Examining asymmetric effects in the South African Philips curve: Evidence from logistic smooth transition regression (LSTR) models

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EXAMINING ASYMMETRIC EFFECTS IN THE SOUTH AFRICAN PHILLIPS CURVE: EVIDENCE FROM LOGISTIC SMOOTH TRANSITION REGRESSION (LSTR) MODELS

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ABSTRACT: This study contributes to the foregoing literature by investigating asymmetric behaviour within the South African short-run Phillips curve for three versions of the Phillips curve specification namely; the New Classical Phillips curve, the New Keynesian Phillips curve and the Hybrid New Keynesian Phillips curve. To this end, we employ a logistic smooth transition regression (LSTR) econometric model to each of the aforementioned versions of the Phillips curve specifications for quarterly data spanning from 1970:01 to 2014:01. Our empirical results indicate that both the marginal-cost based as well as the output gap based versions of the Hybrid New Keynesian Philips curve provide a good fit for South African data. Therefore, our empirical results indicate that monetary policy in South Africa has an influence on the demand side of the economy through inflation inertia and inflation expectations whilst appearing to exhibit no significant effects on the supply side of the economy.

Keywords: New Classical Phillips Curve; New Keynesian Phillips curve; Hybrid New Keynesian Phillips curve; inflation; output gap; marginal costs; smooth transition regression; monetary policy; South Africa, developing country.

JEL Classification Code: C22, E31, E37.

1 INTRODUCTION

The ‘Phillips curve’ has attracted a considerable amount of attention by academics and policymakers alike, after the seminal paper of Phillips (1958) revealed the possibility of an approximation to the inner boundary or frontier for optimal combinations between inflation and unemployment. Metaphorically speaking, the Phillips curve presents a statement in which monetary policy actions repel inflation and unemployment in opposite directions. This ‘realization’ has earned the Phillips curve a prominent role in the design of monetary policy as it functions as a determining factor in setting the interest rate as well as in producing reliable inflation forecasts (Atkeson and Ohanian, 2001). The debate surrounding the Phillips curve has intensified over the last couple of decades as several authors have questioned the usefulness of the curve as a macroeconomic policy tool (see Niskanen, 2002; Barnes and Olivei, 2003). A re-occurring explanation for this ambiguouity is that the dynamics of the Phillips curve have changed over the last couple of decades and this has resulted in several attempts having been made to empirically quantify the Phillips curve under various assumptions concerning its specification.

Currently, there is a surge of academic interest which adheres to the possibility of asymmetric Phillips curves as a means of revitalizing the policy relevance of the Phillips curve. Even though the traditional theory of a linear Phillips curve remains dominant in the literature (see Lipsey, 1960; Phelps, 1967; Lucas and Rapping, 1969; Gordon, 1997), commentators, such as De Veirman (2007); Buchmann (2009); and Balaban and Vintu (2010), have all argued that the original `Phillips curve did not intend to describe the correlation between inflation and excess demand as being symmetric. Emerged literature in empirical support of existing asymmetries in the short-run Phillips curve has been found for the cases of South Africa (Burger and Marnikov, 2006; and Nell, 2006); Columbia (Gomez and Julio, 2000); Canada (Huh and Lee, 2002); the United States, Sweden, Australia (Eliasson, 2001); Brazil (Correa and Minella, 2010); Turkey (Bilman and Utkulu, 2010) and also for a cluster of Euro area countries (Pyyhtia, 1999). It is worth noting that empirical studies based on asymmetric versions of the Phillips curve tend to produce estimates that are more robust to the treatment of expectations as well as to their measurements of demand pressure.

Theoretically, there are a number of microeconomic models of price setting behaviour which depict the transition of asymmetric effects between demand pressure and inflation. Existing theoretical arguments in support of Phillips curve asymmetries are established in models based on capacity constraints (Clark et. al.,1996); signal extraction (Lucas, 1973); menu costs (Ball et. al., 1988); downward nominal wage rigidity (Fisher, 1989); and oligopolistic markets (Stiglitz, 1984). The shape of the curve is paramount to the theoretical foundations supporting the mechanism of asymmetric behaviour in the Phillips curve and generally the asymmetric versions of the Phillips curve can be classified as being either convex or concave during certain stages of the business cycle. Phillips curve convexity, on one hand, implies that inflation behaves more sensitive to output adjustment as the economy weakens. When convexity occurs in the Phillips curve, inflation is assumed to be more sensitive to output adjustments as the economy weakens such that restrictive monetary policy boosts the macroeconomy during an upswing in the business cycle by stabilizing the inflation rates. Contrariwise expansionary monetary policies are deemed as being useful in stabilizing inflation during the downswing phase of the business cycle associated with a convex Phillips curve. On the other hand, a concave Phillips curve implies that as the economy strengthens, inflation becomes more sensitive to output adjustments. Evidence of a concave Phillips curve hence motivates the use of expansionary monetary policies in stabilizing prices during the upswing phase of the business cycle and further implies that restrictive monetary policy would be effective in stabilizing the inflation rate during the downswing of the business cycle.

Regardless of whether the source of asymmetry is attributed to convexity or concavity, the implications arising from asymmetric behaviour in the Phillips curve are considered crucial towards the conduct of monetary policy. Firstly, asymmetric Phillips curves are considered flexible enough to capture the output costs that are cyclically sensitive yet precise enough to use in complex structural models of the macroeconomy (Filardo, 1998). Secondly, it is feared that the use of linear representations of the Phillips curve, might lead to suboptimal policy settings, in which interest rates are not adjusted sufficiently during upturns or downswings in the business cycle (Schalang, 2004). Thirdly, asymmetries in the Phillips curve provide a theoretical rationale for the recently popularized asymmetric policy reaction functions which advocate that inferences based on linear policy rules provide misleading signals about the appropriate policy stance (see; Dolado et. al., 2005). Emphasis on these models is important because an asymmetric response of inflation to demand shocks induces an asymmetric optimal policy feedback rule which involves changing short-term interest rates more forcefully depending on the established shape of the Phillips curve (Enders and Hurn, 2002). Under the asymmetric hypothesis, the associated cost of fighting inflation varies with the shape of the Phillips curve and the resulting dynamics in a nonlinear environment places emphasis on the timing of monetary policy actions in stimulating the macroeconomy.

However, in absence of theoretical or empirical priors to guide the econometrician in capturing the precise form of asymmetry, a number of factors must be considered prior to identifying an appropriate functional form of the Phillips curve. Dupasquier and Ricketts (1998) suggest that the econometrician must be able to model asymmetries without having to make any ad hoc assumptions concerning the asymmetric shape of the Phillips curve. Building along this same line of reasoning, De Veirman (2009); Buchmann (2009); and Balaban and Vintu (2010), more specifically suggest the use of regime-switching econometric models in order to ensure that asymmetric behaviour within the Phillips curve is a natural outcome of the estimation process. A noteworthy advantage of using regime switching models is that these models allow their parameters to vary over time hence reducing the possibility of an unstable Phillips curve. This is a relevant issue in the South African context as the South African Reserve Bank (SARB) has experienced prominent shifts in the conduct of monetary policy over the last couple of decades. The use of appropriate regime switching models would, therefore, ensure that the parameter estimates of the Phillips curve are not subjected to the well-known criticisms of Lucas and Sargent (1978). Another critical consideration to be made in selecting an appropriate regime-switching model concerns the choice of a smooth transition, as opposed to abrupt changes, being imposed between shifts in the regime coefficients of the estimated econometric model. As pointed out by Hasanov et. al. (2010), such an assumption is pivotal since economic agents within the macroeconomy do not behave simultaneously and in the same direction. Therefore, in carrying out the transition between economic regimes in a smooth manner, such an assumption becomes coherent with the stylized fact that the slow adjustments as well as inertia in inflation and consumer's expectations are the main reason for the trade-off between inflation and unemployment (Huh, 2009).

Against this background, our paper makes use of STR modeling techniques to capture possible asymmetries in the short-run South African Phillips curve. This particular class of nonlinear econometric models is essentially a piecewise model with smooth transitioning among the regression regimes and its structure presents several advantages over other competing nonlinear or regime-switching models. Firstly, STR models are theoretically more appealing compared to other threshold or Markov switching models, which impose an abrupt change in coefficients (Omay and Hasanov, 2010). Secondly, the STR model is designed in a manner which encompasses other threshold or regime-switching models (Stimel, 2010). Lastly, the STR modeling approach allows the econometrician to choose both the appropriate switching variable and the type of transition function unlike other regime-switching models (Hasanov et. al., 2010). Having thus provided a background to our study, we structure the remainder of the paper as follows. Section 2 presents the different specifications of the Phillips curve used in the empirical study. The third section deals with the data and data construction of the variables used in the study. The fourth section presents the empirical study to South

African data. Section 5 concludes the paper and draws policy implications associated with the study.

2 *EMPIRICAL CONSIDERATIONS*

2.1 SPECIFYING VARIOUS FORMS OF THE PHILLIPS CURVE

Distinguishing between different forms of the Phillips curve is a first element of complexity which should be taken into consideration when attempting to link theory to the data. Initially, the Phillips curve entered the economic field as a negative relationship between wage inflation and unemployment; and enjoyed wide-spread yet short-lived empirical support from South African case studies (Gallaway et. al. (1970); Hume (1971); Truu (1975); Strebel (1976)) as well as in the literature concerning other international economies (Routh (1959); Lipsey (1960); and Samuelson and Solow (1960)). Relying on this empirical evidence of a negative relationship between inflation and unemployment led policymakers worldwide to believe that they were offered a choice between different sets of inflation-unemployment combinations. Therefore, by laying out a Phillips curve framework, the objective of policymaking was centered upon selecting an optimal point within this relation that minimized the unemployment costs of fighting inflation. However, the usefulness of the initial Phillips curve as a policy tool was severely questioned following extended periods of stagflation during the 1970's and the 1980's and this led to the development of the New Classical Phillips Curve (NCPC), as inspired by Phelps (1967); Friedman (1968); and Lucas and Rapping (1969). Proponents of the NCPC emphasized on the role of rationale expectations and argued that there was no permanent trade-off between inflation and unemployment, with a unique natural unemployment rate compatible with any rate of inflation. The underlying intuition of the natural rate is that changes in the inflation rate are a labour market phenomenon whose magnitude can be proxied by the unemployment rate (Stiglitz, 1997). Under the NCPC framework, monetary authorities could either peg unemployment or stabilize the inflation rate but they are unable to simultaneously do both. Thus contrary to the original Phillips curve, monetary authorities cannot peg unemployment at a given constant rate of inflation but they can choose the steady-state inflation rate at which unemployment returns to its natural rate (Humphrey, 1985). Empirically, the functional form of the NCPC can be expressed as follows:

$$\pi_t = \beta_i \pi^e_{t|t-h} + \kappa_{(y-\widehat{y})} y - \hat{y} + \varepsilon_t \qquad (1)$$

Where π_t refers to the rate of inflation, the term $\pi^e_{t|t-h}$ indicates that the economic agents construct their inflation forecasts rationally in accordance with the period t-h and the term $y - \hat{y}$ denotes macroeconomic demand pressures as measured by the deviation of output (or unemployment) from its natural rate. However, this initial specification of the NCPC was heavily criticized for its apparent inability to characterize inflation dynamics in the face of external shocks. Gordon (1984) introduced the role of supply shock variables to the Phillips curve which, he argued, made the NCPC curve less vulnerable to depicting an extraneous positive inflation-unemployment correlation. In particular, the omission of supply shocks from the Phillips curve causes excess demand to account for a smaller share of the variation in inflation thus creating a regression bias in the model estimates. The so-called triangle model of Gordon (1984) was therefore developed, in which the inflation rate is considered to be determined by three main factors namely; inertia; demand shocks; and supply shocks i.e.

$$\pi_t = \beta_i \pi^e_{t|t-h} + \kappa_{(y-\widehat{y})} y - \hat{y} + \psi \ni_t + \varepsilon_t \qquad (2)$$

Where the term $\ni_t$ captures supply shocks, such as those which occurred in the 1970's. Overall, contrasting degrees of skepticism exist with regard to the empirical validity of either forms of the NCPC, of which a substantial amount of evidence indicates that the NCPC is not compatible with data for industrialized economies (King and Watson (1994); DiNardo and Moore, 1999; and Niskanen (2002)), and neither has it been found to be compatible with South African data (Pretorius and Small (1994); Hodge (2002, 2006); and Fedderke and Schaling (2005)). A plausible explanation for this initial failure of the NCPC, as pointed out by Lucas and Sargent (1978) is that expectations of economic agents are adaptively formed based on the perceptions of the prevailing policy regime. In other words, a transparent shift in the conduct of monetary policy would alter the coefficients of any reduced-form Phillips curve specification hence resulting in parameter instability in the model estimates. In response to the Lucas-Sargent critique, a number of authors have either estimated the NCPC by either using time-varying NAIRU approach (Gordon (1997); Stock and Watson (1999); and Fitzenberger et. al., 2008)) or by applying piecewise econometric estimation techniques to the data (Dupasquier and Ricketts (1998); Enders and Hurn (2002); and Hasanov et. al. (2010)). At this juncture, it is worth noting that the studies which followed a piecewise modeling approach in application to South African data produced more significant results in identifying a short-run Phillips curve under the NCPC framework (i.e. Nell (2000); and Burger and Marnikov (2006)).

Despite these relevant empirical advancements made in estimating the NCPC, the lack of microfoundational underpinnings left macroeconomists dissatisfied with the theoretical validity of the NCPC and an alternative theory of the Phillips curve emerged which has been dubbed as the New Keynesian Phillips Curve (NKPC). The rationale behind the development of the NKPC was to specify the Phillips curve upon a solid theoretical foundation of which, according to Olafsson (2006), two key improvements to inflation dynamic modeling were introduced. Firstly, was the explicit modeling of the inflation expectations variable and the emphasis on forward-looking behaviour. A second development saw the introduction of implicit wage and price optimization problems within a monopolistic environment, leading to staggered price and wage setting within stochastic, agent-optimizing models. The pricing assumption underlying the NKPC framework depicts that firms set their prices on the basis of expectations revolving around the future evolution of demand and cost factors. Rudiment models of this theory are found in Taylor's (1979, 1980) overlapping contracts model; Rotemberg's (1982) model of quadratic costs of price adjustments or Calvo's (1983) model with random price adjustment. The resulting canonical expression of the NKPC model is represented as follows:

$$\pi_t = \beta_i \pi^e_{t+h|t} + \kappa_{\widehat{mc}} \widehat{mc} + \varepsilon_t \qquad (3)$$

Where $\pi^e_{t+h|t}$ is the expected inflation rate and ε_t represents a stochastic term which includes exogenous factors that can affect the inflation process over time i.e. cost-push factors. Economic theory suggests that β_i is approximately one and $\kappa_{\widehat{mc}}$ should be positive. A distinguishing element of the empirical form of the NKPC in contrast to its NCPC counterpart is that the parameters in equation (3) are derived from deep structural parameters and therefore bear a precise microeconomic interpretation. Specifically, the parameter β is defined as the rate at which future profits are discounted and the parameter $\kappa_{\widehat{mc}}$ is defined as $(1-\theta)(1-\beta\theta)\xi\theta^{-1}$, where $(1-\theta)$ denotes the probability that a firm will reset its prices in any period t and ξ represents a parameter depending upon returns to scale (Barkbu et al. 2005). Under the NKPC, systematic monetary policy cannot influence real variables such as unemployment and output even in the short-run since rational agents can predict what the policy outcomes and act upon those anticipations. Monetary authorities are only able to have an impact on real macroeconomy variables by creating a divergence between actual and expected inflation (Humphrey, 1985). Another fundamental building block in the construction of the NKPC links the marginal costs of firms to the output gap. Under certain assumptions concerning the technology, preferences and the labour market process, marginal costs are assumed to be procyclical such that:

$$\kappa_{\widehat{mc}}\widehat{mc} = \kappa_{(y-\widehat{y})}y - \hat{y} \tag{4}$$

With $\kappa_{(y-\widehat{y})} > 0$. Consequentially, a rational is created for incorporating measures of the output gap into the NKPC; resulting in an "output-gap-based" specification of the NKPC i.e.

$$\pi_t = \beta_i\pi^e_{t+h|t} + \kappa_{(y-\widehat{y})}y - \hat{y} + \varepsilon_t \tag{5}$$

A forerunning complexity in estimating the NKPC concerns the choice of the forcing variable, that is, whether the marginal cost based NKPC (i.e. equation 3) or the output-gap based NKPC (i.e. equation 5) would produce a significant fit when applied to empirical data. Even though theory depicts that marginal costs are the forcing variable in the NKPC, it is problematic to find a direct estimate of marginal costs. Initially, Gali and Gertler (1999) had proposed to proxy the real marginal cost with unit labour costs and yet Roberts (2001); Rudd and Whelan (2001), Genberg and Paulwels (2005) and Mazumder (2010) have all argued that unit labour costs are a poor proxy for marginal costs since they are procyclical and can only capture a limited portion of economic activity. On the end of the sepctrum, the use of the output gap has also been found to be a poor proxy of marginal costs in the NKPC as it often produces an insignificant estimate (Rudd and Whelan, 2007) or the wrong regression coefficient sign (i.e. Fuhrer (1997); Gagnon and Khan (2001) and Dees et. al. (2009)). Given the statistical failure of the NKPC when confronted with data, some authors, such as Hall et. al. (2009) and Kim and Kim (2009), have argued that the misspecification of the NKPC is primarily due to the omission of structural breaks and unobserved nonlinearity in the regression equations. Paloviita and Mayes (2005) and Lee and Yoon (2012), successfully demonstrate this argument by employing nonlinear econometric models to obtain significant empirical estimates of the NKPC. And yet another distinct cluster of authors, which are inclusive of Fuhrer and Moore

(1995) as well as Mankiw and Reis (2002); have opted to circumvent the problem of NKPC parameter inconsistencies by theoretically extending the NKPC into its hybrid version which incorporates measures of inflation inertia into the traditional NKPC. In absence of inflation inertia or lagged inflation variables, these authors argue that the traditional NKPC rests upon the unrealistic assumption of complete flexibility in the inflation process in which an inflation target can be achieved without any significant output costs. Consequentially, the hybrid version of the NKPC is able to account for the longer lasting effects of monetary policy while being able to account for persistence in the inflation process due to delayed effects of monetary policy on inflation (Paloviita, 2008). Under the theoretical construct of the hybrid NKPC (HNKPC), a certain portion of overall inflation is determined by previous inflation i.e. backward-looking expectations. In its empirical form, the HNKPC relates current inflation to both currently expected future inflation, the lagged inflation rate and a measure of marginal costs i.e.

$$\pi_t = \gamma_b \pi^e_{t|t-h} + \gamma_f \pi^e_{t+h|t} + \kappa_\Psi \Psi \quad (6)$$

The regression coefficients γ_f and γ_b reflect the degree of forward-lookingness and inertia in inflation, respectively. By design, the HNKPC generates prices stickiness whilst simultaneously reflecting inflation inertia and, as a result, encompasses number of Phillips curve specifications i.e. the NCPC (i.e. $\gamma_f = 0$) and the NKPC (i.e. $\gamma_b = 0$). Empirically, estimates of the HNKPC have proven to produce satisfactory regression estimates regardless of whether the output-gap (Linde (2005), Burger and Du Plessis (2007); Vogel (2008)) or the labour share (Gali et. al. (2005) and Lanne and Luoto (2011)) are used as the driving variable. Furthermore, Correa and Minella (2010), Areosa et. al. (2011) and Lee and Yoon (2013) have demonstrated the compatibility of the HNKPC with regime-based econometric models regardless of whether unit labour costs or the output gap are used as proxies for the driving variable in the estimated regressions.

2.2 Modeling Asymmetric Phillips Curve In A Logistic Smooth Transition Regression (LSTR) Model

Our baseline STR model takes the form:

$$y_t = \phi' \psi_{t1} (1-G(\zeta_{t-d}; \lambda, c) + \Theta' \psi_{t2} G(\zeta_{t-d}; \lambda, c) + \varepsilon_t \quad (7)$$

Where y_t is a scalar; $\phi' = (\phi_0, \phi_1,\ldots, \phi_p)'$; $\Theta' = (\Theta_1, \Theta_2,\ldots, \Theta_p)'$; ψ_t represents the vector of explanatory variables; ϕ' and Θ' are parameter vectors and $\varepsilon_t \sim$ iid $N(0, h^2{}_t)$. The transition function $G(\zeta_{t\text{-}d}; \lambda, c)$ determines whether the economy is in the 'high regime', the 'low regime' or is transitioning between the two. The variable $\zeta_{t\text{-}d}$ is the transition variable; the variable λ measures the smoothness of transition between the regimes and c represents the threshold parameter that measures the location of the transition function. Different choices exist for the transition function $G(\zeta_{t\text{-}d}; \lambda, c)$ which give rise to different types of regime switching behaviour. For instance, when $G(\zeta_{t\text{-}d}; \lambda, c) = 0$, then equation (7) reduces to a linear model; whereas when $G(\zeta_{t\text{-}d}; \lambda, c) = 1$, equation (7) transforms into a two regime TAR model with abrupt regime-switching behaviour. When $0 < G(\zeta_{t\text{-}d}; \lambda, c) < 1$, then the model is a weighted average of the 'low regime' and the 'high regime'. In further specifying the transition function $G(\zeta_{t\text{-}d}; \lambda, c)$, we use the following logistic function:

$$G(\zeta_{t\text{-}d}; \lambda, c) = 1 + \exp\{-\lambda\,(\zeta_{t\text{-}d} - c_K)\}^{-1},\ \lambda>0 \qquad (8)$$

From which we can further decompose the resulting logistic smooth transition regression (LSTR) model into two model specifications dependent upon whether the threshold variable, c_K, assumes the functional form of K=1 or K=2. When K=1, the model parameters may change monotonically depending on the transition variable s_t., thus yielding the LSTR(1) model. When K=2, the parameters change depending upon whether the transition variable is below c_1 or above c_2, hence we refer to this regression specification as the LSTR(2) model. However, prior to determining whether the LSTR(1) or LSTR(2) model is the most suitable specification, we must first test for linearity within the data generating process. In referring back to equation (7), the null hypothesis of linearity can be retrospectively expressed as H_0: $\Theta_1 = 0$. However, the testing procedure is complicated by the presence of unidentified nuisance parameters λ and c, under the null hypothesis. As a means of circumventing the identification problem, Luukkonen et. al. (1988) propose a solution to replace the transition function $G(\zeta_{t\text{-}d}; \lambda, c)$ by a suitable Taylor series which is expanded around $\lambda = 0$. In practice, this is performed by constructing the following auxiliary function:

$$y_t = \phi'\ \psi_t\ (1\text{-}G_\lambda)(\zeta_{t\text{-}d}; \lambda= 0, c) + \Theta'\ \psi_t\lambda\ G_\lambda(\zeta_{t\text{-}d}; \lambda= 0, c) + \varepsilon^*{}_t \qquad (9)$$

Where $G_\lambda(.)$ indicates the first derivative of $G(\zeta_{t-d};\ \lambda = 0,\ c)$ with respect to λ. By substituting this expression into equation (9) results in:

$$y_t = \delta_0 + \delta_1\psi^*_t + \beta'_1\psi^*_t\zeta_{t-d} + \beta'_2\psi^*_t\zeta^2_{t-d} + \varepsilon^*_{t2} \qquad (10)$$

In the re-parameterized equation (10), the identification problem is no longer present and consequentially, testing the null hypothesis is equivalent to testing a re-specified null hypothesis of $H_0' = \beta'_1 = \beta'_2 = 0$. This can be tested via a Lagrange Multiplier (LM) test statistic (LM_1) which retains an asymptotic χ^2 distribution with p+1 degrees of freedom, where p is the dimension of the vector ψ. However, the process specified in equation (10) can be explosive and the LM test could have a low power against the alternative hypothesis when the model is LSTAR and the intercept is different across regimes (Escribano and Jorda, 2001). To overcome this difficulty, Luukkonen et. al. (1988) opt to replace the transition function with a third order Taylor approximation i.e.

$$y_t = \delta_0 + \delta_1\psi^*_t + \beta'_1\psi^*_t\zeta_{t-d} + \beta'_2\psi^*_t\zeta^2_{t-d} + \beta'_3\psi^*_t\zeta^3_{t-d} + \varepsilon^*_{t3} \qquad (11)$$

Where the null hypothesis can now be tested as $H''_0 = \beta'_1 = \beta'_2 = \beta'_3 = 0$. Under the null hypothesis of linearity, the LM test statistic is still applicable and has as asymptotic χ^2 distribution with 3(p+1) degrees of freedom.

The next step in the specification process is to select an appropriate transition variable, c_t, from which the LM2 statistic is computed for several candidates and the variable which produces the lowest p-value is selected. Once an appropriate transition variable has been selected, the econometrician has got to select whether the STR model follows the LSTR(1) or the LSTR(2) function. Terasvirta (1994) suggests employing a decision rule using a sequence of tests based on the following hypotheses derived from equation (11):

$$\begin{aligned} &H_{03}: \beta_3 = 0 \\ &H_{02}: \beta_2 = 0 \mid \beta_3 = 0 \qquad (12) \\ &H_{01}: \beta_1 = 0 \mid \beta_3 = \beta_2 = 0 \end{aligned}$$

The above hypotheses are to be tested by F-tests denoted as F3, F2 and F1 respectively. The decision rule is that the LSTR(2) model is selected if the p-value corresponding to F2 is the smallest while in the case of the smallest p-value associated with either F1 or F3, the LSTR(1) model should be preferred. If the test fails to provide a clear-cut choice between the two options, Teravirsta (1994) recommends the econometrician to fit both models and decide on the appropriate model at the evaluation stage. Subsequent to selecting an appropriate STR model, the parameters of the chosen model can be estimated through optimization procedures. Escribano and Jorda (2001) points out that estimation can be made efficient by making use of the fact that, when the coefficient parameters of γ and c (see equations (7)) are fixed, the models are linear in parameters. In this case the parameters of ϕ and Θ can be estimated by least squares (LS) method. Conditioning upon these estimates, we can obtain the estimates for γ and c. Hence the parameter vector of ψ_t is estimated by minimizing the following objective function:

$$\psi^* = \min_\psi \sum_{t=1}^{T}(y_t - G(z_t, y_t : \psi))^2 \qquad (13)$$

Once the parameters have been estimated, it is imperative to investigate the validity of the estimated model. In our empirical study, we employ three diagnostic testing procedures. Firstly we test for no error autocorrelation based on the regression of the estimated residuals from the STR model on lagged residuals and the partial derivatives of the log-likelihood function with respect to the model parameters. Secondly, we test for no remaining non-linearity against the alternative hypothesis of additional nonlinearity. And lastly, we perform the LM-test of no ARCH as well as the Jarque-Bera test for normality.

3 DATA DESCRIPTION AND UNIT ROOT TESTS

The dataset consists of the annual growth in the gross domestic product (*y*); inflation in total consumer prices (π); unit labour costs (*ulc*), the real effective exchange rate (*reer*), import prices (*imp*), export prices (*exp*). The described data has been collected on a quarterly basis over a period of 44 years i.e. 1970:01 to 2014:04 from the South African Reserve Bank (SARB) online database. Following Nell (2008) and Burger and Marnikov (2007), we are able to derive the output gap variable by applying the Hodrick-Prescott (HP) filter to the output growth time series and extracting a smooth trend of the output variable (i.e. $\hat{y}$). Ultimately, the output gap variable is computed as the difference between the actual output series and the computed HP output trend (i.e. $y-\hat{y}$). Furthermore, we choose to proxy the backward measure of inflation (i.e. $\pi^e_{t|t-h}$) by applying a lag-distributed model on the inflation data; whereas the forward-looking inflation expectations variable ($\pi^e_{t|t+h}$) is proxied by data collected through an inflation expectations survey as published by the Bureau of Economic Research (BER). In further following Burger and Marnikov (2006) as well as Correa and Minella (2010), we chose to proxy our supply shock variables through the exchange rate ($REER$) variable as well through the terms of trade (TOT) variable. The later variable is computed as percentage representation of the ratio between export prices and import prices (i.e.$TOT=\frac{exp}{imp}\times 100\%$).

Having outlined out dataset, we proceed to make use of the Augmented Dickey-Fuller (ADF) and Phillip and Perron (PP) unit root tests in order to examine the integration properties of the time series. As is reported in Table 1 below, all the time series are found to be stationary in their levels (i.e. integrated of order I(0)), thus providing us with substantial evidence against possible spurious regressions obtained in the estimating phase of the empirical analysis.

Table 1: Unit root tests results

	ADF test statistic		PP test statistic		decision
	Drift	Trend	Drift	trend	
Y	-6.32***	-6.30***	-10.26***	-10.23***	I(0)
π	-3.22**	-4.13***	-6.33***	-7.27***	I(0)
ulc	2.59*	-0.90	3.79***	-0.54	I(0)
$\pi^e_{t\|t-h}$	3.21**	-3.95**	-6.59***	-7.08	I(0)
$\pi^e_{t\|t+h}$	-3.09**	-3.97**	-6.72***	-7.53***	I(0)
Reer	-6.55***	-6.54***	-13.18***	-13.17***	I(0)
TOT	-8.49***	-8.46***	-12.98***	-12.95***	I(0)

Significance level codes: '***', '**' and '*' represent the 1%, 5% and 10% significance levels respectively. The lag length for each of the time series with the ADF tests is selected through the minimization of the AIC and BIC.

4 EMPIRICAL ANALYSIS

4.1 LINEARITY TESTS

To facilitate our empirical analysis, we begin by constructing a total of 10 regression specifications comprising of two estimation equations for the NCPC model specification; four estimation equations for the NKPC specification and another four estimation equations for the HNKPC specification. The first equation under the NCPC is obtained by regressing output gap variable on the inflation rate variable whereas the second equation for the NCPC is constructed by adding supply shock terms (i.e. the real exchange rate and the terms of trades) as independent variables; which in effect, transforms the model into a triangular version of the NCPC. Next, we derive our NKPC specifications by first constructing two regressions consisting of the output-based version of the NKPC, on one hand, and the marginal-costs version, on the other hand. The remaining two NKPC regressions are obtaining by adding the supply shock variables to both out-gap based and marginal costs based versions of the NKPC. Finally, the HNKPC specifications are derived in a similar manner to those of the NKPC, except in the former specifications, inflation inertia is added to each of the regression equations.

As first step in the empirical process, we test each of the regression equations for the presence of nonlinearities and decide on an appropriate transition variable as well as deciding on whether to fit a LSTR(1) or a LSTR(2) model to the data. In order to facilitate this, we conduct a sequence of F-tests for all potential transition variables and further compute their corresponding p-values. The results of the performed linearity tests are reported in Table 2.

Table 2: Linearity Tests

model type	equation	transition variable	test statistics				decision
			F	F_4	F_3	F_2	
NCPC	1.1	$\pi^e_{t\|t-h}$	0.0110	0.0248	0.3970	0.0204	LSTR(1)#
		$y-\hat{y}$	0.6312	0.3455	0.7799	0.3842	Linear
	1.2	$\pi^e_{t\|t-h}$	0.0387	0.4707	0.0125	0.2273	LSTR(2)#
		$y-\hat{y}$	0.5033	0.3095	0.2503	0.9040	Linear
		$REER$	0.0494	0.6133	0.3928	0.0056	LSTR(1)
		TOT	0.1485	0.5989	0.0673	0.2330	Linear
NKPC	2.1	$\pi^e_{t\|t+h}$	0.3711	0.7327	0.1806	0.2921	Linear
		ulc	0.0000	0.0894	0.0001	0.0000	LSTR(1)#
	2.2	$\pi^e_{t\|t+h}$	0.0245	0.1312	0.4221	0.0108	LSTR(1)#
		$y-\hat{y}$	0.0520	0.9368	0.0038	0.6319	LSTR(2)
	2.3	$\pi^e_{t\|t+h}$	0.3433	0.6872	0.2627	0.2038	Linear
		ulc	0.0000	0.1214	0.0425	0.0000	LSTR(1)#
		$REER$	0.0040	0.9497	0.0101	0.0040	LSTR(1)
		TOT	0.6562	0.9254	0.2887	0.4438	Linear
	2.4	$\pi^e_{t\|t+h}$	0.0450	0.2897	0.0805	0.0855	LSTR(2)#
		$y-\hat{y}$	0.8279	0.3123	0.9117	0.8088	Linear
		$REER$	0.0614	0.5807	0.1281	0.3302	Linear
		TOT	0.4269	0.2889	0.3611	0.5824	Linear
HNKPC	3.1	$\pi^e_{t\|t-h}$	0.0179	0.0809	0.2949	0.2374	LSTR(2)
		$\pi^e_{t\|t+h}$	0.2785	0.8056	0.1943	0.1481	Linear
		ulc	0.0001	0.3127	0.0015	0.0018	LSTR(2)#
	3.2	$\pi^e_{t\|t-h}$	0.0227	0.0098	0.5859	0.1153	LSTR(1)#
		$\pi^e_{t\|t+h}$	0.1118	0.5547	0.2079	0.0484	Linear
		$y-\hat{y}$	0.2319	0.0691	0.4335	0.6007	Linear
	3.3	$\pi^e_{t\|t-h}$	0.0011	0.1061	0.0002	0.5531	LSTR(2)
		$\pi^e_{t\|t+h}$	0.1437	0.4821	0.6043	0.0240	Linear
		ulc	0.0003	0.3089	0.0930	0.0000	LSTR(1)#
		$REER$	0.0064	0.5948	0.0957	0.0015	LSTR(1)
		TOT	0.8017	0.9556	0.3892	0.5387	Linear
	3.4	$\pi^e_{t\|t-h}$	0.0142	0.1309	0.0056	0.5074	LSTR(2)#
		$\pi^e_{t\|t+h}$	0.0276	0.2843	0.2041	0.0161	LSTR(1)
		$y-\hat{y}$	0.5926	0.4193	0.2488	0.9239	Linear
		$REER$	0.0222	0.1840	0.4234	0.0078	LSTR(1)
		TOT	0.6123	0.9173	0.1602	0.6165	Linear

The F-tests for nonlinearity are performed for each possible candidate of the transition variable and the variable with the strongest test rejection (i.e. the smallest p-value) is tagged with symbol #. p-values less than 0.0005 are reported as .0000

Based on the reported results, we observe that there exists at least one significant nonlinear relationship for each specified version of the Phillips curve. In particular, we observe that for the NCPC (equation 1.1), it is appropriate to fit a LSTR(1) function with inflation inertia being the transition variable whereas under the NCPC versions with supply shocks included (equation 1.2), we are obliged to fit a LSTR(2) in which inflation inertia remains as the transition variable. We next divert our attention to the results of the linearity tests performed on the four versions of the NKPC. Under the marginal costs based NKPC (equation 2.1), we find that a LSTR(1) regression with unit labour costs being the transition variable is a suitable model whereas for the output gap based NKPC (equation 2.2), a LSTR(1) model is also applicable but with inflation expectations being an appropriate transition variable. Also concerning the marginal-cost based NKPC with supply shocks (equation 2.3), we similarly find a LSTR(1) model with unit labour costs acting as a transition variable whilst, on the other hand, a LSTR(2) model with inflation expectations being the transition variable is more suitable for the NKPC inclusive of supply shocks (equation 2.4). For the HNKPC specifications, we observe that for the marginal cost based version (equation 3.1) and the marginal cost version with supply shocks (equation 3.3), unit labour costs are appropriate transition variables, expect in the former case we fit a LSTR(2) model whereas in the latter case we fit a LSTR(1). For the cases of the output gap based HNKPC (equation 4.2) and the output gap based version inclusive of supply shocks (equation 3.4), the inflation expectations variables is a suitable transition variable with the exception that a LSTR(1) is fitted for the former case and a LSTR(2) for the latter case..

4.2 LSTR REGRESSION ESTIMATES

Having conducted our linearity tests and designated a transition variable for each of the estimated equations, we proceed to estimate each of the regression specifications through the use of conditional maximum likelihood estimates. The regression results are reported as follows. In Table 3, we report the results for the two NCPC specifications; in Table 4 we reported the results for the four NKPC specifications whereas in Table 5 we report the results for the four HNKPC specifications.

Table 3: STR estimates of the NCPC model specification

equation	1.1	1.2
transition variable	$\pi^e_{t\|t-h}$	$\pi^e_{t\|t-h}$
	linear part	
$\pi^e_{t\|t-h}$	0.79	0.89
	(0.00)***	(0.00)***
$y - \hat{y}$	-0.04	-0.03
	(0.67)	(0.77)
$REER$		0.17
		(0.03)**
TOT		-0.04
		(0.02)**
	nonlinear part	
$\pi^e_{t\|t-h}$	-0.05	-0.44
	(0.92)	(0.00)***
$y - \hat{y}$	-0.27	-0.16
	(0.34)	(0.35)
$REER$		-0.43
		(0.0.0)***
TOT		0.02
		(0.64)
γ	10.00	10.00
	(0.27)	(0.99)
c_1	15.65	5.14
	(0.00)***	(0.06)**
c_2		14.69
		(0.76)
R^2	0.39	0.46
SSR	2838.02	2579.10

t-statistics reported in parentheses. Significance level codes are as follows: '***', '**' and '*' represent the 1%, 5% and 10% significance levels respectively.

In reference to the results of the NCPC as reported in Table 1, we observe that for both equation 1.1 and 1.2 (i.e. the NCPC with and with supply shocks, respectively), the signs of the inflation inertia variable are correct in the lower regime of the STR model. And yet we further observe that even though the sign of the output gap variable is correct in the regression equations, they are however insignificant. Concerning the NCPC specification inclusive of supply shocks (equation 1.2), we note that the sign on the terms of trade variable is only significant in the lower regime of regression equation 1.2; whilst the real effective exchange rate is the only supply shock variable which significantly produces he correct coefficient sign in the upper regime of the same regression equation. The described empirical results are generally in coherence with those obtained in Nell (2000) as well as with those obtained in Burger and Marnikov (2007) who both find that output gap is an insignificant variable within the NCPC model estimated for South African data. Thus, and in alignment with aforementioned authors, we conclude that the NCPC, both with and without supply shocks, provides a poor fit for South African data.

Table 4: STR estimates of the NKPC model specification

Equation	2.1	2.2	2.3	2.4
transition variable	ulc	$\pi^e_{t\|t+h}$	$\pi^e_{t\|t+h}$	$\pi^e_{t\|t+h}$
		linear part		
$\pi^e_{t\|t+h}$	-0.07	0.16	-0.10	-0.33
	(0.86)	(0.65)	(0.37)	(0.52)
$y-\hat{y}$		-0.44		-0.46
		(0.06)*		(0.13)
ulc	-0.29		3.09	
	(0.64)		(0.00)***	
$REER$			0.21	-0.31
			(0.00)***	(0.06)*
TOT			-0.13	0.02
			(0.03)**	(0.81)
		nonlinear part		
$\pi^e_{t\|t+h}$	0.41	0.19	0.09	0.69
	(0.37)	(0.60)	(0.56)	(0.18)
$y-\hat{y}$		0.19		0.21
		(0.45)		(0.51)
ulc	-0.29		-3.25	
	(0.70)		(0.12)	
$REER$			-0.29	0.51
			(0.01)**	(0.00)***
TOT			0.10	-0.05
			(0.13)	(0.59)
γ	13.75	24.02	10.54	7.08
	(0.37)	(0.53)	(0.09)*	(0.30)
c_1	5.99	6.46	4.20	5.88
	(0.00)***	(0.00)***	(0.00)***	(0.00)***
c_2				
R^2	0.38	0.40	0.55	0.45
SSR	2854.17	2750.22	2054.95	2508.99

t-statistics are reported in parentheses. Significance level codes are as follows: '***', '**' and '*' represent the 1%, 5% and 10% significance

Next, we examine the STR regression estimates obtained for the NKPC specifications as reported in Table 5. We firstly observe that only in the lower regime of the output gap based version of the NKPC, does the model produces correct coefficient signs on the inflation expectations variable and the driving variable; even though the coefficient signs on the inflation expectations variable is insignificant. However, in the remaining versions of the NKPC, the inflation variable either produces the wrong sign (i.e. in the lower regimes of equation 2.1 and 2.4) or the driving variable similarly has the wrong sign (i.e. in the lower regimes of equations 2.1, and in the upper regimes of equations 2.1, 2.2, 2.3 and 2.4). Du Plessis and Burger (2013) make similar observations in finding that the inflation expectations variable produces the correct sign whereas the driving variable produces a wrong sign on the NKPC model for South African data. In turning our attention exclusively to regression equations 2.3 and 2.4, we observe that the supply shock variables only produce significant coefficient estimates with the correct signs for the real effective exchange rate in lower regimes of equation 3.4 and the upper regime of both equations 2.3 and 2.4. On the other hand the terms of trade variable produces no significant coefficient estimates, albeit the regression coefficients are of a correct sign. However, in none of the aforementioned regressions do the inflation expectations and the driving variables simultaneously produce significant and correct coefficient estimates. Therefore, and in similarity to the results obtained for the NCPC specification, we find that the NKPC does not provide a good fit towards the data.

Table 5: STR estimates of the HNKPC model specification

Equation	3.1	3.2	3.3	3.4
transition variable	ulc	$\pi^e_{t\|t-h}$	ulc	$\pi^e_{t\|t-h}$
		linear part		
$\pi^e_{t\|t-h}$	0.42	0.57	0.01	0.74
	(0.04)**	(0.00)***	(0.92)	(0.00)***
$\pi^e_{t\|t+h}$	0.39	0.41	0.03	0.43
	(0.03)*	(0.00)***	(0.84)	(0.00)***
$y-\hat{y}$		-0.13		-0.10
		(0.10)*		(0.32)
ulc	14.52		6.17	
	(0.00)***		(0.12)	
$REER$			0.25	0.20
			(0.01)**	(0.00)***
TOT			-0.11	-0.02
			(0.14)	(0.13)
		nonlinear part		
$\pi^e_{t\|t-h}$	0.80	0.21	0.40	-0.48
	(0.00)***	(0.68)	(0.18)	(0.00)***
$\pi^e_{t\|t+h}$	0.85	-0.06	0.32	-0.06
	(0.00)***	(0.75)	(0.26)	(0.63)
$y-\hat{y}$		-0.33		-0.18
		(0.25)		(0.25)
ulc	-14.80		-0.04	
	(0.00)***		(0.99)	
$REER$			-0.42	-0.44
			(0.05)*	(0.00)***
TOT			0.11	-0.01
			(0.26)	(0.083)
γ	10.00	10.14	2.28	10.00
	(0.71)	(0.18)	(0.10)*	(0.99)
c_1	1.81	15.83	4.07	4.89
	(0.00)***	(0.00)***	(0.00)***	(0.00)***
c_2	2.62			14.58
	(0.00)***			(0.00)***
R^2	0.57	0.50	0.58	0.58
SSR	2015.57	2304.42	1928.63	2063.24

t-statistics reported in parentheses. Significance level codes are as follows: '***', '**' and '*' represent the 1%, 5% and 10% significance

Finally, we analyze the estimation results for all the specified variations HNKPC as given in Table 5. As can be observed, the marginal cost based HNKPC specification without supply shocks (equation 2.1) and output gap based HNKPC specification without supply shocks (equation 2.2) provide a good fit for the data. Notably, the fit of the HNKPC to South African data has also been confirmed in the studies of Du Plessis and Burger (2013) as well as in that of Malikane (2014). In further referring to the results reported in Table 5, we find it encouragingly that for the output gap based HNKPC, the sum of the coefficients for the inflation inertia variable and the inflation expectations variable is close to unity (i.e. $\pi^e_{t|t-h}$+ $\pi^e_{t|t-h}$ = 0.98). These results are an improvement over those obtained in Du Plessis and Burger (2013) and are closer in nature to those obtained in Malikane (2014) who finds that under the marginal cost based South African HNKPC curve, the sum of the coefficients on the inflation inertia and inflation expectations variables is close to unity. As rigorously discussed by Gali and Gertler (2001), this is a theoretically sufficient condition for proving the validity of the HNKPC specification. Therefore, in placing our obtained results into perspective, we are able to conclude that the output-based HNKPC without supply shocks provides the best fit for the data used in our current study.

4.3 Diagnostic Tests

As a final step in the empirical process, we evaluate the estimated model specifications by applying a battery of diagnostic tests and we report the test results in Table 6 below. As previously discussed we employ three diagnostic tests namely; test for no error autocorrelation, tests for neglected conditional heteroskedasticity (ARCH) and the Jarque-Bera (JB) test for normality. As Table 6 reveals, a majority of all of the estimated regression specifications pass the diagnostic tests. In particular, we observe that the probability values of the LM test statistics for each of the evaluated regression specifications shows that they are no error autocorrelation up to the 8^{th} lag. Similar inferences are drawn for the tests of no ARCH effects as the p-values of the test statistics reveal that the null hypothesis of no ARCH effects can be reject up to the 8^{th} lag. However, when diverting our attention to the results for the JB tests statistics for normality our results turn a bit abstruse. We specifically observe that misspecification tests for normality indicate that a majority of the NCPC and NKPC specifications do not pass the JB normality tests. And yet, we also observe that the all the HNKPC specifications are able to pass the JB misspecification tests, which is encouraging because, as previously mentioned, the HNKPC specifications without supply shocks provides the best fit of the data.

Table 6: Residual diagnostic tests

Equation	1.1	1.2	2.1	2.2	2.3	2.4	3.1	3.2	3..3	3.4
Transition variable	$\pi^e_{t\|t-h}$	$\pi^e_{t\|t-h}$	ulc	$\pi^e_{t\|t+h}$	$\pi^e_{t\|t+h}$	$\pi^e_{t\|t+h}$	ulc	$\pi^e_{t\|t-h}$	ulc	$\pi^e_{t\|t-h}$
					No Autocorrelation					
LM(2)	8.59 (0.00)***	7.61\ (0.00)	16.54 (0.00)***	10.97 (0.00)***	11.25 (0.00)**	9.46 (0.00)***	11.27 (0.00)***	15.64 (0.00)***	12.68 (0.00)***	8.54 (0.00)***
LM(4)	6.14 (0.00)	5.69 (0.00)	12.34 (0.00)***	7.78 (0.00)***	7.81 (0.00)***	7.18 (0.00)***	4.83 (0.00)***	8.27 (0.00)***	7.92 (0.00)***	5.41 (0.01)**
LM(6)	4.97 (0.00)***	4.99 (0.00)	7.24 (0.00)***	5.00 (0.00)***	5.19 (0.00)***	4.67 (0.00)***	4.17 (0.01)**	5.72 (0.00)***	6.58 (0.00)***	3.13 (0.03)*
LM(8)	3.93 (0.00)***	2.97 (0.00)	4.19 (0.00)***	2.42 (0.00)	4.05 (0.00)***	3.51 (0.00)***	3.69 (0.01)**	4.91 (0.00)***	4.67 (0.00)***	2.98 (0.04)*
					No ARCH					
ARCH(8)	17.23 (0.02)**	11.02 (0.03)*	12.51 (0.10)*	11.21 (0.10)	12.63 (0.08)	10.21 (0.02)	15.77 (0.01)	4.09 (0.85)	5.69 (0.68)	4.23 (0.83)
					Normality					
J-B(8)	1. 71 (0.42)	2.78 (0.30)	6.54 (0.03)	2.75 (0.25)	8.80 (0.00)	2.37 (0..30)	6.17 (0.04)	8.72 (0.01)	6.77 (0.02)	7.05 (0.02)

LM(j) is a LM test statistic for jth order autocorrelation. ARCH(j) is the LM test statistic for the jth order autoregressive conditional heteroskedasticity. J-B is the Jarque Bera's test statistic for normality as performed on the 8th lag of the regression specifications. The p-values of all the associated tests statistics are reported in parentheses.

5 CONCLUSSION

The empirical evolution of the Phillips curve has undergone various stages and recently much attention has been directed towards examining asymmetric effects within the relationship. Previous studies investigating the nonlinear Phillips curve for South Africa have exclusively focused on using abrupt regime switching models and notably none of these studies has managed to provide a fit of the data to the various model employed. In our current study, we deviate from the traditional norm and opt to use smooth transition regression (STR) models to investigate nonlinear effects within the South African Phillips curve for three versions of the Phillips curve specification namely; the New Classical Phillips curve; the New Keynesian Phillips curve and the Hybrid New Keynesian Phillips curve. Our empirical results indicate that whilst all versions of the New Classical and New Keynesian versions of the Phillips curve fail to produce an appropriate fit for the data; both the marginal cost based as well as the output gap based versions of the Hybrid New Keynesian Philips curve manage to produce significant fits towards the observed data. Notably, with the inclusion of asymmetric effects within the estimated empirical models, the common problem of a perverse sign on the marginal cost and the output gap variables (i.e. the driving variables in the system) appears to be resolved whereas supply shocks appear play no significant role within the estimated models. Therefore, from a policy perspective, we conclude that monetary policy asymmetrically affects the demand side of the economy and works through both inflation inertia as well as inflation expectations, with inflation inertia appearing to have more of a significant effect on policy decisions in comparison to inflation expectations. On the end of the spectrum, our empirical results also put into question as to whether monetary policy indeed has any influence on the supply side of the economy.

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