with supply shocks
R^2	0.90	0.94
S.E. of regression	2.56	2.25
AR (1) [19]	F(1, 53)=0.29 (0.59)	F(1, 43)=0.05 (0.82)
AR(4)	F(4, 50)=0.57 (0.68)	F(4, 40)=0.63 (0.65)
ARCH 4	F(4,46)=0.62(0.65)	F(4, 36)=0.42 (0.79)
Heteroscedastic errors	F(40, 13)=0.65 (0.85)	
Normality, $\chi^2(2)$	3.71(0.16)	0.42(0.81)

F. Stability test results

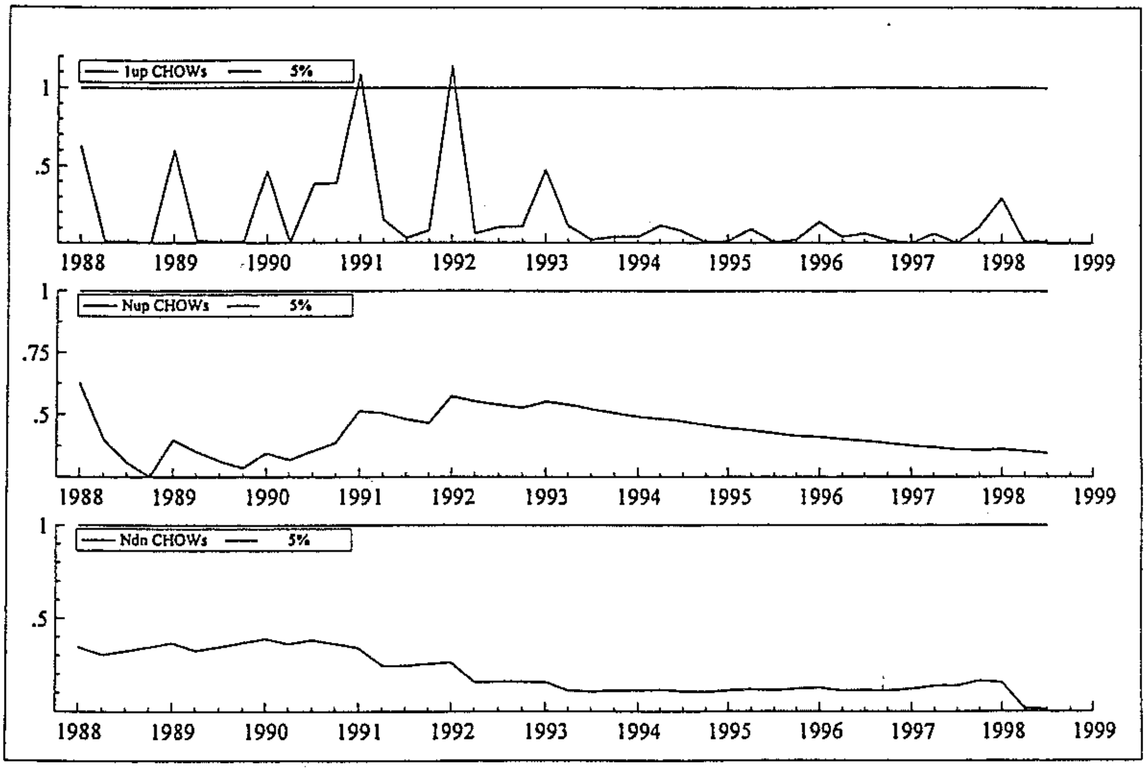


Figure F.1. Stability test, no supply shocks.
One-step-ahead Chow test, Break-point Chow test and Forecast Chow test.

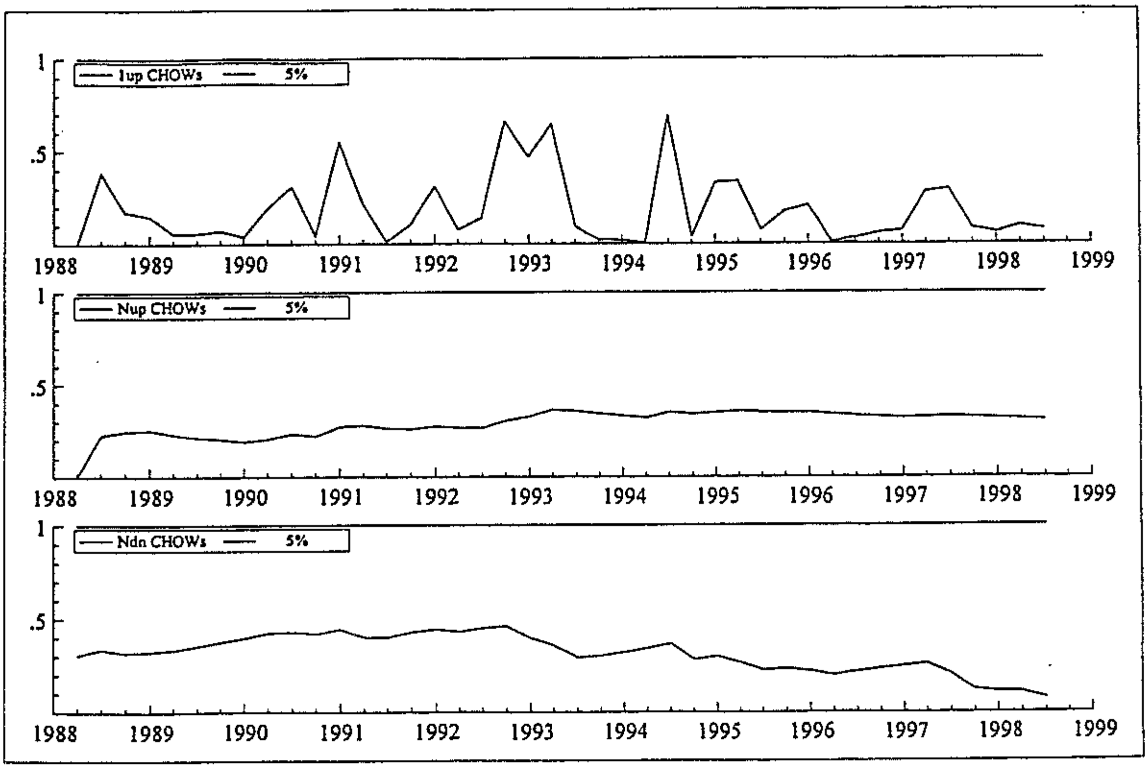


Figure F.2. Stability test for the Phillips curve relation with supply shocks. One-step-ahead Chow test, Break-point Chow test and Forecast Chow test.

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