Time series estimates of the US new Keynesian Phillips curve with structural breaks

Rao, B. Bhaskara and Paradiso, Antonio

University of Western Sydney, University of Rome La Sapienza

20 January 2011

20/1/11

Time Series Estimates of the US New Keynesian Phillips Curve with Structural Breaks

B. Bhaskara Rao

raob123@bigpond.com

School of Economics and Finance

University of Western Sydney, Sydney (Australia)

Antonio Paradiso

anto_paradiso@hotmail.com

Department of Economics

University of Rome La Sapienza, Rome (Italy)

Abstract

This paper uses recent US data to estimate the new Keynesian Phillips curve (NKPC) with three modifications. Firstly, the variables in the NKPC are found to be nonstationary. Therefore, it is estimated with the time series methods and the cointegrating equations are tested for structural breaks. Secondly, inflationary expectations are proxied with the survey data. Thirdly, unlike in the hybrid NKPC, the effects of the lagged inflation rates are introduced into the dynamic adjustment equations. This offers an opportunity to estimate these dynamic effects with a more general specification instead of the restricted partial adjustment mechanism underlying the hybrid NKPC. Our NKPC, with these changes, is consistent with its underlying micro foundations and forward looking expectations. The results of our NKPC can explain the dynamics of the US inflation rate as well as any other alternative model.

Keywords: US New Keynesian Phillips Curve, Forward looking expectations, Survey data, Wage share, Cointegration.

JEL: C2, C12, E3.

1. Introduction

Recent empirical studies of the new Keynesian Phillips curve (NKPC) have examined several issues concerning its specification and estimation. Two important controversial issues are the relative importance of the backward and forward looking expectations and whether the output gap (GAP) or share of wages (S) is a satisfactory proxy for real marginal costs (MC). The first issue is more important because if backward-looking expectations dominate, disinflationary policies will be costly in terms of lost output and employment. However, the theoretical derivations of the NKPC are based on entirely forward looking expectations but this theory based specification is found to be less satisfactory for explaining observed facts like the high observed persistence in the rate of inflation. Therefore, in an influential paper, Gali and Gertler (1999) have developed a hybrid version of the NKPC by introducing the lagged inflation rate into its theoretical specification to capture persistence in inflation. The estimated coefficients of the forward looking expectations and lagged inflation rate for persistence are then used to determine the relative importance of the forward and backward looking expectations. Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2005) have found that backward looking expectations, although significant, are relatively less important than forward looking expectations and the share of wages (S) is a better proxy for MC. The former conclusion is interpreted as indirectly validating the theoretical models underlying the NKPC.

Although many new Keynesians have accepted these findings as a good compromise between theory and data, Rudd and Whelan (2006, 2007) question them. They showed that in specifications, where model consistent rational expectations are used, the coefficient of forward looking expectations is insignificant and inflation is highly persistent. Their conclusion holds whether MC is proxied with the output gap or the share of wages.

This paper examines a neglected issue concerning the time series properties of the key variables in the NKPC. In our specification and sample from 1978Q1 to 2011Q2, all the variables are found to be *I(1)* in their levels. Therefore, the NKPC is estimated with the time series methods of unit roots and cointegration. Our approach has another advantage. In the time series methods a distinction is made between the long run equilibrium relationship and the short run dynamic adjustments. Such a distinction offers an opportunity to use the theory based NKPC, with fully forward looking expectations, for its equilibrium specification and introduce the effects of lagged inflation rates into the dynamic adjustment equation. This is a reasonable approach because that the effects of lagged inflation rate are transitory is noncontroversial. Furthermore, it is possible to use a more flexible dynamic adjustment process than the restrictive partial adjustment underlying the hybrid NKPC. Therefore, if our estimates can adequately explain the data, it will also weaken the criticism that the theory based NKPC is unsatisfactory to explain facts, unless the lagged inflation rate is somehow introduced into its specification.

The remainder of this paper is as follows. Section 2 discusses specification and estimation issues. Estimates of the cointegrating equations are in Section 3 and the dynamic equations in Section 4. Section 5 concludes.

2. Specification and Estimation

We shall use Gali and Gertler's (1999) theory based forward looking expectations NKPC as our long run specification:

(1)
$$\Delta \ln P = \alpha + \gamma \ln S + \beta E_t(\Delta \ln P_{t+1}) + \varepsilon_t$$
$$\gamma > 0; \beta \simeq 1; \varepsilon_t \sim N(0, \sigma^2)$$

where $\Delta \ln P$ =the rate of inflation, $\ln S$ =share of wages expressed in natural log (and multiplied for 100) and $E_t(\Delta \ln P_{t+1})$ =expected rate of inflation. Virtually all empirical works on the NKPC have ignored the time series properties of the variables and used Gali and Gertler's (1999) method of estimation. The forward looking expected rate of inflation is proxied with the actual rate of inflation ($\Delta \ln P_{t+1}$) and the generalised method of moments (GMM) is used for estimation to ensure that the explanatory variables are not correlated with the error. It is well known that if the variables are nonstationary classical methods of estimation give spurious regression results and the NKPC should be estimated with time series methods of unit roots and cointegration.[1]

---

[1] In the original Gali and Gertler (1999) sample period of 1960Q1 1997Q4 although S is marginally stationary, the rate of inflation, however it is measured, is a nonstationary variable. We tried to estimate the long run relationship for this sample period with a suitable method of Pesaran and Shin (1999). In this approach the cointegrating equations can be estimated when both *I(1)* and *I(0)* variables are present. However, consistent

Table 1 Unit Root Tests (sample 1978Q1 – 2010Q2)		
Variable	*ADF*	*KPSS*
$\Delta \ln P$	-1.227	0.997***
$\Delta^2 \ln P$	-5.917***	0.053
$\ln S$	-0.049	1.086***
$\Delta \ln S$	-14.056***	0.115
$MICH_t$	-1.872	0.646**
$\Delta MICH_t$	-11.523***	0.069
Notes: *** Significant at 10%; **Significant at 5%. The $p_{\max}$ in ADF test is selected with Schwert's (1989) rule: $\text{int}\left(12\left(T/100\right)^{1/4}\right)$. The lags in ADF are selected with Schwartz Information Criterion and in KPSS with the Newey-West Bandwith Bartlett kernel. The null in ADF is that the variable is non-stationary and this is reversed in KPSS.		

Time series methods impose a limitation on the Gali and Gertler's (1999) approach of proxying forward looking expectations with the actual rate of inflation one period ahead because leads and lags of variables cannot be introduced into the specification of the NKPC. Therefore, we use the survey data of the University of the expected rate of inflation for 12 months ahead. This is denoted as *MICH* and according to Baghestani and Noori (1988) these expectations are consistent with Pearce's (1979) criteria of rationality. Our tests in the above Table 1 for the order of the variables show that they are integrated of order one in our sample from 1978Q1 to 2010Q2. The selection of this sample period is based on the ready availability of data on *MICH* without any significant revisions. The specification of our NKPC with *MICH* is:

(2) $$\Delta \ln P = \alpha + \gamma \ln S + \beta MICH + \varepsilon_t$$

---

survey data on the expected rate of inflation are not available for this sample period. We are grateful to Professor Gali for the original data in Gali and Gertler (1999).

The specification of the short run dynamic equation, implied by equation (2), is as follows.

$$\Delta^2 \ln P_t = \lambda ECM_{t-1} + \sum_{i=1}^{n1} \varpi_i \Delta \ln S_{t-i} + \sum_{j=1}^{n2} \pi_j \Delta MICH_{t-j} + \sum_{m=1}^{n3} \theta_m \Delta^2 \ln P_{t-m} \quad (3)$$

where *ECM* is the residuals from equation (2). This dynamic equation takes the view that dynamics is an empirical issue and needs to be estimated to be consistent with the underlying data generating process. Known as the general to specific method, it is extensively used in time series papers for estimating dynamic adjustment equations. It is a more general adjustment mechanism than the partial adjustment dynamics, implicit in the hybrid NKPC.

3. Cointegrating Equations

Equations (2) and (3) are estimated with US quarterly data from 1978Q1 to 2010Q2. Our measure of inflation is the core inflation rate. Definitions of the variables and sources of data are in the appendix. Four alternative methods of estimating the cointegrating equations are used. These are the Phillips and Hansen (1990) fully modified *OLS* (FMOLS), Park's (1992) canonical cointegrating regression (CCR), the Stock and Watson (1993) dynamic *OLS* (DOLS) and the Johansen (1988) maximum likelihood (JML) methods. If these alternative methods give similar results, then, confidence in their estimates will also increase. Estimates of (2) with these four methods are in Table 2. While the first three methods assume that a single cointegrating equation exists, this assumption is tested in JML. Its two tests, based on Eigen value and Trace statistic (reported), show that a single cointegration relationship exists.

Estimates of the coefficients of $\ln S$ and *MICH* are significant and close in all estimates. The NKPC is slightly flatter in the DOLS and JML estimates and the coefficient of *MICH* is not significantly different from unity (Wald test for $H0: \beta = 1$), validating the expectations hypothesis.

Table 2 Estimates of the Cointegrating Equations. Sample (unadjusted) 1978Q1-2010Q2 $\Delta \ln P = \alpha + \gamma \ln S + \beta MICH$				
	FMOLS	*CCR*	*DOLS*	*JML*
Intercept	-143.651***	-143.726***	-129.871***	-131.426***
$\ln S$	0.309***	0.309***	0.279***	0.282***
$MICH_t$	1.055***	1.051***	1.115***	1.265***
EG Test for Cointegration	-4.867***			-
JML Trace Test *None* *At most 1* *At most 2*	-	-	-	36.186*** 13.088 0.00
Wald Test $H0: \beta = 1$ *(Prob. Value)*	0.418	0.442	0.06	-
LR test for restriction. $\beta = 1$ *(Prob. Value)*	-	-	-	0.05
Notes: *** Significance at 10%; **Significance at 5%. EG = Engle-Granger t-test for cointegration. FMOLS and CCR use the Newey-West automatic bandwith selection in computing the long-run variance matrix. In DOLS leads and lags are selected with SIC criteria. The standard errors for DOLS are Newey-West corrected.				

4. Break Detection

Our results have established that a theory consist long run NKPC exists for USA from 1978 to 2010. In this section we investigate if this relationship has undergone any structural change over the three decades. This is some interest because some researchers have claimed that the US Phillips curve has become flatter because of productivity gains due to the implementation of market liberalization policies and the ICT revolution. If this is valid, then, the Phillips curve may shift down and/or its slope may decrease. For this purpose we shall use the Gregory and Hansen (1996) tests for unknown structural breaks in the cointegrating equations[2]. If a break is detected we try a confirmation with the Johansen Trace test (Johansen et al. (2000)) that a cointegrating equation exists with a structural break. Only when the Trace test and the DOLS, CCR, FMOLS estimations produce plausible results, we are confident of the existence of the break. We test the presence of the break with GH test according with these two models:

(GH1 – Level shift only)

(4) $$\Delta \ln P = \alpha_1 + \alpha_2 DUM + \gamma \ln S + \beta MICH_t + \varepsilon_t$$

(GH2- Regime shift)

(5) $$\begin{aligned}\Delta \ln P = \alpha_1 + \alpha_2 DUM + \gamma_1 \ln S + \gamma_2 \ln Sf_{tk} \\ + \beta_1 MICH_t + \beta_2 MICH_t \times DUM + \varepsilon_t\end{aligned}$$

DUM =1 after the break and zero before the break. Table 3 below presents the results with the Gregory and Hansen's critical values.

Table 3: Gregory-Hansen (GH) cointegration test

	Break date			GH *t*-statistic		
	ADF^*	Z_t^*	Z_α^*	ADF^*	Z_t^*	Z_α^*
GH-1	1993Q3	1997Q1	1997Q1	-5.360**	-46.50**	-5.41***
GH-2	1997Q1	1998Q2	1998Q2	-5.89**	-54.84*	-6.11***

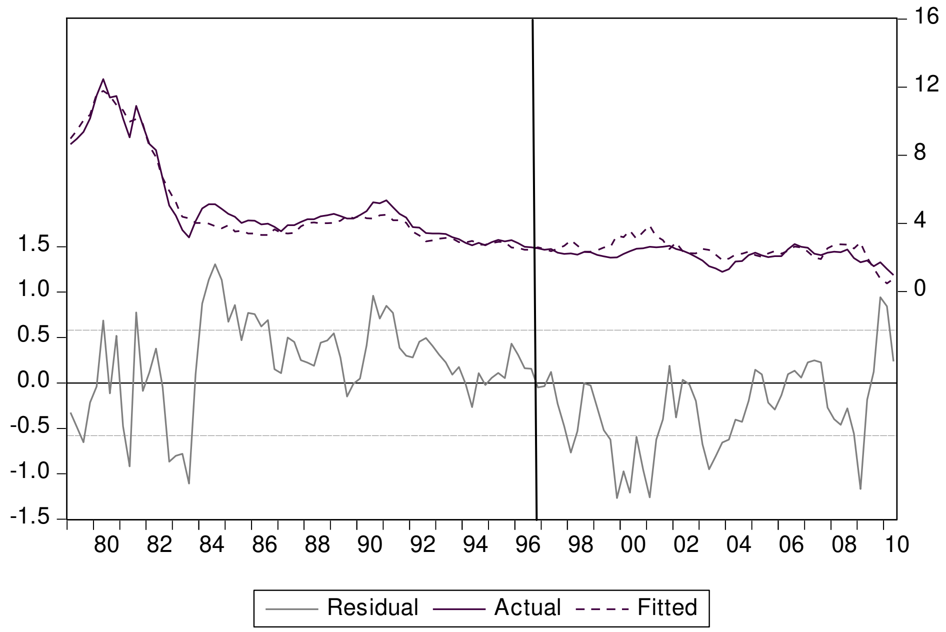
Notes: Z_t^*, Z_α^* and ADF^* are modifications, respectively, of the test statistics Z_t and Z_α (suggested by Phillips (1987)) and the ADF statistics. The null hypothesis is no cointegration with structural break. *, ** and *** indicate significance at 10%, 5% and 1% respectively.

The GH-1 test confirms the existence of long-run relationship with a break in 1993Q3 or 1997Q1 depending on the test observed. GH-2 test says that a long-run relationship exists with a break in 1997Q1 or 1998Q2. A further analysis can be conducted graphically. If we plot the long run relationship with the actual data (Figure 1), we can see that a departure in

[2] Gregory and Hansen (1996) compute the cointegration test statistics for each possible level shift $\tau \in T$ and take the smallest value (the largest negative values) across all possible break points. In principle the set T can be any compact subset of (0,1). However, in practice $T = (0.15, 0.85)$ seems a reasonable suggestion following the earlier literature.

the relationship emerged from 1997.[3] The increase in productivity due to information and commutation technology revolution and/or the decline in imports prices starting in the middle of 1990s (Rich and Rissmiller (2000)) could explain the shift in the long-run relationship studied. In addition, the availability of inexpensive consumer goods from China and a small decline in medical costs may have contributed to this shift. We test these two cases (GH1 and GH2) estimating a long-run relationship with DOLS, CCR, and FMOLS to check for plausible results.

Figure 1: Possible Break in the Cointegrating Relationship (DOLS Estimate)



[3] A similar departure can also be seen starting from 1981 and the opposite shifts that seem to have occurred may have offset each other. In contrast, from 1997 the predicted inflation rate is consistently higher than the actual rate until 2005-2006. This result is not new in literature. The over-prediction of price inflation from 1990s is considered a regularity by Andersen and Wascher (2001) for US economy.

Table 4 Cointegrating Equations with level shift (GH1) in 1997Q1. Sample (unadjusted) 1978Q1-2010Q2 $\Delta \ln P = \alpha_1 + \alpha_2 DUM + \gamma \ln S + \beta MICH + \varepsilon_t$			
	FMOLS	*CCR*	*DOLS*
Intercept	-86.982***	-86.092***	-76.848***
Intercept $\times DUM$	-0.957***	-0.965***	-0.926***
$\ln S$	0.188***	0.187***	0.166***
MICH	1.019***	1.017***	1.082***
Wald Test $H0: \gamma = 1$ *(Prob. Value)*	0.684	0.713	0.02

All the estimated cointegrating equations and their results are plausible. Except for DOLS estimation the Wald test accepts the restriction of $\gamma = 1$ at the 5%. We tested for regime shifts with GH2, but obtained implausible estimates of the cointegrating equations. To conserve space these are not reported. We seek a further confirmation for this break with the Johansen Trace Test; Johansen et al. (2000). Trace test results are in Table 5 and confirm the presence of one long-run relationship with a break in 1997Q1. Therefore, in Table 6 we report the estimated cointegrating equation with a level shift. Estimated parameters of the cointegrating equations, with the four alternative methods, are similar and close. These results indicate that the US NKPC has shifted down in 1997Q1 by a small amount of about 1%. Therefore, we may infer that the micro-theory based NKPC, with only forward looking expectations, has adequately captured the long run relationship between the rate of inflation, wage share and forward looking expectations and the expectations hypothesis is valid in the long run.

Table 5 Johansen Trace Test With a Level Shift in 1997Q1					
	LR	p-value	90%	95%	99%
$r=0$	54.99	0.00	37.70	39.94	44.36
$r\geq 1$	19.42	0.25	22.34	24.25	28.12
$r\geq 2$	3.77	0.80	11.01	12.81	16.66
Note: Lags selected according to AIC criteria.					

Table 6 JML Cointegrating Relationship. Sample (unadjusted) 1978Q1-2010Q3 $\Delta \ln P = \alpha_1 + \alpha_2 DUM + \gamma \ln S$ $+ \beta MICH + \varepsilon_t$	
$\Delta \ln P_{t-1}$	1
Intercept	-98.054***
DUM_{t-1}	-0.868***
$MICH_{t-1}$	0.991***
$\ln S_{t-1}$	0.212***
LR test for restriction. $\beta = 1$ *(Prob. Value)*	0.810

4. Short Run Dynamics

So far, we did not introduce persistence in the rate of inflation into our estimates. This is important since Gali and Gertler (1999) have developed the hybrid NKPC because the pure theory based NKPC with only forward looking expectations is inadequate for explaining the dynamics of inflation. As stated before, we introduce now persistence through dynamic adjustment and estimate equation (3) with the lagged error terms from the four cointegrating equations in Table 4 and 6. A summary of these estimates are in Table 7.

Table 7

Summary: Dynamic Equations. Sample 1980Q1-2010Q2

Dependent Variable: $\Delta^2 \ln P$

	(1)	*(2)*	*(3)*	*(5)*
	FMOLS	*CCR*	*DOLS*	*JML* *(with outliers)*
ECM_{t-1}	-0.246 (0.035)***	-0.247 (0.035)***	-0.191 (0.033)***	-0.259 (0.030)***
Outliers	1980Q3:-1.312 1981Q3:+2.149	1980Q3:-1.307 1981Q3:+2.153	1980Q3:-1.379 1981Q3:+2.099	1981Q3:+1.838
$\Delta^2 \ln P_{t-i}$	$i = 5$	$i = 5$	$i = 5$	$i = 4$
$\bar{R}^2$	0.744	0.745	0.741	0.670
LLH	186.957	187.072	186.173	171.599
SEE	0.227	0.227	0.230	0.251
AR 1-4	0.399 [0.807]***	0.381 [0.822]***	0.975 [0.425]***	0.486 [0.746]***

Notes: Standard errors are below the coefficients in the parentheses and *p*-values are in square brackets. *** and ** signify significance at 1% and 5% levels, respectively.

The coefficients of the lagged ECMs in the four estimates have the correct negative sign and are significant. Their estimates are also close with the exception of DOLS estimate which is marginally smaller. The adjustment coefficients imply that about 20% to 25% of the adjustment in the rate of inflation towards its equilibrium takes place in one quarter. Our dependent variable in the dynamic equations is the rate of acceleration of inflation and it is persistent up to five quarters implying that lagged inflation rates up to six quarters have their effects on the current rate of inflation. However, acceleration of the rate of inflation is not a highly persistent variable compared to the rate of inflation of about 0.8 and above found in several empirical studies of the US NKPC. Our estimates of the persistent coefficient for the rate of acceleration ranges from 0.187 to 0.354 in the JML and DOLS based equations respectively. The negative and positive outliers in 1980Q3 and 1981Q3 correspond, respectively, to the trough and peak of the cycle during 1980-1982 (NBER dates).

The summary statistics of the four estimates are very close and similar. Their R bar squares are high given that the dependent variable is the rate of acceleration of inflation. Therefore, any one of them is satisfactory to explain the dynamics inflation in the USA.

5. Conclusions

This paper has found that the variables in the US NKPC are nonstationary and therefore used the time series methods to estimate this relationship. As in all time series methods a distinction is made between the long and short run relationships. Unlike in the existing empirical studies where there is no distinction between the long and short run relationships and the effects of persistence in the rate of inflation are directly added to the NKPC, in this paper such persistent effects are introduced into the dynamic adjustment equations. This modification offered the opportunity to estimate the dynamic adjustments with a more flexible general to specific method than the somewhat restrictive partial adjustments.

Some important conclusion are the following. First, the micro theory based specification of the NKPC with only forward looking expectations is a valid specification to estimate the long run Phillips curve. Second, this long run Phillips curve offers no trade-off between inflation and its driving forces, which is the share of wages in this paper. Third, survey based data on inflation expectations are good proxies for the expected rate of future inflation. Four, compared to the persistence in the rate of inflation, persistence in the rate of acceleration of inflation is relatively small. Five, there has been a small downward shift in the US NKPC in 1997Q1, perhaps due to the favourable effects of ICT revolution and large decline in import prices which both began in 1995. We hope that our methodology and findings would be useful to other researchers on the NKPC.

Data Appendix

Definitions and Data Source: 1978Q1 – 2010Q2

Variable	Definition	Source
$\Delta \ln P$	Measured as $\ln\left[\frac{p_t}{p_{t-4}}\right]$ using core CPI. Consumer Price Index (All Items Less Food and Energy), Index 1982-1984=100.	research.stlouisfed.org/fred2/categories/9
$\ln S$	Labour's Share of Income (Nonfarm Business Sector, Index 2005=100) expressed in natural log and multiplied for 100.	www.bls.gov/data
$MICH_t = E_t\left(\Delta \ln P_{t+1}\right)$	Median expected price change next 12 months, Survey of Consumers.	www.sca.isr.umich.edu

References

Andersen, P. S. and Wascher, W. L. (2001), "Understanding the recent behaviour of inflation: An empirical study of wages and price developments in eight countries", in: *Empirical Studies of Structural Changes and Inflation*, Bank of International Settlements, BIS Paper No. 3, 267-302.

Baghestani, H. and Noori, E. (1988), "On the rationality of the Michigan monthly survey of inflationary expectations", *Economics Letters*, 27, 333-315.

Gali, J. and Gertler, M. (1999), "Inflation dynamics: A structural econometric analysis", *Journal of Monetary Economics*, 44, 195-222.

Gali, J., Gertler, M. and Lopez-Salido, J. D. (2005), "Robustness of the estimates of the hybrid New Keynesian Phillips Curve", *Journal of Monetary Economics*, 52, 1107-118.

Gregory, A. W. and Hansen, B. E. (1996), "Residual-based tests for cointegration in models with regime shifts", *Journal of Econometrics*, 70, 99-126.

Johansen, S. (1988), "Statistical analysis of cointegration vectors", *Journal of Economic Dynamics and Control*, 12, 231-254.

Johansen, S., Mosconi, R. and Nielsen, B. (2000), "Cointegration analysis in the presence of structural breaks in the deterministic trend", *Econometrics Journal*, 5, 216-249.

Pearce, D. K. (1978), "Comparing survey and rational measures of expected inflation: Forecast performance and interest rate effects", *Journal of Money, Credit and Banking*, 11, 446-456.

Pesaran, H. M., and Shin, Y. (1999), "Autoregressive distributed lag modelling approach to cointegration analysis, Chapter 11, in: Storm, S. (ed.), *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium*, Cambridge University Press.

Park, J. Y. (1992), "Canonical cointegrating regression", *Econometrica*, 60, 119-143.

Phillips, P. C. B. (1987), "Times series regression with a unit root", *Econometrica*, 55, 277-301.

Phillips, P. C. B. and Hansen, B. E. (1990), "Statistical inference in instrumental variables regression with I(1) processes", *Review of Economic Studies*, 57, 99-125.

Rich, R. W. and Rissmiller (2000), "Understanding the recent behaviour of U.S. inflation", *Current Issues in Economics and Finance*, 6 (July 2000), Federal Reserve Bank of New York.

Rudd, J. and Whelan, K. (2006), "Can Rational Expectations Sticky-Price Models Explain Inflation Dynamics?", *American Economic Review,* 96 (March), 303–320.

Rudd, J. and Whelan, K. (2007), "Modelling inflation dynamics: A critical review of recent research", *Journal of Money, Credit and Banking,* 39, 155–170.

Schwert, G. W. (1989), "Tests for unit-roots: A Monte Carlo investigation", *Journal of Business and Economic Statistics*, 7, 147-159.

Stock, J. and Watson, M. (1993), "A simple estimator of cointegrating vectors in higher order integrated systems", *Econometrica*, 61, 783-820