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How Do Oil Shocks Affect the Structural Stability of Hybrid New Keynesian Phillips Curve?

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Working Paper No. 12/20
October 2012

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October 3, 2012

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Abstract

In this paper, the structural stability of the hybrid New Keynesian Phillips Curve (NKPC) and possible changes in pricing behaviour of firms are investigated in the context of oil price shocks. Using quarterly US aggregate data, this curve is estimated in subsamples formed with oil price shock dates by generalized method of moments (GMM) and continuously updated GMM (CU-GMM). The results for the structural break test confirm 1974:I, 1979:II and 1990:III as identified oil price shock dates and do not reject the structural stability of the over-identifying restrictions implied by the Gali and Gertler's (1999) hybrid NKPC. However, there is evidence for parameter instability for this hybrid NKPC in terms of backward-looking rule-of-thumb behaviour in both set of estimations. The standard GMM estimates suggest that although the forward-looking behaviour is predominant in the period before the 1974 Oil Crisis, it loses ground against backward-looking behaviour after every oil shock. In contrast, the CU-GMM estimates suggest the opposite: forward-looking behaviour becomes more important after oil price shocks, and inflation persistence decreases as a result. The difference between the two sets of results may be due to weak instruments. Alternatively, given that the CU-GMM seems to suffer smaller bias in the finite sample than the 2-step GMM in the presence of weak instruments, it is more likely that the structural instability of the hybrid NKPC is captured by the CU-GMM estimates.

JEL Codes: E31, E52

Key Words: hybrid New Keynesian Phillips curve, oil price shock, structural stability, inflation, forward-looking behaviour, backward-looking behaviour, GMM, Continuously Updated GMM.

1 Introduction

Since the 1970s, the decade that is known for major oil crises, there has been widespread interest in the controversial question of how oil price shocks, due to supply shortfalls largely caused by political turmoil in the Middle East, affect macroeconomic variables such as inflation, output and employment. There are three different answers to this question. The first group, including Bruno and Sachs (1985), Hamilton (1983, 1996, 2001 and 2003), Keane and Prasad (1996), Finn (2000), Davis and Haltiwanger (2001) and Lee and Ni (2002), by different models and estimation techniques, show that there exist non-negligible relationships between oil price shocks and macro variables. Burbidge and Harrison (1984), Santini (1985), Gisser and Goodwin (1986), Daniel (1997) and Raymond and Rich (1997), among others reported a negative correlation between the two variables.

The second group believe that the correlation between oil prices and macro variables has weakened after the period[1] 1980, see for example Hooker (1996 and 2002), Rotemberg and Woodford (1996), Blanchard and Simon (2001), Stock and Watson (2003) and Blanchard and Gali (2009). The third group, including Bernanke et al. (1997), Barskey and Kilian (2002, 2004), argue that there is no relationship between oil price shocks and macro variables. They conclude that the stagflations of the 1970s were due to the impact of other factors, such as exogenous changes in monetary policy or rise in interest rates.

The oil shocks literature, however, has largely ignored the effect of oil prices on inflation dynamics and firms' pricing behaviour. The particular question that is addressed in the present paper is that how oil shocks, as major macro-political events, are associated with change in firms' price-setting strategies in the context of the hybrid pricing model in Gali and Gertler (1999). Namely, with oil shocks do firms become more forward- or backward-looking in their price-setting behaviour?

The present paper relates to the oil shock as well as inflation dynamics from a new point of view, i.e. not only oil price changes may affect the formation of inflation expectation by firms but also they may cause the structural instability of pricing parameters underlying the hybrid NKPC.

The stability of these pricing parameters is investigated using the standard generalised method of moments (GMM) estimator as well as the continuously updating GMM (CU-GMM) estimator which, according to Hansen, Heaton and Yaron(1996), produces less biased estimates and more reliable results than the former. The structural break date tests are conducted in order to make sure that the oil price shock dates identified in the oil economics literature are indeed econometrically sound structural break dates. The data set covers the period between 1954 and 2010, which includes US aggregate data containing several major oil price shocks discussed in the next section.

The structural break date tests for both estimators, GMM and CU-GMM, confirm our choice of break dates in general. For the former, when using more moment conditions, the test statistics prove more problematic in providing evidence on structural change around identified dates, but the latter always strongly rejects the null hypothesis of no structural

[1] This literature can be attributed to the literature on the "Great Moderation", a term that refers to decline in output fluctuations over the last 30 years.

change. Using fewer moment conditions, on the other hand, the identified oil price shock dates are confirmed by both techniques. The overidentifying restrictions, however, are almost never rejected across specifications and estimators.

The first set of results based on the standard GMM estimator, estimated for two different measures of real marginal cost and two different orthogonality condition normalisations, indicate that the hybrid NKPC is not stable in terms of backward-looking component, but is reasonably stable in terms of other structural parameters. The overidentifying restriction test almost always fails to reject, but the estimates for the coefficient on marginal cost are not always significant, especially when more instruments are used. The estimates for the fraction of backward-looking firms as well as the coefficient on backward-looking component are also insignificant in some cases. The results also suggest that although the forward-looking behaviour is more important for the whole sample and pre-oil shock periods, it loses ground against the backward-looking component after every oil shock.

The inflation persistence also increases after identified oil shocks. Although the predominant role of backward-looking behaviour after oil shocks is consistent with similar findings in Fuhrer and Moore (1995), Fuhrer (1997), Linde (2005), Roberts (2005) and Rudd and Whelan (2005), they can also be attributed to standard GMM estimator drawbacks, including biased coefficients and standard error estimates and unreliable J statistics in the finite sample. A commonly believed cause for these problems is the weak instruments, i.e. instruments that are not highly correlated with the endogenous regressors.

Hansen, Heaton and Yaron (1996) shown that the CU-GMM estimator may be less susceptible to problems caused by weak instruments, so the second set of results are based on the CU-GMM estimator. The same pattern of structural changes is found in parameter estimates but there are three important differences in results when using CU-GMM. First, all estimates are now statistically significant. Second, J statistics for model specification testing are smaller in values in general, consistent with the smaller size distortion in this test associated with continuously updating GMM results reported in Hansen et al. (1996). Last but not least, oil shocks are now associated with changes in price-setting behaviour opposite to what the standard GMM estimates imply. In other words, now the forward-looking behaviour is more important after oil shock and the share of the firms indexing their prices to lagged inflation falls substantially after every oil shock. The greatest change in the latter always takes place in the post-1974:I sample, declining by almost 75% in general. This is conceivable because major economic events may shape pricing behaviour by inducing economic agents to become more forward-looking and plan ahead more in order to suffer less from such events. By experiencing major events and watching what happens to other firms, these economic agents may learn something useful for formulation decisions, or update their prior beliefs about an economic process, and act accordingly, including forming expectations in a more rational way.

The rest of the paper is organised as follows. Section 2 reviews the New Keynesian Phillips Curve. Section 3 looks into the identification of oil price shock dates. Section 4 outlines the econometric approach, namely looking at the GMM and CU-GMM techniques.

Structural stability tests used in the present study are documented in Section 5. Section 6 describes the data and presents the estimations results. Section 7 concludes.

2 The New Keynesian Phillips Curve

There are different ways to formulate sticky prices, such as Fischer (1977), Taylor (1980) and Calvo (1983). The first two build on the assumption of nominal wage rigidity. In the derivation of the New Keynesian Phillips Curve, however, Calvo (1983) formulation is used which assumes nominal price rigidity in the form of delays between price adjustments in a forward-looking context.

In the Calvo model, monopolistically competitive firms set prices according to a constraint on the frequency of price adjustments. They have to choose between updating their prices in each period or keep them as constant. $(1-\theta)$ is the exogenously determined fraction of firms that reset their prices in a given period, where θ refers to degree of price stickiness. If firms choose to reset their prices, they should know that the prices may be fixed for many periods. Assume that they do so by choosing an optimal price level, p_t^*, that minimises the following loss function:

$$L(p_t^*) = \sum_{s=1}^{\infty} (\theta\beta)^s E_t (p_t^* - p_{t+s}^*)^2 \tag{1}$$

where β is restricted between zero and 1, p_{t+s}^* refers to the optimal price for period $t+s$ and future losses are discounted at rate $(\theta\beta)^s$.

Solving equation (1) with respect to the optimal value of price yields:

$$p_t^* = (1-\theta\beta) \sum_{s=1}^{\infty} (\theta\beta)^s E_t p_{t+s}^* \tag{2}$$

which means that the optimal price for the firm equals to the weighted average of its future prices. Assuming that this optimal price is defined as mark-up over prices, i.e. μ, then the optimal reset price can be written as:

$$p_t^* = (1-\theta\beta) \sum_{s=1}^{\infty} (\theta\beta)^s E_t (\mu + mc_{t+s}) \tag{3}$$

2.1 The New Keynesian Phillips Curve

The aggregate logarithmic price level in the Calvo model[2] is a weighted average of last period's aggregate price and the newly optimised logarithmic price or:

$$p_t = \theta p_{t-1} + (1-\theta) p_t^* \tag{4}$$

Combining equation (3) and (4) with further re-arrangement gives:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda mc_t + \epsilon_t \tag{5}$$

[2]For more detail about the derivation of the Phillips curve based on Calvo model see for example Goodfriend and King (1997).

where $\pi_t = p_t - p_{t-1}$ is the inflation rate at time t, E_t is the expectations operator conditional on time t information, mc_t refers to the firms' real marginal cost, λ is the response of current inflation to marginal cost and is defined as $\lambda = (1-\theta)(1-\theta\beta)/\theta$[3] and ϵ_t refers to random disturbances. Equation (5) is known as *New Keynesian Phillips Curve (NKPC).* This equation states that the current inflation is a function of next period's expected inflation and current marginal cost.

In the empirical literature on NKPC output gap is used to approximate marginal cost. The reason is that under some conditions, the deviation of marginal cost from its steady-state value is proportional to output gap.

$$mc_t = \varphi y_t^* = \varphi(y_t - y_t^n) \tag{6}$$

where y_t^* is output gap, y_t refers to actual output, y_t^n is the natural level of output and φ indicates the output elasticity of marginal cost.

Therefore, the NKPC based on output gap proxy can be shown as:

$$\pi_t = \beta E_t \pi_{t+1} + \gamma y_t^* + \epsilon_t \tag{7}$$

where $\gamma = \vartheta\varphi$. There were two reasons to terminate the use of output gap as the marginal cost proxy. First, as Dees et al. (2008) argue, if inflation is highly persistent, most probably I(1), it cannot be explained by output gap as it certainly is I(0) because it would imply approximating a very persistent variable by a rather low persistent series. Second, the obvious advantage of a marginal cost measure compared to output gap, as Gali and Gertler (1999) argued, is that it accounts for the direct impact of productivity gains on inflation.

On the other hand, the problem with marginal cost measure is that it cannot be directly observed. To solve this problem, however, it is assumed that firms' marginal cost is equal to the average marginal cost. Hence, Gali and Gertler argue that the marginal cost can be measured as the deviation of labour share of income from its steady-state value.

2.2 The hybrid New Keynesian Phillips Curve

Gali and Gertler (1999) hypothesised that among firms that reset their prices in a given period according to Calvo model, a share of ω use rule-of-thumb type of backward-looking in their price-setting. Thus, the share of forward-looking firms in their model is $\theta\,(1-\omega)$. Therefore, the new aggregate price level is given by:

$$p_t^* = \omega p_t^b + \theta(1-\omega)p_t^f \tag{8}$$

where p_t^b and p_t^f refer to prices set by backward-looking and forward-looking firms, respectively. With this setup, Gali and Gertler (1999) introduce the hybrid NKPC as follows:

[3]Note that the coefficient of marginal cost is decreasing in θ, which means that the higher the degree of price stickiness, the lowers is the sescitivity of inflation to changes in real marginal cost.

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda mc_t + \epsilon_t, \tag{9}$$

The coefficients γ_b, γ_f, and λ depend nonlinearly on the pricing parameters θ and ω and the time discount factor of the firm, β, as given in Gali and Gertler (1999):

$$\begin{aligned}
\gamma_b &= \omega\phi^{-1}, \\
\gamma_f &= \beta\theta\phi^{-1}, \\
\lambda &= (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1}, \\
\phi &= \theta + \omega[1 + \theta(1-\beta)].
\end{aligned}$$

Gali and Gertler (1999) estimated equation (9) for the US economy for the period of 1960:I-1997:IV and reported that the hybrid version of the NKPC captures the inflation dynamics. They also concluded that real marginal cost is a significant determinant of inflation in the US, and forward-looking behaviour dominates the backward-looking component. Since then this equation has been estimated by many authors in different countries, and its power in explaining the inflation dynamics has either been confirmed or rejected.

Gagnon and Khan (2005) estimated this equation for the US and Canada and provided some evidence that the choice of marginal cost proxy affects the importance of backward-looking component. Dufour et al. (2006) estimated this equation for the same countries and found that although the results provide support for the hybrid NKPC in the US economy, but it fails to capture the Canadian inflation dynamics.

Linde (2005) and Rudd and Whelan (2005), on the other hand, empirically shown that the hybrid NKPC is not the best formulation to capture inflation dynamics in the US. Their results indicated that the estimated hybrid NKPC using either the output gap or the marginal cost fails to explain reduced-form inflation equation. Roberts (2005) also questioned the validity of the hybrid NKPC due to the use of average labour productivity and shown that the models of inflation work better when including lags of inflation, hence he rejected the pure RE assumption. Gali et al (2005) responded to these criticisms by non-linear instrumental variable estimation of the structural form of the hybrid NKPC and continues to maintain the empirical validity of their formulation.

Cogley and Sbordone (2008) proposed an alternative mechanism to incorporate lags of inflation in the hybrid NKPC framework. They argued that to understand the degree of inflation persistence, variations in trend inflation should be modelled instead of assuming an ad-hoc rule-of-thumb behaviour or price indexation which lack microfoundation. This framework led to a time-varying coefficient NKPC with backward and forward-looking elements. The estimates of this equation for the US economy suggested that a pure forward-looking time-varying version of the NKPC fits the data better than other versions.

3 The Oil Price Shock Dates

There are several ways to explore oil price behaviour over time. A natural way to study its behaviour is to focus on considerable increases or decreases in oil prices known as oil shocks. One of the most popular ways of identifying oil shocks is to examine oil price reactions to oil supply disruptions. This is not trivial as Hamilton (2009) studied oil price behaviour through the main determinants of demand and supply and found that vulnerability of oil supply to macroeconomic disruptions is one of the key factors of broad oil price behaviour. Kilian (2008) also provided evidence for impact effects of oil shocks on macroeconomic variables such as real GDP growth and CPI inflation, but the effects appear with five quarters delay for the former and three quarters delay for the latter.

In the present paper, oil price shocks are defined as a sharp increase in the oil price caused by a substantial decline in the production of crude oil. In particular, the quarter associated with the largest percentage increase in oil price over a quarter has been selected as the oil price shock date. Therefore, the possible candidates that could make such an increase in oil prices since 1970 are: the Yom Kippur War in early October 1973 followed by Arab oil Embargo, Iranian Revolution in late 1978, Iran-Iraq War in late 1980, Gulf War in 1990, Venezuelan Unrest in early 2002, Iraq War in March 2003, and Libyan Uprising in February 2011.[4] Table 1 summarises these political events.

Early 1974 heralded the beginning of OPEC activity as a cartel to control crude oil production and prices. On the other hand, the Yom Kippur War started early October the same year with an attack on Israel by Syria and Egypt. The US and many other western countries supported Israel which led to a reaction by Arab countries and Iran to impose an embargo on Israel and its supporters. The net reduction in oil supply was about 4 million barrels per day. The resulting sharp increase in oil price occurred in the first quarter of 1974, when the nominal price of oil had quadrupled from $3.50 to more than $12.00 per barrel. Therefore, 1974:Q1 matches the definition of oil price shock in the present paper.

[4]The main sources for data and figures in this sections are: 1. International Energy Agency (IEA) online statistics available on: http://www.iea.org/stats/index.asp. 2. Organisation of the Petroleum Exporting Countries (OPEC) online database available on: http://www.opec.org/opec_web/en/data_graphs/40.htm. 3. West Texas Research Group (WTRG) website available on: http://www.wtrg.com/.

Table 1: Political Events that may Contribute to Oil Price Shocks due to Oil Supply Disruption

Dates	Political Event
October 1973	Yom Kippur War - Arab Oil Embargo
October 1978	Iranian Revolution
September 1980	Iran-Iraq War
August 1990	Gulf War
December 2002	Venezuelan Unrest
March 2003	Iraq War
February 2011	Libyan Uprising

Source: www.wtrg.com

The Iranian Revolution was the beginning of another round of oil price increases due to the decline in oil supply. The revolution resulted in the loss of 2.0-2.50 million barrels per day between November 1978 and June 1979, when price of oil increased by almost 37%. The revolution's effect on oil prices continued for another three quarters due to the subsequent political events in Iran. The second quarter of 1979, however, is the best match with the oil price shock criteria, as it contains the highest percentage increase in oil prices. This choice of the oil price shock date is consistent with Hamilton's (1983) and Kilian (2007 and 2008). Figure 1[5] shows the crude oil production by OPEC countries versus oil prices between 1973 and 2011.

There are two reasons that the Iran-Iraq War cannot be considered as an oil price shock date. First, as Kilian (2008) argued, by constructing a counterfactual, before the war and right after the Iranian revolution Iraq tripled its oil production which means that Iraq had offset ahead the possible decline during the war. Second, a period of rapidly increasing oil prices between 1979 and 1980 caused several reactions from oil consumers: improving insulation in homes, increasing energy efficiency in industrial sector and producing more fuel efficient cars. These factors along with a global recession caused a substantial reduction in oil demand, which led to lower oil prices.

The prices of crude oil spiked in August 1990 once again followed by lower production due to Iraqi invasion of Kuwait, known as Gulf War. The considerable decline in oil supply can be attributed to the harsh view of the Arab world of Saddam Hussein attacking an Arab country. The proximity of Kuwait to the world's largest oil producer, Saudi Arabia, helped to shape the reaction. Crude oil prices rose by 47% in August 1990 over the previous month, hence 1990:Q3 will be the third oil price shock date which is consistent with Hamilton (2003) and Kilian (2008).

Venezuelan unrest in early 2002 led to a general oil strike in December 2002, resulting in a decline in oil production of the country, but it did not cause a considerable increase in oil prices because, in mid-2002, there were six million barrels of excess capacity in the world market. Kilian (2007 and 2008) also rejected the occurrence of the oil shock in

[5]The source for Figure 1 and Figure 2 is www.wtrg.com.

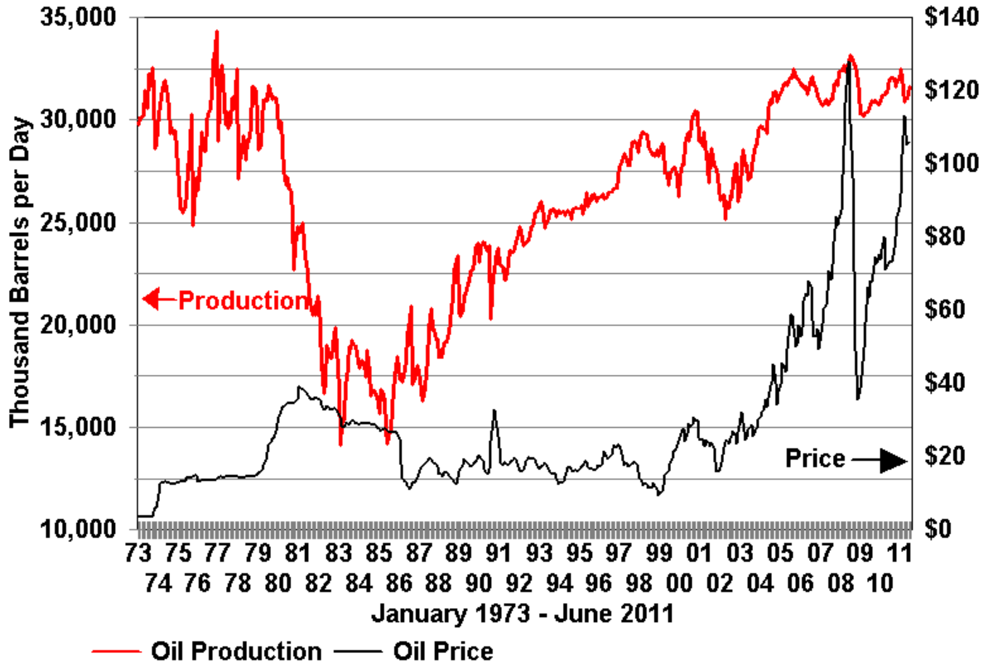

Figure 1: Crude Oil Production of OPEC Countries vs. Oil Price

2002:Q4.

Right after the Venezuelan strike, the US and the UK invaded Iraq on March 20, 2003. In the meantime, the improvement in the US and Asian economies increased demand for oil. The reduction in oil production in Venezuela and Iraq, led to decline in excess oil production capacity, to two million barrels in mid-2003, but it was still enough to cover the disruption in oil supply and avoid the ensuing jump in oil prices. The upward trend of the oil prices afterwards can be attributed to the global recession.

Oil prices jumped again due to the loss of Libyan oil production as a result of the Libyan uprising in February 2011. Although, this event accords with the oil shock definition in the present paper, but the small sample length after 2011:Q1 does not allow analysing the effect of this shock on firms' pricing behaviour. Figure 2 summarises the world events that may contribute to oil price increases.

4 Econometric Specification

One of the common techniques to estimate equation (9) is the Generalised Method of Moment (GMM) approach first introduced by Hansen (1982). Gali and Gertler (1999), Clarida, Gali and Gertler (2000), Rudd and Whelan (2005), Gali, Gertler and Lopez-Salido (2001 and 2005), Bardsen et al. (2004), Fuhrer (2005), Dufour, Khalaf and Kichian (2006), Zhang, Osborne and Kim (2006 and 2008), Dees et. al (2008), Nason and Smith (2008)

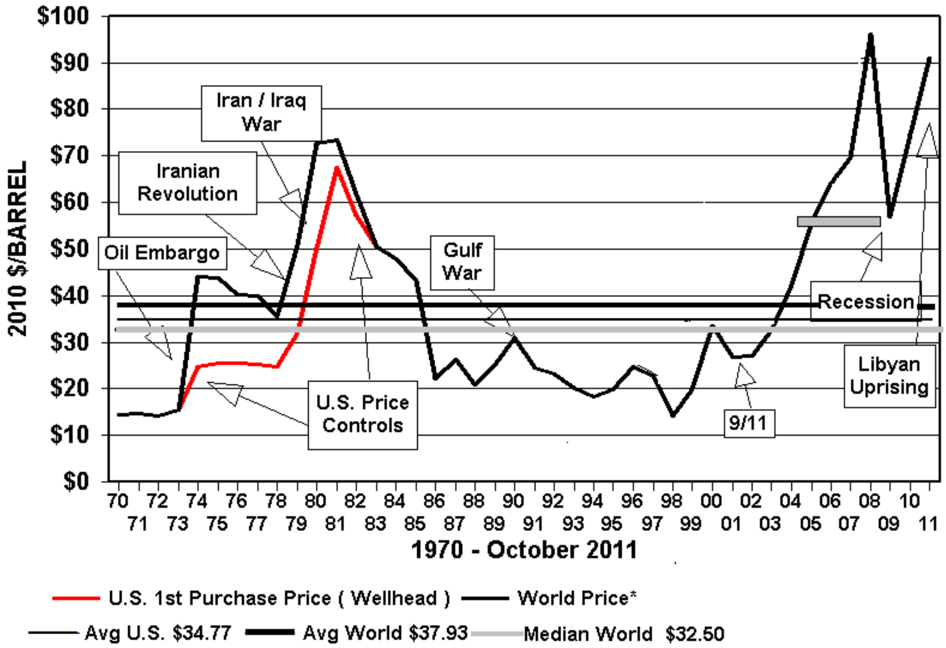

Figure 2: Crude Oil Prices Based on 2010 Dollars and World Events

and Kleibergen and Mavroeidis (2009) are examples where the GMM technique has been used to estimate the NKPC equation.[6]

In the present paper the hybrid NKPC in equation (9) is estimated for two different specifications of orthogonality conditions, i.e. with and without multiplying ϕ on both sides of equation (9), to avoid the small sample normalisation problem,

$$Specification1 : E_t \{(\phi\pi_t - (1-\omega)(1-\theta)(1-\beta\theta)s_t - \theta\beta\pi_{t+1})z_t\} = 0 \tag{10}$$

$$Specification2 : E_t \left\{(\pi_t - (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1}s_t - \theta\beta\phi^{-1}\pi_{t+1})z_t\right\} = 0 \tag{11}$$

To investigate the effect of oil price shocks on firms' pricing behaviour in the context of the hybrid NKPC, equation (9) has been estimated for two above specifications, two different measures of real marginal cost and two different sets of instruments detailed in section 6.1.

4.1 GMM Drawbacks

Despite the popularity of GMM estimation of the NKPC equation in the literature, it has several drawbacks that cannot be ignored. These well-known shortcomings are listed below:

[6]For a comprehensive discussion about the GMM estimation method, see Davidson and MacKinnon (1993), Hall (1993), Newey and McFadden (1994), Mátyás (1999) and Hall (2005).

1. The most important drawback of the standard GMM estimation is its finite sample properties. In other words, when the number of moment conditions increases and the sample size is small, the GMM estimates and their standard errors may deviate from the nominal asymptotic properties. Tauchen (1986), Kocherlakota (1990), Eichenbaum and Hansen (1990), Ferson and Foerster (1994), Anderson and Sorensen (1996), Hansen, Heaton and Yaron(1996) and Altonji and Segal (1996) all studied the small sample behaviour of GMM estimation in different contexts and all agreed that this estimator is highly sensitive to the choice of instruments and length of sample and at least under some circumstances both coefficient estimates and the estimated standard errors sharply deviate from asymptotic properties. Altonji and Segal (1996) and Hansen, Heaton and Yaron(1996) among others focused on the strength of different types of GMM estimator. The former applied the standard GMM estimator in simulating the covariance structure model and found that surprisingly a two-step GMM estimator produces more biased results than a GMM estimator based on the identity weighting matrix. Hansen, Heaton and Yaron, on the other hand, compared the two-step and iterated GMM estimators and reported that both of them produce biased estimates. Although they initially introduced repeatedly iterated estimator instead of the two-step estimator to cope with small sample properties, it produced even worse results.

2. The second drawback of the standard GMM estimator, as Newey (1985) suggested, was the validity of the J test in misspecified models. He argued that although in a misspecified model some of the moment conditions are not valid but the J statistics still converges to a chi-squared distribution. This is more probable in a structurally unstable model, see for example, Ghysels and Hall (1990). The strength of the J test has also been questioned by Kocherlakota (1990) who found evidence that this test often rejects the true null hypothesis.

3. Another problem with the standard GMM estimator is that it is sensitive to the choice of the initial weighting matrix. As Ramalho (2002) explained, the use of a consistent estimate of the optimal weighting matrix instead of estimating it jointly with model parameters can lead to sensitivity of GMM estimator to the choice of the initial weighting matrix. Therefore, the GMM estimator is not invariant to linear transformations of the original moment conditions, unless the number of parameters is equal to the number of moment conditions.

4.2 Continuous-Updating GMM (CU-GMM) Estimation

The problems of the conventional GMM estimator that Eichenbaum and Hansen (1990) encountered in terms of biased estimations etc. were the starting point of Hansen, Heaton and Yaron (1996). They conducted Monte Carlo experiments to find an alternative one-step estimator in which the weighting matrix and the parameters are estimated simultaneously and it is also invariant to parameter-dependant transformations of moment indicator. This estimator is called Continuous-Updating GMM or CU-GMM for short. The other positive properties of this estimator is that although the tails of this estimator are fatter, it has a smaller median bias in finite samples than the standard GMM estimator and the

J test statistics for overidentifying restrictions in many cases are more reliable. Stock and Wright (2000) studied this estimator by applying a simulation technique and they found similar findings as Hansen, Heaton and Yaron(1996). Newey and Smith (2000) and Bonnal and Renault (2000) also focused on the properties of the CU-GMM estimator and shown how to nest the continuously updated estimator into a class of estimators that includes empirical likelihood.

It is worth mentioning that the weighting matrix in the CU-GMM estimator can no longer be considered as a non-random matrix and because of the nature of this estimator, the limiting distribution of the CU-GMM is not distorted relative to the standard version of the estimator. So, these two estimators are asymptotically equivalent and all specification tests could also be examined by the CU-GMM estimator, see for example Ramalho(2002).

In the present paper equation (9) is also estimated by the CU-GMM estimator in order to see if the structural stability of the hybrid NKPC in the presence of oil shocks is affected by the aforementioned GMM drawbacks.

5 Structural Stability Test

The recent econometric literature contains a considerable amount of work on structural changes that can be classified in four categories including single and multiple known changes as well as single and multiple unknown changes (breaks). In known structural break tests the data are partitioned into different subsamples generated by the given break date and the original equation is re-estimated for each of the subsamples. It is worth mentioning that in this type of test, the variance-covariance matrix of the error term vary between the subsamples. When the change point is unknown the same method of estimation is used but now the change point is the point where the Wald statistics is a global maximum point and then the sample is splitted into subsamples according to this point.

Another line of research in the structural change literature is to consider this test in linear and non-linear models. Quandt (1958) and then Chow (1960) discussed the structural change by F-statistics for a linear regression model. The most popular test statistics in the linear context, however, are Wald statistics studied by Hawkins (1987) and Andrews (1993), optimal test of Andrews and Polberger (1994) and fluctuation test of Ploberger, Kramer and Kontrus (1989). Lo and Newey (1985) designed a new test for linear simultaneous equations models. Chu (1989), Banerjee, Lumsdaine and Stock (1992) and Hansen (1992) also focused on linear regression models. Furthermore, Bai (1994 and 1997) investigated for the structural change in the linearly dependent stochastic processes.

On the other hand, the multiple structural break tests in linear models recently received more attention. Bai and Perron (1998 and 2002) are two examples of works in this context studying limiting distribution of estimators in linear models. Bai and Perron (1998) considered multiple structural break points, and they developed this idea in Bai and Perron (2002) by applying the same method for pure and partial structural changes. Andrews, Lee and Ploberger (1996), Garcia and Perron (1996), Wu and Zidek (1997), Morimune and Nakagawa (1997), Hansen (2001), Andreou and Ghysels (2002), Narayan (2006), Perron and Qu (2006) and Blander (2008) are some other examples of empirical work on multiple known structural break tests. Hall et al. (2010), however, proposed tests for multiple unknown structural breaks for linear models with endogenous regressors. They also reported evidence of two structural breaks in estimations of the linear hybrid NKPC in the US data for the period of 1968:III-2001:IV. The two break dates that they found for this set of data were 1975:II and 1981:I. Their first break date is the same as that found by Zhang, Osborne and Kim (2008), who conduct tests of single structural break.

The influential paper by Andrews and Fair (1988) established another line of research in structural change by introducing a new test for single break point test in non-linear regression models with endogenous variables, namely Wald, Lagrange-multiplier type and likelihood ratio-like test statistics. Hansen (1990) also used Wald test to conduct the single structural break test in a non-linear model. Andrews (1993) extended this test to include tests for parameter instability and structural breaks with unknown change points in parametric models mostly estimated by GMM. Hansen (2000) drived the large sample properties of unknown structural break point tests allowing for structural change in the marginal distributions of the regressors.

Although the multiple structural point tests are well developed for linear models, tests of multiple unknown structural break points in nonlinear models are yet to be developed. This reason plus the fact that in the present paper structural stability of NKPC has been investigated in presence of known oil price shocks, the most suitable test is the structural break test with known dates. Therefore, the structural stability of equation (9) parameters estimated by GMM and CU-GMM over subsamples separated by oil shock dates is investigated using the Andrews-Fair (1988) Wald test as well as the Andrews-Fair Likelihood-Ratio (LR) type test. The reason for choosing these two test is that they are the most appropriate tests for known break date tests for GMM-type estimators. This helps to make sure that the identified oil price shocks are indeed the right choices to break the data. The third test that is conducted for the NKPC equation is Hall and Sen's (1999) overidentification restriction J test.[7]

5.1 Andrews-Fair (1988) Wald Test

The Wald-type statistics can be considered as a distance measure between the estimates of pre-change point and post-change point parameters. If the change point is correctly identified, this distance will be maximised. Wald statistics can be also thought of as "between sample variance" if different distributions are considered for pre- and post- change point samples (Bai, 1993). The Andrews-Fair Wald test is used for a single known structural break case and tests the null hypothesis that there are no structural breaks in the equation parameters. This statistic is calculated by the following formula:

$$AF_1 = (\theta_1 - \theta_2)'(\frac{1}{T_1}V_1^{-1} + \frac{1}{T_2}V_2^{-1})(\theta_1 - \theta_2) \quad (12)$$

where θ_i refer to estimated coefficients for subsample i , T_i represents the number of observations in subsample i and V_i refers to the variance-covariance matrix for subsample

[7]The reasons for this test is simply because the assumption that the instruments are not correlated with the error term is not testable in exactly identified models.

i.

In the present paper, this test has been conducted for four different specification of the GMM setup, two different instrument sets (Gali and Gertler (1999) and Gali et al. (2005)) and two different marginal cost measures (Cogley and Sbordone (2008) and Nason and Smith (2008)). Three single oil shock dates are used as break points, i.e. 1974:I, 1979:II and 1990:III. The results for this test with Gali et al. (2005) instrument set (GG05, henceforth) are reported in Table 2 and results with Gali and Gertler (1999) instrument set (GG99, henceforth) are reported in Table 3.

As can be seen in the third columns of Table 2 and 3, headed by AF_1, according to standard GMM estimates there is structural break in equation (9) parameters in identified oil shock dates except for the last GMM specification in which the Andrews-Fair Wald statistics for 1990:III are not as strong as other specifications to reject the null hypothesis of no structural stability.

The most powerful break date is 1974:I as expected because the oil price increase for this quarter was the largest increase amongst others. Although the test statistic for the 1979:II break date in the last specification proves to be too weak to reject the null, it does not affect this choice of break dates as it is strong enough in other specifications. If the estimator is CU-GMM then the Wald statistics are much larger in value in general, ranging from 28.119 to 90.876 with the p-values always being zero, so that it strongly rejects the null hypothesis of no structural breaks almost in all cases.

5.2 Andrews-Fair LR Type Test

The null hypothesis for this test is exactly the same as the Andrews-Fair Wald statistics. The LR type test is a comparison between J-statistics for different subsample estimates and the statistic is calculated as:

$$AF_2 = J_R - (J_1 + J_2) \tag{13}$$

where J_R is the J-statistic calculated with the residuals for the original equation, but in the associated GMM estimation the weighting matrix equals to the weighted (by the number of observations) sum of the estimated weighting matrices for each of the subsample estimates.

The Andrews-Fair LR-type test statistics for different specifications are reported in the fourth columns of Table 2 and Table 3, headed by AF_2.

The results for the Likelihood-Ratio test confirms the previous results in general, particularly in the first two specifications of the GMM setup in which the statistics for the first oil shock with standard GMM estimator, i.e. 1974:I, is too large at 18860.75 and 974.21 with zero p-values. The results for break point test for the CU-GMM estimator also rejects the null hypothesis of no structural break.

According to these two sets of results, it can be said that the identified oil price shock dates seem to be the correct break dates in the tests of the structural stability of the hybrid NKPC.

Table 2: Structural Stability and Over-Identifying Test Statistics for Identified Oil Shock Dates with GG05

GMM Specification	Oil Shock Dates		AF_1	AF_2	O_T
1. GG05 Inst. set and C&S MC	1974:I	(1)	10.203 (0.000)	18860.75 (0.000)	4.011 (0.986)
		(2)	35.221 (0.000)	260.761 (0.000)	1.032 (0.765)
	1979:II	(1)	10.251 (0.005)	7.314 (0.065)	7.502 (0.859)
		(2)	28.731 (0.000)	121.409 (0.000)	1.123 (0.889)
	1990:III	(1)	8.060 (0.004)	7.431 (0.059)	5.481 (0.998)
		(2)	24.764 (0.000)	60.201 (0.000)	1.876 (0.954)
2. GG05 Inst. set and N&S MC	1974:I	(1)	10.570 (0.000)	974.21 (0.000)	6.24 (0.801)
		(2)	90.876 (0.000)	301.432 (0.000)	2.087 (0.834)
	1979:II	(1)	10.933 (0.000)	9.123 (0.008)	5.96 (0.698)
		(2)	89.245 (0.000)	93.780 (0.000)	1.901 (0.745)
	1990:III	(1)	8.932 (0.008)	9.543 (0.010)	7.46 (0.743)
		(2)	48.340 (0.000)	67.245 (0.000)	2.001 (0.823)

Notes: A 12-lag Newey-West estimator of the covariance matrix is used in the GMM estimation for 1954:III-2010:IV period for every GMM specification and then structural break tests are conducted for each one. (1) refers to break point test for standard GMM estimator. (2) indicates results for structural break tests based on CU-GMM estimator. The p-values are reported in parentheses.

5.3 Hall and Sen's (1999) Test of Over-Identifying restrictions

The null hypothesis for this test is the structural stability of the over-identifying (OID henceforth) restrictions across two subsamples. The structural stability in this sense allows for the parameters to take on different values in each subsample, as long as the OID restrictions are met in both subsamples. The idea is that if the OID restrictions are rejected in either subsample, then the model specification does not hold in at least one subsample. The parameter estimates obtained in these subsamples should therefore not be considered consistent for the whole sample. In addition, the whole-sample parameter estimates do not apply to subsamples. The Hall and Sen (1999) test statistic is constructed as the sum of the two Hansen's J statistics for testing OID restrictions in each of the two subsamples.

$$O_T = J_1 + J_2 \tag{14}$$

Table 3: Structural Stability and Over-Identifying Test Statistics for Identified Oil Shock Dates with GG99

GMM Specification	Oil Shock Dates		AF_1	AF_2	O_T
1. GG99 Inst. set and C&S MC	1974:I	(1)	11.324 (0.000)	12.563 (0.005)	14.43 (0.654)
		(2)	31.712 (0.000)	60.214 (0.000)	1.342 (0.671)
	1979:II	(1)	10.765 (0.013)	3.082 (0.379)	17.62 (0.701)
		(2)	28.119 (0.000)	58.874 (0.000)	2.065 (0.763)
	1990:III	(1)	9.765 (0.000)	2.652 (0.448)	10.62 (0.598)
		(2)	34.337 (0.000)	24.665 (0.000)	3.823 (0.714nb)
2. GG99 Inst. set and N&S MC	1974:I	(1)	10.570 (0.000)	11.453 (0.004)	22.442 (0.745)
		(2)	42.543 (0.000)	78.421 (0.000)	3.241 (0.592)
	1979:II	(1)	2.933 (0.417)	4.653 (0.245)	17.521 (0.845)
		(2)	45.654 (0.000)	48.213 (0.000)	1.360 (0.731)
	1990:III	(1)	1.932 (0.718)	3.127 (0.385)	16.414 (0.586)
		(2)	37.476 (0.000)	72.145 (0.000)	1.873 (0.629)

Notes: A 12-lag Newey-West estimator of the covariance matrix is used in the GMM estimation for 1954:III-2010:IV period for every GMM specification and then structural break tests are conducted for each one. (1) refers to break point test for standard GMM estimator. (2) indicates results for structural break tests based on CU-GMM estimator. The p-values are reported in parentheses.

Under the assumption of zero covariance of partial sums in the limit, this statistic converges to a chi-squared distribution with the degree of freedom given by $2(q-p)$, where q is the number of orthogonality conditions and p is the number of parameters to be estimated.[8]

The last columns of Table 2 and 3, headed by O_T, report the Hall and Sen (1990) statistics for testing structural stability in the over-identifying (OID) restrictions. For every pair of subsamples separated by an oil shock date, the null hypothesis of structural stability in the OID restrictions is not rejected at the conventional significance levels for both standard GMM and CU-GMM estimators. These results are not surprising, because almost every Hansen's J statistic in the last column of Tables 4 to 19 (headed by J) fails to reject the orthogonality conditions implied by the hybrid NKPC. Therefore, the O_T statistic, being the sum of two J statistics, is never sufficiently large enough to warrant rejection of the null of structural stability.[9]

[8] See pp. 172-173 of Hall (2005) for the partial sums assumption.

[9] However, these non-rejections may at least partly reflect the possibly low power of the J test. Another possibility is that the assumption of zero covariance of the partial sum may have failed to hold in the moderate to small sample sizes of our data when using the standard GMM technique, due to the use of four and two lags for instruments.

6 Results

6.1 Data

The hybrid NKPC with constant slope coefficients has been estimated using the 2-step GMM, following Gali et al (2005). The quarterly US aggregate data covering 1954:III-2010:IV are used to estimate this equation. Inflation is measured as the percentage change in the GDP deflator. Following Gali and Gertler (1999), the deviation of the labour share of the non-farm business sector from its steady-state value is used to approximate the real marginal cost, and two measures of the labour share variable according to the description in Nason and Smith (2008) and that in Cogley and Sbordone (2008) are constructed. To make these sets of results comparable with those reported in Gali and Gertler (1999) and Gali et al. (2005), the same instruments as theirs are used.

To study the impact of oil price shocks on the structural stability of the hybrid NKPC, firstly the sample is divided into two parts using the 1974 Oil Crisis. Therefore, the first subsample is from 1954:III to 1973:IV, and the second covers the period 1974:I-2010:IV. Then looking into two other subsamples starting from the oil shock dates 1979:II and 1990:III and ending in 2010, the hybrid NKPC is also estimated for three more subsamples to cover the pre-oil shock periods between each of the oil shock dates. These are 1954:III-1979I, 1954:III-1990:II and 1974:I-1990II. These sets of estimation could reflect the impact of oil shock on structural stability more precisely. The hybrid NKPC equation is also estimated for the same sample period of Gali et al. (2005) and Gali and Gertler (1999), i.e. 1960I-1997IV, which allows for a more realistic comparison of our choice of instruments.

The empirical results for the GG99 constant-coefficient hybrid NKPC are reported in Tables 4 to 7. The results for GG05 are presented in Tables 8 to 11. These are four tables for each instrument set, because there are two sets of results for two real marginal cost measures and two sets of results for two normalisations of the orthogonality conditions, i.e. with and without multiplying ϕ on both sides of equation (9).

6.2 Results for GMM Estimation of the Hybrid NKPC with the Gali and Gertler (1999) Instrument Set

The GG99 instrument set includes the first four lags of price inflation, labour share income, HP-filter detrended output gap, long-short interest rate spread, nominal wage inflation and commodity price inflation. Table 4 is based on the specification of the orthogonality conditions that multiply ϕ on both sides of the Gali and Gertler (1999) hybrid NKPC equation, and the Cogley and Sbordone (2008) measure of the real marginal cost. The results in this table indicate that there is evidence of structural instability in ω and λ. The range of ω estimates is from 0.09 to 0.62, and the range of λ estimates is from 0.0007 to 0.031. The λ estimates are, however, statistically insignificant but always of the correct sign. The estimates of β and θ are reasonably stable over various subsamples. In terms of the backward- and forward-looking parameters γ_b and γ_f, there are also considerable variations overall. For example, γ_b changes from 0.11 to 0.71 across subsamples.

The γ_f estimates for all subsamples except for the post 1979:II and the post 1990:III subsamples, 0.29 and 0.39, indicate that the forward-looking behaviour is predominant in whole sample as well as pre-oil shock periods as in Gali and Gertler (1999).

The results for estimating the hybrid NKPC without multiplying ϕ on both sides of the hybrid NKPC equation, presented in Table 5. There are three major changes in this table relative to the results just described for the previous table. First, the number of statistically insignificant λ estimates has diminished so much that only for 1954:III-1990:III and 1990:III-2010:IV subsamples λ is insignificantly estimated. Second, the strength of forward-looking behaviour is estimated to be slightly smaller than in the previous table, although the share of forward-looking firms still dominates that for backward-looking firms. The third difference is that β estimates exceeds one in four subsamples, but it can be said that they are still stable as the estimates fluctuate in the 0.16 range. The other aspects of this table, in terms of structural stability of Calvo parameters, are very similar to Table 4.

Table 4: Nonlinear GMM Estimation of Specification 1 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.31	0.88	0.99	0.32	0.68	0.002	6.03
	(0.16)	(0.03)	(0.02)	(0.08)	(0.07)	(0.001)	(0.12)
1954:III-1973:IV	0.13	0.79	0.87	0.12	0.88	0.004	6.57
	(0.01)	(0.03)	(0.03)	(0.01)	(0.07)	(0.004)	(0.92)
1974:I-2010:IV	0.51	0.90	0.99	0.41	0.59	0.0007	7.86
	(0.19)	(0.07)	(0.03)	(0.08)	(0.05)	(0.001)	(0.91)
1954:III-1979:I	0.12	0.81	0.88	0.14	0.86	0.005	9.46
	(0.01)	(0.02)	(0.01)	(0.00)	(0.05)	(0.002)	(0.95)
1979:II-2010:IV	0.29	0.94	1.00	0.71	0.29	0.004	8.16
	(0.06)	(0.05)	(0.00)	(0.09)	(0.04)	(0.001)	(0.85)
1954:III-1990:II	0.09	0.83	0.94	0.11	0.89	0.010	4.81
	(0.00)	(0.02)	(0.01)	(0.02)	(0.12)	(0.005)	(0.90)
1990:III-2010:IV	0.62	0.91	1.00	0.61	0.39	0.005	5.85
	(0.07)	(0.07)	(0.05)	(0.16)	(0.01)	(0.006)	(0.91)
1960:I-1997:IV	0.44	0.83	0.92	0.27	0.73	0.012	6.04
	(0.11)	(0.06)	(0.02)	(0.07)	(0.05)	(0.004)	(0.86)
1974:I-1990:II	0.23	0.81	0.90	0.35	0.65	0.031	7.71
	(0.09)	(0.05)	(0.03)	(0.06)	(0.28)	(0.010)	(0.94)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

The ω and θ estimates for the Gali and Gertler (1999) sample period reported in the penultimate rows of Table 4 to 7, are quite close to Table 2 of Gali and Gertler (1999), but β estimates differ by 10% in both specifications. The difference between γ_b and γ_f could be due to the assumption of $\gamma_b + \gamma_f = 1$. Problematic λ estimates are also considerably different.

Table 5: Nonlinear GMM Estimation of Specification 2 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.50 (0.10)	0.89 (0.00)	1.03 (0.03)	0.44 (0.11)	0.56 (0.11)	0.005 (0.002)	8.12 (0.13)
1954:III-1973:IV	0.21 (0.00)	0.76 (0.01)	0.89 (0.03)	0.23 (0.04)	0.77 (0.12)	0.007 (0.003)	5.37 (0.81)
1974:I-2010:IV	0.60 (0.12)	0.94 (0.07)	1.02 (0.13)	0.51 (0.05)	0.49 (0.02)	0.009 (0.002)	7.64 (0.70)
1954:III-1979:I	0.24 (0.05)	0.84 (0.10)	0.90 (0.00)	0.28 (0.07)	0.72 (0.07)	0.008 (0.001)	5.66 (0.73)
1979:II-2010:IV	0.49 (0.16)	0.99 (0.02)	1.05 (0.05)	0.79 (0.15)	0.21 (0.02)	0.006 (0.002)	8.04 (0.63)
1954:III-1990:II	0.23 (0.03)	0.86 (0.03)	0.96 (0.07)	0.27 (0.08)	0.73 (0.22)	0.013 (0.008)	6.73 (0.72)
1990:III-2010:IV	0.52 (0.01)	0.94 (0.01)	1.03 (0.08)	0.67 (0.19)	0.33 (0.09)	0.007 (0.008)	5.90 (0.24)
1960:I-1997:IV	0.55 (0.11)	0.85 (0.02)	0.95 (0.01)	0.39 (0.14)	0.61 (0.05)	0.014 (0.003)	7.26 (0.51)
1974:I-1990:II	0.35 (0.11)	0.82 (0.01)	0.91 (0.06)	0.41 (0.13)	0.59 (0.02)	0.029 (0.001)	5.27 (0.84)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 2. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

The results based on an alternative measure of the real marginal cost due to Nason and Smith (2008) are presented in Tables 6 and 7. Perhaps the most substantive change that this measure of real marginal cost produces is in λ estimates: they are statistically significant in all subsamples except for 1979:II-2010:IV. Now, however, ω and γ_b estimates are insignificant in three pre-oil shock and one post-oil shock sample.

Table 6: Nonlinear GMM Estimation of Specification 1 with Real Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.21 (0.09)	0.90 (0.03)	0.99 (0.007)	0.27 (0.10)	0.72 (0.10)	0.007 (0.002)	8.46 (0.68)
1954:III-1973:IV	0.43 (0.24)	0.92 (0.03)	0.95 (0.03)	0.13 (0.19)	0.87 (0.19)	0.021 (0.01)	11.56 (0.92)
1974:I-2010:IV	0.51 (0.20)	0.91 (0.07)	0.99 (0.04)	0.36 (0.09)	0.64 (0.09)	0.003 (0.003)	10.88 (0.53)
1954:III-1979:I	0.21 (0.17)	0.85 (0.03)	0.97 (0.05)	0.20 (0.13)	0.78 (0.12)	0.020 (0.01)	8.21 (0.95)
1979:II-2010:IV	0.30 (0.07)	0.95 (0.05)	1.03 (0.01)	0.24 (0.04)	0.38 (0.04)	0.0007 (0.002)	9.41 (0.88)
1954:III-1990:II	0.14 (0.10)	0.85 (0.01)	0.99 (0.01)	0.14 (0.09)	0.85 (0.08)	0.022 (0.005)	6.39 (0.79)
1990:III-2010:IV	0.17 (0.19)	0.89 (0.05)	1.00 (0.05)	0.16 (0.15)	0.65 (0.16)	0.008 (0.003)	4.27 (0.87)
1960:I-1997:IV	0.33 (0.11)	0.86 (0.02)	0.98 (0.01)	0.28 (0.07)	0.71 (0.07)	0.014 (0.004)	7.61 (0.73)
1974:I-1990:II	0.53 (0.12)	0.81 (0.04)	0.92 (0.03)	0.41 (0.07)	0.57 (0.06)	0.023 (0.005)	8.21 (0.31)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

The estimates of other Calvo parameters do not seem to vary substantially across subsamples, although the θ and β estimates seem to be larger with the second measure of real marginal cost. Again, the J statistics fail to reject the OID restrictions, just as in the previous two tables. The number of insignificant estimates of ω reduces to two in the second specification of orthogonality condition, but there are still four insignificant estimates of γ_b in Table 6. λ estimates are smaller in value in general but they are insignificantly estimated just for two subsamples, i.e. 1974:I-2010:IV and 1979:II-2010:IV.

Non-linear GMM estimation of hybrid NKPC using GG99 instrument set suggests that no matter which measure of marginal cost is used and which specification is estimated, the forward-looking behaviour is always dominant in the whole sample. It seems, however, that this is just true for pre-oil shock periods because as Tables 4 to 7 show, the forward-looking behaviour loses ground against the backward-looking after every oil shock. The same pattern can be seen in ω estimates where the fraction of backward-looking firms also increases in post-oil shock subsamples, but other structural parameters are almost invariant to oil shocks. The largest decline always takes place in the 1974:I-2010:IV subsample with the largest increase in oil prices. Although the decrease in the forward-looking share is smaller when the Nason and Smith (2008) measure of marginal cost is used, especially in Table 7 in which γ_f is greater in the post 1990:III oil shock period, the general conclusion of structural instability of the hybrid NKPC in the presence of oil price shock is still valid.

Table 7: Nonlinear GMM Estimation of Specification 2 with Real Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.42 (0.12)	0.92 (0.01)	0.98 (0.01)	0.29 (0.08)	0.71 (0.10)	0.005 (0.002)	6.26 (0.68)
1954:III-1973:IV	0.55 (0.35)	0.95 (0.02)	0.97 (0.08)	0.33 (0.24)	0.67 (0.19)	0.012 (0.005)	3.34 (0.70)
1974:I-2010:IV	0.64 (0.14)	0.96 (0.04)	1.06 (0.14)	0.41 (0.05)	0.59 (0.09)	0.001 (0.003)	6.73 (0.43)
1954:III-1979:I	0.33 (0.25)	0.90 (0.08)	1.00 (0.05)	0.29 (0.15)	0.71 (0.12)	0.015 (0.004)	7.09 (0.56)
1979:II-2010:IV	0.39 (0.04)	1.12 (0.02)	1.04 (0.07)	0.44 (0.07)	0.56 (0.04)	0.008 (0.001)	4.27 (0.44)
1954:III-1990:II	0.26 (0.13)	0.88 (0.05)	0.99 (0.10)	0.36 (0.19)	0.64 (0.08)	0.018 (0.006)	4.26 (0.54)
1990:III-2010:IV	0.28 (0.10)	0.97 (0.07)	1.09 (0.12)	0.27 (0.23)	0.73 (0.16)	0.004 (0.003)	6.40 (0.82)
1960:I-1997:IV	0.45 (0.14)	0.91 (0.03)	0.99 (0.06)	0.37 (0.01)	0.67 (0.07)	0.011 (0.005)	3.41 (0.71)
1974:I-1990:II	0.58 (0.14)	0.87 (0.06)	0.98 (0.05)	0.53 (0.09)	0.47 (0.06)	0.019 (0.002)	6.01 (0.21)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 2. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

6.3 Results for GMM Estimation of the Hybrid NKPC with the Gali and Gertler (2005) Instrument Set

The GG05 instruments set includes the first two lags of real marginal cost, HP-filter detrended output gap, nominal wage inflation, and four lags of price inflation. The hybrid NKPC is again estimated non-linearly for two different real marginal cost measures and two specifications in equations (10) and (11). The results for both specifications using Cogely and Sbordone (2008) real marginal cost measure is reported in Table 8 and Table 9.

Although the range of λ estimates is now narrower from 0.0008 to 0.020, it is significantly estimated just for two subsamples. Almost the same range as Table 4 can be seen for ω estimates and the forward- and backward-looking components still suffer from non-ignorable variations. θ and β estimates seem to be stable over subsamples ranging from 0.82 to 0.98 in the former and from 0.92 to 1.00 in the latter.

The same pattern of structural instability can be seen in Table 9 when the hybrid NKPC is estimated without multiplying ϕ on both sides of equation (9). Despite the larger values for structural parameters they are varying over the same range. γ_b and γ_f estimates, however, are more stable than before, moving in a 0.29 range, and λ is significantly estimated only for three subsamples.

Table 8: Nonlinear GMM Estimation of Specification 1 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.33 (0.06)	0.97 (0.03)	0.98 (0.009)	0.26 (0.04)	0.73 (0.04)	0.0008 (0.001)	3.21 (0.11)
1954:III-1973:IV	0.09 (0.05)	0.88 (0.02)	0.90 (0.02)	0.10 (0.05)	0.82 (0.04)	0.020 (0.007)	1.89 (0.13)
1974:I-2010:IV	0.64 (0.14)	0.93 (0.09)	0.96 (0.04)	0.41 (0.05)	0.58 (0.05)	0.001 (0.004)	2.12 (0.22)
1954:III-1979:I	0.35 (0.14)	0.91 (0.08)	0.97 (0.03)	0.28 (0.07)	0.71 (0.07)	0.006 (0.009)	3.17 (0.44)
1979:II-2010:IV	0.50 (0.14)	0.91 (0.05)	1.00 (0.04)	0.35 (0.06)	0.65 (0.06)	0.002 (0.003)	4.33 (0.26)
1954:III-1990:II	0.29 (0.13)	0.90 (0.04)	0.97 (0.01)	0.25 (0.08)	0.73 (0.08)	0.008 (0.007)	3.14 (0.03)
1990:III-2010:IV	0.49 (0.17)	0.98 (0.14)	0.97 (0.04)	0.34 (0.06)	0.65 (0.07)	0.003 (0.003)	2.34 (0.12)
1960:I-1997:IV	0.27 (0.09)	0.82 (0.04)	0.98 (0.02)	0.33 (0.05)	0.67 (0.05)	0.006 (0.003)	5.22 (0.10)
1974:I-1990:II	0.36 (0.13)	0.88 (0.09)	0.92 (0.06)	0.48 (0.04)	0.51 (0.04)	0.003 (0.002)	6.20 (0.18)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

Table 9: Nonlinear GMM Estimation of Specification 2 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.55	0.99	1.00	0.39	0.61	0.0009	3.98
	(0.16)	(0.08)	(0.010)	(0.02)	(0.09)	(0.002)	(0.25)
1954:III-1973:IV	0.31	0.90	0.92	0.36	0.64	0.018	2.47
	(0.09)	(0.04)	(0.04)	(0.03)	(0.02)	(0.004)	(0.33)
1974:I-2010:IV	0.85	0.95	0.98	0.65	0.35	0.003	1.56
	(0.08)	(0.11)	(0.05)	(0.03)	(0.09)	(0.003)	(0.33)
1954:III-1979:I	0.57	0.93	0.99	0.49	0.51	0.008	4.89
	(0.25)	(0.10)	(0.05)	(0.05)	(0.17)	(0.009)	(0.66)
1979:II-2010:IV	0.72	0.94	1.04	0.57	0.43	0.003	2.62
	(0.14)	(0.07)	(0.06)	(0.09)	(0.11)	(0.001)	(0.48)
1954:III-1990:II	0.41	0.92	0.99	0.45	0.55	0.010	3.21
	(0.19)	(0.06)	(0.04)	(0.12)	(0.05)	(0.003)	(0.19)
1990:III-2010:IV	0.59	1.00	0.99	0.60	0.40	0.007	2.27
	(0.23)	(0.16)	(0.07)	(0.12)	(0.03)	(0.006)	(0.14)
1960:I-1997:IV	0.49	0.84	1.01	0.48	0.52	0.008	2.44
	(0.08)	(0.06)	(0.11)	(0.09)	(0.10)	(0.005)	(0.13)
1974:I-1990:II	0.58	0.90	0.95	0.51	0.49	0.004	6.41
	(0.26)	(0.12)	(0.08)	(0.03)	(0.06)	(0.006)	(0.39)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 2. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

The results of the GMM estimation of two specifications of equation (9) with the Nason and Smith's (2008) real marginal cost measure are reported in Table 10 and Table 11, respectively. Although the number of insignificant estimates reduces in specification 1 results, compared to Table 8, they are smaller in value. The same pattern of variation can be seen in all estimated parameters.

Table 10: Nonlinear GMM Estimation of Specification1 with Real Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.34 (0.11)	0.92 (0.06)	0.97 (0.02)	0.27 (0.06)	0.71 (0.06)	0.004 (0.000)	5.84 (0.45)
1954:III-1973:IV	0.11 (0.11)	0.88 (0.05)	0.98 (0.07)	0.35 (0.02)	0.67 (0.05)	0.002 (0.001)	4.85 (0.77)
1974:I-2010:IV	0.59 (0.04)	0.91 (0.02)	0.95 (0.02)	0.41 (0.09)	0.59 (0.07)	0.003 (0.001)	1.39 (0.31)
1954:III-1979:I	0.32 (0.13)	0.88 (0.06)	0.98 (0.02)	0.27 (0.08)	0.72 (0.07)	0.009 (0.009)	3.58 (0.89)
1979:II-2010:IV	0.48 (0.12)	0.93 (0.05)	0.97 (0.03)	0.34 (0.06)	0.65 (0.06)	0.002 (0.003)	2.38 (0.40)
1954:III-1990:II	0.25 (0.06)	0.87 (0.01)	0.97 (0.005)	0.22 (0.08)	0.77 (0.02)	0.010 (0.005)	3.71 (0.21)
1990:III-2010:IV	0.40 (0.04)	0.96 (0.02)	0.97 (0.01)	0.30 (0.02)	0.69 (0.02)	0.001 (0.0009)	3.75 (0.14)
1960:I-1997:IV	0.46 (0.08)	0.87 (0.02)	0.98 (0.01)	0.35 (0.04)	0.64 (0.04)	0.008 (0.003)	5.65 (0.29)
1974:I-1990:II	0.76 (0.13)	0.88 (0.09)	0.92 (0.01)	0.47 (0.01)	0.52 (0.07)	0.006 (0.001)	4.75 (0.12)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

Estimating the second specification of equation (9) using Nason and Smith (2008) does not change the general picture of structural instability in previous tables. λ estimates are still small and statistically insignificant in some subsamples. In terms of consistency with Gali and Gertler's (1999) results, it seems that the Cogley and Sbordone's (2008) marginal cost measure performance outperforms Nason and Smith's (2008) measure.

Table 11: Nonlinear GMM Estimation of Specification 2 with Real Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.51 (0.21)	0.91 (0.08)	0.98 (0.04)	0.36 (0.10)	0.64 (0.09)	0.021 (0.010)	6.97 (0.76)
1954:III-1973:IV	0.24 (0.01)	0.90 (0.06)	1.00 (0.15)	0.41 (0.05)	0.59 (0.01)	0.001 (0.001)	3.76 (0.32)
1974:I-2010:IV	0.65 (0.03)	0.95 (0.04)	0.95 (0.03)	0.53 (0.04)	0.47 (0.03)	0.005 (0.003)	2.48 (0.22)
1954:III-1979:I	0.39 (0.11)	0.90 (0.05)	0.99 (0.01)	0.38 (0.03)	0.62 (0.05)	0.010 (0.013)	3.46 (0.56)
1979:II-2010:IV	0.66 (0.10)	0.94 (0.03)	0.98 (0.13)	0.65 (0.01)	0.35 (0.06)	0.001 (0.004)	2.50 (0.23)
1954:III-1990:III	0.30 (0.08)	0.89 (0.07)	0.99 (0.03)	0.31 (0.05)	0.69 (0.03)	0.011 (0.007)	1.93 (0.16)
1990:III-2010:IV	0.48 (0.06)	0.98 (0.01)	0.96 (0.01)	0.56 (0.05)	0.44 (0.02)	0.009 (0.009)	5.53 (0.04)
1960:I-1997:IV	0.53 (0.03)	0.87 (0.01)	1.05 (0.11)	0.51 (0.01)	0.49 (0.04)	0.014 (0.002)	8.81 (0.13)
1974:I-1990:II	0.69 (0.17)	0.86 (0.11)	0.94 (0.08)	0.44 (0.07)	0.56 (0.03)	0.011 (0.005)	7.12 (0.54)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 2. Standard errors are reported in parentheses except for the last column where p-values are reported instead. A 12-lag Newey-West estimator of the covariance matrix is used in the estimation. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

Forward-looking behaviour is again more important in whole and pre-oil shock subsamples and loses its dominance after oil shock, not as much as results with GG05, however. In other words, γ_b and γ_f estimates are more stable with GG99 than GG05, but the range of variation in structural parameters are quite close in both set of instruments. Moreover, although the J statistics fail to reject the overidentifying restrictions almost in all subsamples using GG99, they are larger in values in contrast to GG05. Therefore, it can be said that GG05 produces more statistically significant estimates as well as more reliable J statistics than GG99. The reason is that, as discussed before, when the number of moment conditions increases, it is more likely that GMM estimates and their standard errors deviate from asymptotic properties.

The structural parameters estimates and J statistics are not reported in Gali et al. (2005) but the λ estimates for their sample, i.e. 1960:I-1997:IV, reported in penultimate rows of tables 8 to 11, are reasonably close to the estimates reported in Table 1 (p. 1114) of their paper for both specifications. Although the differences between estimates for backward- and forward-looking coefficients are acceptable, they are much closer to their estimates in second specification.

6.4 Results for CU-GMM Estimation of the Hybrid NKPC with Gali and Gertler (1999) Instrument Set

The aforementioned drawbacks of the GMM estimator and the insignificant estimates of λ, ω and γ_b in previous tables was the initial motivation for CU-GMM estimation which, according to Hansen, Heaton and Yaron (1996), produces less biased estimates for both coefficients and standard errors as well as more reliable J statistics. In order to study the impact of the choice of instruments on performance of the CU-GMM estimation, the hybrid NKPC is once more estimated for two different set of instruments, i.e. GG99 and GG05. It has also been estimated for two different orthogonality normalisations as well as two different measures of marginal cost in order to make these sets of results comparable to standard GMM results.

Table 12: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 1 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.22 (0.03)	0.82 (0.07)	0.89 (0.01)	0.28 (0.01)	0.72 (0.06)	0.021 (0.003)	2.51 (0.09)
1954:III-1973:IV	0.43 (0.08)	0.75 (0.02)	0.87 (0.03)	0.58 (0.03)	0.42 (0.01)	0.015 (0.003)	8.61 (0.08)
1974:I-2010:IV	0.10 (0.001)	0.80 (0.01)	0.90 (0.02)	0.19 (0.07)	0.81 (0.01)	0.051 (0.006)	3.40 (0.13)
1954:III-1979:I	0.17 (0.04)	0.84 (0.05)	0.86 (0.02)	0.36 (0.06)	0.64 (0.07)	0.024 (0.009)	3.67 (0.17)
1979:II-2010:IV	0.26 (0.03)	0.86 (0.10)	0.88 (0.01)	0.22 (0.03)	0.78 (0.01)	0.031 (0.001)	4.20 (0.15)
1954:III-1990:III	0.14 (0.04)	0.83 (0.01)	0.77 (0.02)	0.31 (0.02)	0.69 (0.10)	0.015 (0.004)	2.89 (0.21)
1990:III-2010:IV	0.28 (0.06)	0.79 (0.09)	0.85 (0.05)	0.11 (0.06)	0.89 (0.17)	0.009 (0.001)	6.21 (0.17)
1960:I-1997:IV	0.23 (0.02)	0.85 (0.09)	0.83 (0.05)	0.27 (0.06)	0.73 (0.06)	0.010 (0.005)	2.63 (0.14)
1974:I-1990:II	0.19 (0.09)	0.84 (0.01)	0.81 (0.08)	0.37 (0.04)	0.63 (0.07)	0.028 (0.008)	5.48 (0.13)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

The results for the first specification that both sides of equation (9) is multiplied by ϕ are reported in Table 12. The main difference between CU-GMM estimates and standard GMM estimates is that now all estimates are statistically significant. λ estimates become larger in values and they are all significant. The J statistics are also smaller in values and more reliable compared to the standard GMM estimates using GG99.

Table 13: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 2 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.26	0.88	0.99	0.32	0.68	0.019	3.72
	(0.05)	(0.17)	(0.03)	(0.08)	(0.08)	(0.001)	(0.15)
1954:III-1973:IV	0.54	0.77	0.91	0.62	0.48	0.014	3.72
	(0.15)	(0.06)	(0.01)	(0.07)	(0.09)	(0.002)	(0.11)
1974:I-2010:IV	0.13	0.86	0.93	0.22	0.78	0.047	1.62
	(0.002)	(0.06)	(0.03)	(0.08)	(0.09)	(0.001)	(0.15)
1954:III-1979:I	0.29	0.89	0.92	0.45	0.55	0.017	2.89
	(0.05)	(0.01)	(0.02)	(0.05)	(0.03)	(0.002)	(0.07)
1979:II-2010:IV	0.23	0.90	0.94	0.30	0.70	0.027	1.42
	(0.04)	(0.01)	(0.02)	(0.09)	(0.09)	(0.003)	(0.10)
1954:III-1990:II	0.26	0.86	0.97	0.44	0.56	0.011	2.07
	(0.01)	(0.07)	(0.08)	(0.09)	(0.08)	(0.005)	(0.18)
1990:III-2010:IV	0.19	0.83	0.98	0.13	0.87	0.006	1.44
	(0.01)	(0.08)	(0.02)	(0.06)	(0.17)	(0.003)	(0.11)
1960:I-1997:IV	0.21	0.88	0.91	0.33	0.66	0.008	2.05
	(0.01)	(0.02)	(0.10)	(0.06)	(0.06)	(0.003)	(0.10)
1974:I-1990:II	0.23	0.88	0.86	0.40	0.60	0.026	3.07
	(0.01)	(0.02)	(0.01)	(0.06)	(0.06)	(0.012)	(0.21)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 2. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

The hybrid NKPC, however, is still structurally instable in terms of the degree of price stickiness, i.e. ω, ranging from 0.10 to 0.43, but θ and β are reasonably stable, changing in 0.75-0.86 range for the former and in 0.77-0.90 range for the latter. In terms of backward- and forward-looking behaviour, they also vary substantially across subsamples.

Table 14: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 1 with Real Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.19	0.87	0.96	0.25	0.75	0.005	5.62
	(0.07)	(0.03)	(0.09)	(0.05)	(0.11)	(0.001)	(0.34)
1954:III-1973:IV	0.36	0.88	0.92	0.47	0.53	0.022	2.74
	(0.12)	(0.06)	(0.05)	(0.14)	(0.09)	(0.009)	(0.54)
1974:I-2010:IV	0.13	0.90	0.97	0.12	0.88	0.048	7.16
	(0.05)	(0.02)	(0.02)	(0.01)	(0.08)	(0.005)	(0.27)
1954:III-1979:I	0.20	0.83	0.95	0.38	0.62	0.018	2.06
	(0.09)	(0.01)	(0.08)	(0.08)	(0.13)	(0.003)	(0.11)
1979:II-2010:IV	0.18	0.91	0.98	0.19	0.81	0.010	6.32
	(0.04)	(0.06)	(0.01)	(0.01)	(0.05)	(0.004)	(0.24)
1954:III-1990:III	0.26	0.84	0.96	0.45	0.55	0.017	7.60
	(0.14)	(0.09)	(0.07)	(0.10)	(0.07)	(0.004)	(0.24)
1990:III-2010:IV	0.15	0.86	0.99	0.32	0.68	0.029	4.25
	(0.02)	(0.02)	(0.04)	(0.04)	(0.02)	(0.005)	(0.29)
1960:I-1997:IV	0.31	0.83	0.95	0.25	0.75	0.009	7.53
	(0.05)	(0.06)	(0.06)	(0.07)	(0.06)	(0.001)	(0.21)
1974:I-1990:II	0.47	0.79	0.90	0.39	0.61	0.023	6.34
	(0.13)	(0.02)	(0.01)	(0.04)	(0.07)	(0.001)	(0.28)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

The same pattern of instability exists when the hybrid NKPC is estimated by the CU-GMM method for the second specification. All parameter estimates are statistically significant and the only difference between the results in Table 8 and 9 is that they are greater in value in the latter except for J statistics that are smaller. The most remarkable change in CU-GMM estimation results compared to standard GMM estimation is that oil shocks are now associated with changes in price-setting behaviour opposite to what the standard GMM estimates imply. In other words, forward-looking behaviour becomes more important after every oil shock. The largest decline occurs in the post-first oil shock sample, i.e. 1974:I-2010:IV, with about 75% decrease in both specifications. This may be because oil shocks, as major macro-political events, inducing firms to become more forward-looking in their price-setting behaviour in order to suffer less from the negative effects of such shocks.

Table 15: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 2 withReal Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.23 (0.09)	0.90 (0.03)	0.99 (0.00)	0.28 (0.11)	0.72 (0.10)	0.007 (0.002)	2.84 (0.45)
1954:III-1973:IV	0.48 (0.20)	0.91 (0.04)	0.95 (0.03)	0.50 (0.18)	0.50 (0.18)	0.025 (0.011)	3.85 (0.77)
1974:I-2010:IV	0.15 (0.01)	0.92 (0.07)	0.99 (0.05)	0.15 (0.02)	0.85 (0.09)	0.051 (0.003)	2.39 (0.32)
1954:III-1979:I	0.22 (0.11)	0.85 (0.08)	0.97 (0.03)	0.43 (0.11)	0.57 (0.12)	0.021 (0.010)	3.58 (0.90)
1979:II-2010:IV	0.20 (0.07)	0.95 (0.05)	1.00 (0.01)	0.22 (0.04)	0.78 (0.04)	0.008 (0.002)	3.38 (0.41)
1954:III-1990:II	0.28 (0.10)	0.86 (0.07)	0.99 (0.01)	0.47 (0.07)	0.53 (0.05)	0.021 (0.005)	3.71 (0.22)
1990:III-2010:IV	0.18 (0.09)	0.89 (0.06)	1.00 (0.06)	0.36 (0.07)	0.64 (0.09)	0.034 (0.011)	1.75 (0.31)
1960:I-1997:IV	0.33 (0.11)	0.86 (0.06)	0.98 (0.01)	0.29 (0.08)	0.71 (0.04)	0.012 (0.002)	2.65 (0.29)
1974:I-1990:II	0.54 (0.12)	0.81 (0.05)	0.93 (0.03)	0.43 (0.07)	0.57 (0.06)	0.026 (0.005)	3.57 (0.12)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 25 in all subsamples.

The results for the CU-GMM estimation of equation (9) based on the Nason and Smith's (2008) measure of the real marginal cost are reported in tables 14 and 15 for the first and second orthogonality specifications, respectively.

The same pattern of structural stability of θ and β and instability of ω is seen when using Nason and Smith's (2008) measure of real marginal cost. All estimates are still significant and J statistics are more reliable than standard GMM estimation. The forward-looking component is again predominant in whole and post-oil shock subsamples.

6.5 Results for CU-GMM Estimation of the Hybrid NKPC with Gali et al. (2005) Instrument Set

In order to make CU-GMM results comparable to those of standard GMM, GG05 instrument set is used for these set of results. Table 16 and Table 17 report results for the first measure of real marginal cost for two different specifications of equation (9). Other features of this set of results are almost the same as results with GG99, but now J statistics are much smaller in value across specifications and different marginal cost measure. Overall, it seems that using fewer number of moment conditions do not alter the structural instability outcome but it produces more reliable J statistics.

Table 16: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 1 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.29 (0.10)	0.77 (0.04)	0.85 (0.10)	0.24 (0.01)	0.76 (0.01)	0.012 (0.003)	1.14 (0.19)
1954:III-1973:IV	0.59 (0.09)	0.73 (0.06)	0.83 (0.04)	0.44 (0.02)	0.66 (0.02)	0.010 (0.004)	2.53 (0.17)
1974:I-2010:IV	0.13 (0.06)	0.79 (0.05)	0.88 (0.05)	0.16 (0.05)	0.84 (0.10)	0.007 (0.002)	1.21 (0.27)
1954:III-1979:I	0.53 (0.02)	0.78 (0.05)	0.90 (0.05)	0.33 (0.08)	0.67 (0.10)	0.008 (0.001)	2.10 (0.08)
1979:II-2010:IV	0.27 (0.01)	0.75 (0.06)	0.94 (0.10)	0.21 (0.03)	0.79 (0.04)	0.012 (0.004)	1.25 (0.31)
1954:III-1990:III	0.53 (0.10)	0.74 (0.09)	0.89 (0.12)	0.35 (0.11)	0.65 (0.11)	0.015 (0.003)	2.18 (0.20)
1990:III-2010:IV	0.14 (0.01)	0.86 (0.12)	0.90 (0.08)	0.14 (0.02)	0.86 (0.02)	0.009 (0.001)	0.71 (0.24)
1960:I-1997:IV	0.42 (0.07)	0.74 (0.06)	0.92 (0.11)	0.29 (0.10)	0.71 (0.06)	0.010 (0.003)	2.83 (0.30)
1974:I-1990:II	0.31 (0.03)	0.79 (0.02)	0.85 (0.03)	0.33 (0.13)	0.67 (0.12)	0.011 (0.002)	1.29 (0.12)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

Table 17: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 2 with Real Marginal Cost Measure 1

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.31 (0.04)	0.80 (0.01)	0.88 (0.12)	0.24 (0.02)	0.76 (0.05)	0.013 (0.001)	1.30 (0.12)
1954:III-1973:IV	0.64 (0.14)	0.76 (0.01)	0.86 (0.06)	0.63 (0.01)	0.37 (0.03)	0.010 (0.002)	0.75 (0.29)
1974:I-2010:IV	0.11 (0.02)	0.83 (0.11)	0.92 (0.01)	0.19 (0.08)	0.81 (0.08)	0.015 (0.002)	2.43 (0.45)
1954:III-1979:I	0.55 (0.14)	0.81 (0.09)	0.94 (0.09)	0.52 (0.01)	0.48 (0.02)	0.023 (0.000)	1.23 (0.46)
1979:II-2010:IV	0.31 (0.09)	0.80 (0.11)	0.97 (0.05)	0.23 (0.01)	0.77 (0.05)	0.016 (0.002)	1.08 (0.43)
1954:III-1990:II	0.50 (0.17)	0.79 (0.03)	0.93 (0.02)	0.51 (0.01)	0.49 (0.02)	0.017 (0.002)	2.40 (0.45)
1990:III-2010:IV	0.12 (0.02)	0.88 (0.10)	0.93 (0.07)	0.34 (0.04)	0.66 (0.04)	0.010 (0.004)	1.33 (0.34)
1960:I-1997:IV	0.45 (0.03)	0.78 (0.01)	0.96 (0.09)	0.31 (0.01)	0.69 (0.07)	0.009 (0.001)	1.10 (0.43)
1974:I-1990:II	0.29 (0.07)	0.82 (0.12)	0.89 (0.01)	0.45 (0.02)	0.55 (0.05)	0.019 (0.001)	0.35 (0.23)

Notes: The estimates in the above table are based on Cogley and Sbordone's (2008) measure of the real marginal cost and Specification 2. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

Table 18: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 1 with Real Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.28 (0.01)	0.87 (0.04)	0.93 (0.01)	0.22 (0.02)	0.78 (0.05)	0.017 (0.002)	0.67 (0.81)
1954:III-1973:IV	0.56 (0.05)	0.86 (0.03)	0.95 (0.04)	0.64 (0.01)	0.36 (0.03)	0.019 (0.001)	1.29 (0.57)
1974:I-2010:IV	0.15 (0.02)	0.88 (0.01)	0.91 (0.07)	0.20 (0.08)	0.80 (0.08)	0.023 (0.002)	2.19 (0.24)
1954:III-1979:I	0.29 (0.01)	0.85 (0.06)	0.96 (0.01)	0.55 (0.01)	0.45 (0.02)	0.014 (0.000)	2.59 (0.19)
1979:II-2010:IV	0.31 (0.08)	0.89 (0.01)	0.93 (0.01)	0.25 (0.01)	0.75 (0.05)	0.022 (0.002)	0.58 (0.18)
1954:III-1990:III	0.46 (0.03)	0.86 (0.01)	0.95 (0.08)	0.47 (0.02)	0.53 (0.02)	0.018 (0.002)	1.11 (0.17)
1990:III-2010:IV	0.36 (0.01)	0.93 (0.05)	0.92 (0.02)	0.26 (0.04)	0.74 (0.04)	0.017 (0.004)	0.68 (0.42)
1960:I-1997:IV	0.39 (0.05)	0.82 (0.09)	0.95 (0.06)	0.32 (0.01)	0.68 (0.07)	0.021 (0.003)	1.29 (0.46)
1974:I-1990:II	0.24 (0.02)	0.84 (0.11)	0.85 (0.03)	0.41 (0.05)	0.59 (0.05)	0.013 (0.001)	0.81 (0.27)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 1. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

Table 19: Nonlinear CU-GMM Estimation of Hybrid NKPC of Specification 2 with Real Marginal Cost Measure 2

Sample Period	ω	θ	β	γ_b	γ_f	λ	J
1954:III-2010:IV	0.34 (0.12)	0.92 (0.06)	0.97 (0.02)	0.27 (0.07)	0.73 (0.06)	0.004 (0.002)	1.46 (0.67)
1954:III-1973:IV	0.60 (0.31)	0.89 (0.05)	0.98 (0.03)	0.67 (0.02)	0.33 (0.05)	0.002 (0.001)	0.75 (0.29)
1974:I-2010:IV	0.11 (0.03)	0.91 (0.02)	0.95 (0.02)	0.23 (0.01)	0.77 (0.03)	0.013 (0.001)	0.68 (0.19)
1954:III-1979:I	0.33 (0.11)	0.88 (0.06)	0.98 (0.03)	0.57 (0.08)	0.43 (0.08)	0.009 (0.002)	1.64 (0.59)
1979:II-2010:IV	0.26 (0.11)	0.93 (0.05)	0.98 (0.03)	0.27 (0.01)	0.73 (0.02)	0.018 (0.000)	2.61 (0.58)
1954:III-1990:II	0.47 (0.01)	0.87 (0.01)	0.97 (0.005)	0.52 (0.01)	0.48 (0.05)	0.012 (0.002)	1.18 (0.10)
1990:III-2010:IV	0.40 (0.00)	0.96 (0.02)	0.96 (0.07)	0.30 (0.02)	0.69 (0.02)	0.007 (0.002)	0.47 (0.23)
1960:I-1997:IV	0.46 (0.08)	0.87 (0.02)	0.98 (0.01)	0.35 (0.04)	0.64 (0.04)	0.015 (0.004)	2.42 (0.68)
1974:I-1990:II	0.26 (0.03)	0.88 (0.09)	0.90 (0.07)	0.47 (0.01)	0.52 (0.07)	0.007 (0.003)	1.19 (0.49)

Notes: The estimates in the above table are based on Nason and Smith's (2008) measure of the real marginal cost and Specification 2. Standard errors are reported in parentheses except for the last column where p-values are reported instead. The instrument rank which is the number of linearly independent instruments used in the estimation is 11 in all subsamples.

The results of the CU-GMM estimation suggest that no matter how many instruments and which measure of real marginal cost or which orthogonality normalisation to use, one always obtains significant and consistent results in terms of structural instability of the backward-looking share of firms, ω, and almost structurally stable estimates for other structural parameters. J statistics always fail to reject the null hypothesis of overidentifying restrictions. The forward-looking behaviour plays the predominant role in price-setting in the whole sample, as well as post-oil shock periods as in Gali and Gertler (1999), Sbordone (2002, 2005), Gali et al. (2005) and Cogley and Sbordone (2008). In other words, backward-looking behaviour loses ground against forward-looking behaviour after every oil shock suggesting that economic agents may learn from past macroeconomic events and adjust their price-setting behaviour in order to minimise the possible losses.

On the other hand, the share of backward-looking firms reduces after every oil shock, suggesting that inflation persistence falls substantially due to a major macro event such as an oil shock. This finding is consistent with similar studies in the literature that point to reduction in inflation persistence since 1980, like Taylor (2000), Cogley and Sargent (2001), Levin and Piger (2004), Zhang (2008) and Cogley and Sbordone (2008), but it finds the source for such decline. In other words, oil shock may explain the reduction in inflation persistence and change in price-setting behaviour over time.

7 Conclusions

Economists have long been interested in the question of how oil price shock could affect macroeconomic activity. Although there are many studies about the relationship between oil prices and macro variables, the literature ignores the effect of these shock on firms' pricing behaviour and formation of inflation expectations. In this paper, this effect has been investigated in the context of the hybrid New Keynesian Phillips Curve (NKPC) framework, which is known for its implication for studying the inflation dynamics.

Using quarterly US aggregate data, the hybrid NKPC is estimated using generalised method of moments (GMM) and continuously updating GMM (CU-GMM) techniques for subsamples formed with oil price shock dates. Two different structural stability tests are conducted to make sure that the oil price shock dates identified in the oil economics literature are indeed econometrically sound structural break dates. The Andrews-Fair Wald test (1988) and Andrews-Fair LR-type test both confirm the structural change in 1974:I, 1979:II and 1990:III. Hall and Sen's (1999) test of structural stability fails to reject, most likely due to the low power of the J test, but parameter instability is found across subsamples formed with these oil price shock dates.

In the standard GMM estimates there is evidence of parameter instability in terms of the backward- and forward-looking behaviour. Moreover, the real marginal cost ceases to be a statistically significant driver of inflation in many cases. This set of results suggests that although the forward-looking behaviour is more important before oil shocks, it seems that economic agents decide to be more backward-looking after these shocks. However, the standard GMM estimator drawbacks, namely its finite sample properties which produces more biased coefficient as well as standard errors estimates and unreliable J statistics, may be the cause of the structural instability of the hybrid NKPC in the presence of oil price shocks.

Hansen, Heaton and Yaron (1996) shown that the CU-GMM estimator has a smaller median bias in finite samples than the standard GMM estimator and J test statistics for overidentifying restrictions in many cases are more reliable. Therefore, the second set of the results are based on CU-GMM estimator. These sets of results also reject the stability of the structural parameters across subsamples, but now all estimates are statistically significant with more reliable J statistics. These results indicate that no matter how many instruments and which measure of real marginal cost or which normalisation of orthogonality conditions is used, forward-looking behaviour is always dominant in the whole sample and post-oil shock samples, but not for pre-oil shock periods. This is an important finding because it finds the source of instability and change in price-setting behaviour towards forward-looking over time.

Overall, the results contain a mixed message in terms of the effect of oil price shocks in firms' price-setting behaviour using different estimation techniques. The difference between the two sets of results may be due to weak instruments. Alternatively, given that the CU-GMM seems to suffer smaller bias in the finite sample than the 2-step GMM in the presence of weak instruments, it is more likely that the structural instability of the hybrid NKPC is captured by the CU-GMM estimates.

The results of the present paper also contribute to inflation persistence literature. Fuhrer and Moore (1995) confirmed the existence of inflation persistence in the US economy. Gali and Gertler (1999) accounted for inflation persistence in the context of the hybrid NKPC by extending the baseline model underlying the NKPC and found the evidence of backward-looking behaviour in the US inflation dynamics. Gali et al. (2001) also reported a substantial degree of price rigidity for European inflation dynamics. Christiano, Eichenbaum and Evans (2005) also provided evidence of inflation persistence in models with moderate degree of nominal stickiness.

The results of this paper indicate that, regardless of which real marginal cost is used, an increase in inflation persistence can be seen after every oil shock when using the standard GMM estimator, whereas in the CU-GMM estimates there is a considerable decline in inflation persistence since the 1974 Oil Crisis, which is close to the date that is typically found by econometric tests of structural breaks and regime change in Zhang et al. (2006) and Kang, Kim and Morely (2009).

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