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Macroeconomic Modelling: From System-of-equations to Dynamic Stochastic Equilibrium A South African Example

by

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1. Introduction

> "One of the functions of theoretical economics is to provide fully articulated, artificial economic systems that can serve as laboratories in which policies that would be prohibitively expensive to experiment with in actual economies can be tested at much lower cost…"
>
> Lucas (1980)

This statement by Robert Lucas neatly summarizes one of the chief aims of the theoretical economist, that is to create a stable, artificial economic system in which experiments can be conducted and theories tested in a closed environment, removing the possibility of causing irreversible damage to the actual economy.

It is, however, exactly this function of the theoretical economist that has lead to much dissent and disagreement among economists. How does one abstract from reality to construct a simple yet powerful and robust artificial economic system? Is it prudent or even possible to draw useful conclusions from policy experiments utilizing these models? Recent developments in macroeconomic modelling have brought us much closer to finding a satisfactory answer to the former and an, albeit tentative at present, affirmative answer to the latter.

In his 2004 Nobel prize lecture, Edward Prescott describes what he calls a "revolution in macroeconomics", a transformation in methodology that fundamentally changed the way in which we view macroeconomic questions. Prior to this transformation, macroeconomics was largely seen as a separate field of study relative to other economic disciplines and there was believed to be little hope of integrating macroeconomics with the rest of economics. This widely held view proved to be unfounded.

Before the transformation, macroeconomic models were systems of equations that determined outcomes based on current policy actions, stochastic shocks and values of certain predetermined variables. These were the so-called macro-econometric models (MEM)[1] which are defined as "a set of behavioural equations…representing the structure and operations of an economy, in principle based upon the behaviour of individual economic agents." (Valadkhani, 2004: 266)

The basic mathematical structure of such a model is given by

$$x_{t+1} = f(x_t, u_t, \varepsilon_t) \tag{1}$$

[1] Based on the recommendations of the Cowles Commission after World War II

where x_t represents the state or position of the dynamic system at the beginning of period t, u_t represents the control or policy variables and ε_t represents the stochastic shock (Prescott, 2004: 372). Each equation in the system is determined up to a set of parameters, after which statistical estimation techniques are used to select the parameters that define the function f. In this tradition, success in macroeconomics was to have your equation incorporated into the macro-econometric models of the time.

Criticism of the system-of-equation approach and its Keynesian underpinnings, spearheaded by economists such as Robert Lucas (1976), Christopher Sims (1980) and Milton Friedman (1968), led to a revolution in the methodology of macroeconomic modelling. This revolution, greatly influenced by the 1982 Kydland and Prescott paper, "Time to build and Aggregate Fluctuations", signified a dramatic paradigm shift concerning macroeconomic modelling. The "next generation" models that came into being as a result of this revolution went far in reconciling macroeconomics with the rest of the economics universe.

The rest of this essay will focus specifically on these next generation models that came into being after the "methodological revolution", spearheaded by economists such as Robert Lucas, Finn Kydland, Edward Prescott, Christopher Sims and Charles Plosser. More concretely, Section 2 will elaborate on the criticism of the traditional system-of-equations approach (focusing on the Lucas and Sims critiques) while Section 3 provides an overview of the main characteristics of the next generation models resulting from this criticism.

Section 4 then provides an empirical example where a New Keynesian model (as an example of a DSGE model) with productivity shocks and cost-push shocks is estimated for the South African economy. The aim of this exercise is to determine to what extent cost-push shocks, rather than productivity shocks, are responsible for fluctuations in output, inflation and the nominal interest rate. This section relies heavily on the work done by Peter Ireland (2002, 2004) and the New Keynesian model which is fitted is taken from his 2004 paper, "Technology Shocks in the New Keynesian model".

Lastly, Section 5 provides some concluding comments.

2. Criticism of the Traditional Approach

In the late 1960's and 1970's cracks began to appear in the Keynesian foundations of the traditional system-of-equations approach (Diebold, 1997: 4). Intellectuals became increasingly dissatisfied with the lack of microeconomic foundations in Keynesian macroeconomics, the *ad hoc* treatment of sticky prices and expectations and, more fundamentally, the overall modelling approach embodied by the Keynesian tradition. The traditional approach concentrated on the estimation of parameters in equations that represented *ad hoc* decision rules (for example consumption functions, investment function, etc), as opposed to estimating more fundamental parameters such as tastes and technology (Diebold, 1997: 5). These cracks began to widen as the economic facts of the 1970's became apparent and it became clear that Keynesian economics was unable to satisfactorily account for these facts.

The rest of this section examines the two most renowned critiques of the traditional macroeconomic modelling approach, the Lucas Critique (Lucas, 1976) and the Sims Critique (Sims, 1980).

One of the key assumptions of the system-of-equations approach is that the equations characterizing the model are *policy invariant* (Prescott, 2004). This implies that any change in policy would have no effect on the functional form of the equations, parameter values or the behavioural aspects of the model. This rather strong assumption came under sharp criticism in a paper by Robert Lucas in 1976, which has since become known as the Lucas Critique[2].

The paper states that it is unrealistic to assume that policy changes will in no way affect the functioning of the economy and the behavioural relationships between agents. Forward-looking agents will modify their expectations following a change in policy, and this in turn will affect and alter agents' behaviour. Lucas alleged that "any change in policy will systematically alter the structure of econometric models" (Lucas, 1976: 41) and thus it is a fallacy of the first degree to evaluate policy implications and policy effectiveness while assuming that behavioural relationships will remain unaffected by the policy change.

According to Lucas, the assumption of policy invariance in a system-of-equations approach is inconsistent with dynamic economic theory and therefore this approach is fundamentally flawed, at least as far as researching policy implications is concerned (Lucas, 1976). Model based policy evaluation required models with parameters that were insensitive to policy changes, which implied the construction of models where forward-looking expectations were endogenised and "deep parameters" estimated separately (Pagan, 2003). Two of the models under inspection in the subsequent section (Real Business Cycle and Dynamic Stochastic General Equilibrium models) are direct results of this idea.

The Lucas Critique had a wide-ranging impact in academic circles and on the development of macroeconomic models, and is arguably one of the most influential macroeconomic articles of the 1970's (LeRoy, 1992: 235). The empirical relevance of the Lucas Critique, however, has not been proven beyond reasonable

[2] Klein (1989) and Bodkin and Marwah (1988) (among others) offer arguments in rebuttal of the Lucas critique and rational expectations theory, while providing justification for the use of the system-of-eqaution approach to macroeconometric modelling

doubt and is increasingly being questioned[3]. While the reaction to the Lucas Critique in academic circles was dramatic, with many academics heralding the end of policy analysis using large-scale macro-econometric models, modelers tended to ignore it in practice.

A second critique leveled at the traditional system-of-equations approach can be found in an article by Christopher Sims in 1980. Sims argued that the interaction between economic variables in a general equilibrium setting is so pervasive that each structural equation in such a model should include all, or almost all, variables in the model (Christ, 1994: 51). The identification of structural equations through the use of numerous zero restrictions[4], as in the traditional approach, was therefore deemed inappropriate by Sims.

Sims (1980) labeled these restrictions as "incredible" and suggested an alternative to the traditional approach, namely vector autoregressions (VARs). This approach is discussed in slightly more detail in the subsequent section.

3. The Next Generation

Following the critique leveled at the traditional approach by economists such as Lucas and Sims, a new generation of macroeconomic models evolved. This section explores three of these models.

3.1 Vector Autoregressions (VARs)

As mentioned in the previous section, Sims (1980) criticized the use of zero restrictions in identifying structural equations in macroeconomic models. As an alternative, Sims strongly advocated the use of vector autoregressions (VARs) in econometrics.

A univariate autoregression is simply a model where a variable is regressed on its own past values. By logical extension, a VAR is estimated by regressing a set of variables on its own past values as well as the past values of all other variables in the system. Consider the following generalized form of a VAR system (Enders, 1995: 301):

$$x_t = A_0 + A_1 x_{t-1} + A_2 x_{t-2} + \ldots + A_p x_{t-p} + \varepsilon_t \qquad (2)$$

where x_t = an (nx1) vector containing each of the n variables in the VAR
A_0 = an (nx1) vector of intercept terms

[3] See Rudebusch (2002), Linde (2001) and Van Bergeijk and Berk (2001)

[4] For example, when identifying an equation on the grounds of economic theory, only certain variables are included; the coefficients on all other variables in the model are then set equal to zero within the relevant equation (in other words, the variables do not appear on the right hand side of the equation)

A_1 = (nxn) matrices of coefficients
and ε_t = an (nx1) vector of error terms

Sims' approach entails little more than determining which variables to include in the VAR and the determination of the appropriate lag length (Sims, 1980). Variables are selected on the basis of relevant economic theory and various lag length tests could be carried out to select the appropriate lag length. Because of the inclusion of lags of all variables in each equation and the allowance for correlations of disturbances across the different equations, cross-variable linkages are automatically incorporated (Diebold, 1997: 11), thereby incorporating the pervasive interdependence between economic variables that Sims advocated.

VARs will unquestionably be *overparameterized* since many of the coefficient estimates can be properly excluded. However, since the goal is to identify important interrelationships between variables and not make short-term forecasts, as well as the fact that important information may be lost by imposing improper zero restrictions, the exclusion of seemingly unimportant coefficient estimates is not encouraged (Enders, 1995: 301).

An important observation is that the right hand side of (2) contains only predetermined variables and (by assumption) serially uncorrelated error terms with constant variance. Therefore, each equation in (2) can be estimated using ordinary least squares (OLS). According to Enders (1995: 301), one-at-a-time OLS estimation procedures produces estimates that are consistent and asymptotically efficient, despite the possibility of correlated disturbances.

There exists a debate as to whether the variables contained in a VAR need to be stationary. Several authors, including Sims (1980) and Sims, Stock and Watson (1990), argue against differencing even if the variable contains a unit root. As mentioned above, the goal of a VAR analysis is to determine the nature of the relationships among variables, *not* the parameter estimates. Differencing throws away important information pertaining to the co-movement of variables and could influence the estimated interrelationships between the variables in the system.

The abovementioned debate surrounding variable stationarity, as well as the reduced form nature of the standard VAR, precludes any sensible interpretation of the individual coefficient (parameter) estimates. Therefore, the results of an estimated VAR are often presented in the form of impulse response function and/or variance decomposition (Enders, 1995). The impulse response function, defined as the moving average representation of the error vector, traces out the impact of a shock to one of the elements of the error vector on the variables in the VAR system. On the other hand, variance decomposition involves the decomposition of the error variance of a sequence to determine how much of this variance can be attributed to shocks to the error vector.

Stock and Watson (2001) assess to what extent VARs have provided a coherent and credible approach to data description, forecasting, structural inference and policy analysis in the years since its inception. Results are, at best, mixed. With regard to data description and forecasting, VARs have proven to be reliable and powerful tools and are widely used in this capacity. Structural inference and policy analysis, on the other hand, are inherently more difficult because of the problem of differentiating between the concepts of *correlation* and *causation*. This problem cannot be solved with a standard statistical test. Economic theory or institutional knowledge provides the only method for solving this problem (Stock and Watson, 2001).

3.2 Real Business Cycle (RBC) Models[5]

This section investigates the development and main characteristics of the so-called RBC models. These models embody a methodology that led directly to the development of the family of models investigated in the next sub-section, namely DSGE models.

At this stage it is necessary to make yet another important distinction. The Keynesian research program of the middle 20th century was concerned with determining the levels of employment and output at specific instances in time and with how to alter the time paths of important macroeconomic variables (Stadler, 1994: 1750). In the 1970's the Keynesian research program increasingly gave way to the study of business cycles, including the study of the nature and causes of these economic fluctuations.

As Long and Plosser (1983) remarks, business cycles in actual economies seem to be characterized by two broad regularities, namely that ups and downs in individual economic series exhibit a substantial amount of persistence and that measures of various economic activities move together. Lucas (1977: 10) argues that "…they appear to be regularities common to all decentralized market economies…one is led by the facts to conclude that, with respect to the qualitative behavior of co-movements among series, business cycles are all alike…it suggests the possibility of a unified explanation of business cycles…" The aim of the RBC research program was (is) to investigate one such a possible explanation.

The most significant contribution to the development of the RBC program came from the 1982 paper by Finn Kydland and Edward Prescott. According to Sergio Rebelo (2005: 217), Kydland and Prescott introduced three revolutionary ideas in

[5] This section provides a very superficial investigation of the RBC research program. For more extensive surveys of the literature see Huh and Trehan (1991), Mankiw (1989) and McCallum (1988), among others

their paper. The first was that business cycles could be studied using dynamic general equilibrium models. Secondly, it is possible to reconciliate growth and business cycle theory by insisting that business cycle models should be consistent with the empirical regularities in long-run growth. Finally, one can go beyond the qualitative comparison of these models with empirical stylized facts by using calibrated models to generate artificial data to be compared with actual data.

The wave of models that followed this ground breaking paper were referred to as “real business cycle” models because of their emphasis on the role of real shocks in driving the business cycle. RBC models view cycles as “arising in frictionless, perfectly competitive economies with generally complete markets subject to real shocks” (Stadler, 1994: 1751). The typical model would include a representative household aiming to maximize utility through the allocation of consumption and leisure, alongside a representative firm seeking to maximize profits (Kremer *et al*, 2006: 4). RBC models show that, even under these extreme assumptions, cycles can arise through the response of optimizing agents to real shocks (such as productivity or technology shocks). These models regard stochastic fluctuations in productivity as the predominant source of business cycles fluctuations.

The fact that RBC models have almost exclusively been characterized by these productivity shocks has led to the generalization that these models are driven by aggregate “supply shocks” (Plosser, 1989: 57). This generalization can be somewhat misleading. In RBC models, shocks occur to preferences, technologies, or resources and endowments, which cannot be easily translated into either supply or demand disturbances. These shocks will typically affect both demand and supply conditions in a given market (Plosser, 1989: 57).

In many cases, evidence of important shifts in “aggregate demand” are taken as evidence *against* RBC models. But, as mentioned above, many authors question the usefulness of the distinction between demand and supply side shocks as there exists evidence that supply side innovations translate into changes in demand and vice versa (Stadler, 1994: 1751).

Stadler (1994) lists the main features of RBC models: i) a representative agent framework is adopted (which circumvent aggregation problems), ii) households and firms minimize objective functions subject to certain constraints, iii) the cycle is driven by exogenous shocks to technology, iv) agents have rational expectations and v) actual cycles are generated via propagation mechanisms built into the model (these include adjustment through consumption, investment, labour-leisure and inventory decisions).

Despite the apparent theoretical validity of the RBC research program and the promising results of early research, it is widely accepted that a business cycle model based solely on technology shocks fails to capture a number of cyclical phenomena (Stadler, 1994: 1751). On the one hand, many empirical regularities could not be reproduced by these models, while, on the other hand, the way in which these models were evaluated (and the way in which their empirical fit was evaluated) came under strong criticism (Kremer *et al*, 2006: 4).

There exist five major criticisms of the RBC research program: i) no evidence of independent, economy-wide productivity disturbances, ii) no formal econometric tests of the models, iii) RBC models cannot account for the periodicity of cycles, iv) RBC models cannot account for recessions and v) the use of the representative agent framework (Stadler, 1994: 1766). Regarding the testing of RBC models, the use of data filters, such as the Hodrick-Prescott filter, have come under heavy fire (Stadler, 1994 and Cogley and Nason, 1995). It is argued that these filters impose spurious cyclical patterns to the data. Passing a random walk through the HP filter results in cyclical behaviour in the data, even though there are no cycles present in the original series (Stadler, 1994: 1769).

These criticisms have lead to the continued development of RBC models and the incorporation of various additional shocks that are analogous to taste shocks. Extensions to the basic RBC model include more rigorously defined labour markets and the inclusion of money, government and the foreign sector (Stadler, 1994: 1758-1765).

Despite the well-grounded criticism leveled against RBC models, researches soon realized that the RBC research program provided much more than an explanation for the business cycle. It was soon realized that the main contribution of this program was methodological in that it provided a consistent way to "describe and solve a rational expectation stochastic dynamic general equilibrium model" (Kremer *et al*, 2006: 4). This observation leads us directly into our next subsection.

3.3 Dynamic Stochastic General Equilibrium (DSGE) Models[6]

The methodology developed through the RBC research program led directly to the development of the last of the "next generation" of macroeconomic models, namely dynamic stochastic general equilibrium (DSGE) models. As mentioned in the previous section, RBC models assumed prices to be fully flexible, thereby providing no role for macroeconomic policy (fiscal or monetary) in impacting real economic activity. Further research and developments have led to the incorporation of various rigidities (including price stickiness) in these models and has led to what is now called DSGE models (IMF, 2004).

Many of today's DSGE models incorporate the general structure of a RBC model. However, these models incorporate various imperfections and rigidities in the markets for goods,

[6] Again, this is but a short review of the main characteristics of DSGE models

factors of production and financial assets, while also featuring a larger set of stochastic disturbances (Kremer *et al*, 2006: 2). Following the RBC tradition, DSGE models can be described as small scale, structural simultaneous equation models firmly grounded in inter-temporal optimization theory and microeconomic principles. They feature an impulse response structure and are structured around optimizing agents in a general equilibrium environment.

The characteristics that set DSGE models apart from previous modeling strategies are explored by Lim and McNelis (2002) and Del Negro and Schorfheide (2003). DSGE models are based on a fully specified economic environment and feature strong microeconomic foundations. These models are populated by utility maximizing households which maximize utility subject to certain budget constraints, and profit maximizing firms which maximize profit subject to technology constraints and productivity shocks. DSGE models provide for forward looking expectations (as embodied by the intertemporal optimization by households and firms) as well as nominal and real rigidities.

A distinguishing feature of these models is that they are firmly grounded in microeconomic theory and that they are derived from first principles, which greatly improves the internal consistency of the model equations (Bank of England, 2005). Another feature, as mentioned above, is the incorporation of forward looking expectation in DSGE models. By introducing forward looking expectations, DSGE models are to a great extent insulated from the Lucas critique.

The model parameters quantify the preferences (or tastes) of agents as well as other features of the economy (such as the production function) and are labeled “deep” parameters. In traditional models (as well as VAR models), these parameters are estimated via traditional econometric techniques. In many DSGE models, however, most of these so-called “deep” parameters are calibrated. This is one of the most controversial aspects of DSGE modeling. Calibration involves the ad hoc evaluation of the distance between the theoretical moments implied by the model and the moments in the actual data. Parameter values are fixed at a level as determined in other microeconomic studies. The model is simulated and the moments of the simulated model compared to the moments in the actual data. If these two sets of moments are “close enough” the model is deemed an adequate description of the data generating process (Del Negro and Schorfheide, 2003, and Kremer et al, 2006).

The impact of these “deep” parameters on the short term dynamics of the model is limited. Since the information contained in the data mainly pertains to these short term dynamic responses, it is difficult to obtain accurate estimates of the parameters (IMF, 2004). Additionally, DSGE models are by definition miss-specified which reduces the viability of classical estimation techniques (Diebold, 1997). These two features imply that traditional estimation techniques are less useful and opens the door for alternative, less-structured approaches such as calibration[7].

In recent times, formal econometric techniques are increasingly being utilized to estimate some of the model parameters, thereby basing inference on well-defined statistical measures (Kremer et al, 2006). The estimation of the parameters in a DSGE model involves determining the values for these parameters through the minimization of a given objective function (Schorfheide, 2000). The most popular method at present is full information maximum likelihood estimation (MLE). This method amounts to "maximizing the likelihood of the observed data given the DSGE model by appropriately choosing the model's parameters" (Kremer et al, 2006: 11). A major problem with this technique is the strong assumption that is made: for this technique to be valid we assume that the DSGE is the true data generating process. This is an implausible assumption and results in the model easily being rejected by the data.

A second estimation technique that is fast gaining popularity is Bayesian estimation. This approach can be seen as consolidating aspects of calibration and more formal econometric techniques. What sets this estimation technique apart from other estimation techniques is that Bayesian estimation entails the specification of some priors for the parameters that are being estimated. These priors could be taken from the same sources utilized in the calibration exercise. The degree of confidence surrounding the prior is measured through the probability distribution of the parameter in question (Kremer et al, 2006: 11). The researcher then allows the data to tilt his/her belief surrounding the prior in one or the other direction.

The basic steps in constructing and solving a DSGE model is given in Kremer et al (2006) and Lim and McNelis (2002). The first step involves the theoretical specification of the environment. In other words, choosing the set of economic assumptions based on the question being asked and translating these assumption into mathematical form.

The second step requires the derivation of the first-order conditions of the optimization problems implied by the model and defining the Euler equations. This is rather straightforward and is based on dynamic programming techniques and the Bellman equation (Lim and McNelis, 2002: 13). Since the first-order conditions are often non-linear in nature, it is required to derive tractable approximations (usually involving a first-order Taylor expansion around a stable steady state).

Thirdly, the solution to the approximated system is calculated. This can often be accomplished through numeric computer algorithms (Kremer at al, 2006: 8).

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[7] A more sophisticated type of calibration is based on Bayesian Monte Carlo techniques and take into account the uncertainty surrounding parameter values, see Canova (1994, 1995)

The next step involves the assignment of values to the parameters of the model. This can be accomplished either through calibration or more formal estimation techniques (as discussed above).

Finally, the complete specified model can be used to simulate the economy and carry out various policy analysis, depending on the question being asked.

An important aspect of any modeling exercise is the post simulation evaluation. This involves accuracy checks as well as testing the uniqueness of the solution (Lim and McNelis, 2002: 14-15). This analysis involves checking the accuracy of the solution, validation (how well does the model 'perform' in terms of fitting actual data, past and present?) and sensitivity analysis (to what extent do policy simulations depend on parameter values, specific initial conditions or assumptions made about the underlying economic environment?).

The most important feature of DSGE models is the incorporation of forward looking expectations on the part of agents and the derivation of the equations from first principles, lending the microeconomic base necessary to address some of the criticism against macroeconometric modeling and policy evaluation. The fact that these models are increasingly being utilized by policymakers is an indication that, at least for the time being, practice and theory are moving in the same direction providing a unified front in the eyes of observers.

The next section of the paper presents an empirical example of a DSGE model, estimated using South African data.

4. An Empirical Example: A South African New Keynesian Model

4.1 The New Keynesian Tradition

According to Ireland (2004), the development of the New Keynesian (hereafter NK) macroeconometric model is one of the decade's most exciting developments. Clarida, Gali and Gertler (1999) place the NK model at the centre of their survey on recent research in monetary policy, and Woodford (2003) builds his manuscript around similar analytical foundations.

The basic NK model consists of three equations (Ireland, 2004: 923). The first links consumption and output growth to the inflation-adjusted return on nominal bonds (in other words, the real interest rate). This amounts to the log-linearization of the a representative, optimizing household's Euler equation. Kerr and King (1996) and McCallum and Nelson (1999) call this the *expectational IS curve*. The second equation is a forward looking version of the Philips curve and describes the behaviour of monopolistically competitive firms that either set prices in a random, staggered fashion (Calvo, 1983) or face explicit costs of price adjustment (Rotemberg, 1982). The third and final equation comprises a monetary policy rule (as suggested by Taylor (1993)) and proposes that the central bank should adjust nominal interest rates based on movements in output and, especially, inflation. The NK model then uses these three equations to characterize the dynamic behaviour of output, inflation and the nominal interest rate (Ireland 2004).

The NK model mainly focuses on nominal variables while paying special attention to monetary policy decisions and frequently alluding back to the IS-LM framework. Despite these characteristics, NK models share many features with the RBC models of Kydland and Prescott (1982) and King, Plosser and Rebelo (1988), among others. Unlike RBC models, however, which make no provision for monetary policy and sees technology shocks as the only driving force behind economic fluctuations, NK models suggests that other shocks may also be important (Ireland, 2004: 923), including monetary policy shocks. Additionally, through incorporating various nominal rigidities, NK models help explain how different shocks are propagated through the economy.

The empirical exercise in following sections of the paper examines this link between NK models and the previous generation of RBC models while further investigating the importance of technology shocks in the NK model in a South African context. To my knowledge, such a model has not been estimated for South African data[8]. As mentioned in the previous section, the rest of the paper follows Ireland (2004) closely.

4.2 The Model

As in Ireland (2004) the model economy consists of a representative household, a continuum of intermediate-goods-producing firms (indexed by $i \in [0,1]$), a representative final-goods-producing firm and a central bank. Each intermediate-goods-producing firms produces a unique, perishable good during each period t = 0, 1, 2... which can also be indexed by $i \in [0,1]$, with firm i producing good i.

I: The Representative Household

The representative household starts each period t with a stock of bonds, B_{t-1}, and a stock of money, M_{t-1}, and at the beginning of each period the household receives a monetary transfer, T_t, from the central bank. Next, the household's bonds mature providing an additional flow of money, B_{t-1}. The household then uses this money to purchase additional bonds at a price of B_t/r_t, with r_t the nominal interest rate between t and $t+1$.

[8] Du Plessis and Burger (2006) estimate a New Keynesian Phillips curve for the South African economy, but not a fully articulated New Keynesian model

In each period t, the household supplies h_t units of labour to the various intermediate-goods-producing firms, receiving $W_t h_t$ in total labour income with W_t denoting the nominal wage. During period t the household consumes C_t units of the final good, purchased at a price of P_t from the representative final-goods-producing firm. At the end of each period the household receives profits, D_t, from the intermediate-goods-producing firm. The household then carries M_t units of money into the next period. M_t is chosen subject to the budget constraint:

$$M_{t-1} + B_{t-1} + T_t + W_t h_t + D_t \geq P_t C_t + B_t / r_t + M_t \tag{3}$$

The household seeks to maximize its per-period utility function, subject to (3). The utility function is given by:

$$E \sum_{t=0}^{\infty} \beta^t \left[a_t \ln(C_t) + \ln\left(\frac{M_t}{P_t}\right) - \frac{1}{\eta} h_t^{\eta} \right] \quad , \quad 1 > \beta > 0 \quad and \quad \eta \geq 1$$

The preference shock a_t, follows the autoregressive process

$$\ln(a_t) = \rho_a \ln(a_{t-1}) + \varepsilon_{at} \quad , \; 1 > \rho_a \geq 0 \tag{4}$$

The serially uncorrelated, zero-mean disturbance ε_{at} is normally distributed with standard deviation σ_a.

The first order conditions of the optimization problem includes the intratemporal optimality condition, linking the marginal rate of substitution between leisure and consumption and the real interest wage,

$$h_t^{\eta-1} = \frac{a_t}{C_t} \frac{W_t}{P_t} \tag{5}$$

the intertemporal optimality condition

$$\frac{a_t}{C_t} = \beta \; r_t E_t \left(\frac{a_{t+1}}{C_{t+1}} \frac{P_t}{P_{t+1}} \right) \tag{6}$$

linking the intertemporal rate of substitution with the real interest rate. The first order conditions include the budget constraint in (3), holding with equality, and an optimality conditions for money holdings that plays the role of a money demand function. Ireland (2004: 924) argues that, under an interest rate monetary policy rule (as introduced below), this last equation can be entirely dropped from the model along with references to the variable M_t. Each of these optimality conditions must hold in each period t.

II: The Representative Intermediate-Goods-Producing Firm

During each period the firm hires $h_t(i)$ units of labour from the household to produce $Y_t(i)$ units of the intermediate good i according to technology describe by the constant-returns-to-scale production function

$$Z_t h_t(i) \geq Y_t(i) \tag{7}$$

The aggregate technology shock, Z_t, follows a random walk with drift

$$\ln(Z_t) = \ln(z) + \ln(Z_{t-1}) + \varepsilon_{zt} \tag{8}$$

with $z>1$ and the serially uncorrelated, zero-mean disturbance, ε_{zt}, normally distributed with standard deviation σ_z.

The intermediate-goods-producing firm sets the price $P_t(i)$ for its output, subject to satisfying the final-goods-producing firm's demand at the given price. The intermediate-goods-producing firm also faces an explicit cost of nominal price adjustment given by

$$\frac{\phi}{2}\left(\frac{P_t(i)}{\pi \; P_{t-1}(i)} - 1\right)^2 Y_t$$

with $\phi \geq 0$ governing the magnitude of the price adjustment and $\pi \geq 1$ measuring the steady state rate of inflation.

This cost of price adjustment makes the intermediate-goods-producing firm's problem dynamic in that it must choose a sequence of $P_t(i)$ to maximize its total market value

$$E\sum_{t=0}^{\infty} \beta^t \frac{a_t}{C_t} \frac{D_t(i)}{P_t}$$

where

$$\frac{D_t(i)}{P_t} = \left(\frac{P_t(i)}{P_t}\right)^{1-\theta_t} Y_t - \left(\frac{P_t(i)}{P_t}\right)^{-\theta_t} \frac{W_t}{P_t}\frac{Y_t}{Z} - \frac{\phi}{2}\left(\frac{P_t(i)}{\pi \; P_{t-1}(i)} - 1\right)^2 Y_t \tag{9}$$

measures real profits and $\beta^t(a_t/C_t)$ measures the marginal utility value to the representative household of an additional unit of profit.

The first order conditions for the representative intermediate-goods-producing firm's problem are

$$(\theta_t - 1)\left(\frac{P_t(i)}{P_t}\right)^{-\theta_t}\frac{Y_t}{P_t} = \theta_t\left(\frac{P_t(i)}{P_t}\right)^{-\theta_t - 1}\frac{W_t}{P_t}\frac{Y_t}{Z_t}\frac{1}{P_t} - \phi\frac{P_t(i)}{\pi\ P_{t-1}(i)} - \frac{Y_t}{\pi\ P_{t-1}(i)}$$
$$+ \beta\phi E_t\left[\frac{a_{t+1}}{a_t}\frac{C_t}{C_{t+1}}\left(\frac{P_{t+1}(i)}{\pi\ P_t(i)} - 1\right)\frac{Y_{t+1}}{P_t(i)}\frac{P_{t+1}(i)}{\pi\ P_t(i)}\right] \tag{10}$$

In the special case where $\phi = 0$, equation (10) becomes

$$P_t(i) = \frac{\theta_t}{\theta_t - 1}\frac{W_t}{Z_t}$$

In the above equations, θ_t measures the time-varying price elasticity of demand, and can be interpreted as a shock to the firm's desired mark-up, interpreted as a cost-push shock of the kind introduced by Clarida et al. (1999).
This cost-push shock follows the autoregressive process

$$\ln(\theta_t) = (1 - \rho_\theta)\ln(\theta) + \rho_\theta \ln(\theta_{t-1}) + \varepsilon_{\theta t} \tag{11}$$

with $\theta > 1$ and $1 > \rho_\theta \geq 0$, and the serially uncorrelated, zero-mean disturbance $\varepsilon_{\theta t}$ normally distributed with standard deviation σ_θ.

III: The Representative Final-Goods-Producing Firm

During each period, the representative final-goods-producing firms uses $Y_t(i)$ units of each intermediate good i, purchased at price $P_t(i)$, to manufacture Y_t units of the finished good according to the constant returns to scale technology given by

$$\left(\int_0^1 Y_t(i)^{(\theta_t - 1)/\theta_t} di\right)^{\theta_t/(\theta_t - 1)} \geq Y_t$$

Again θ_t measues the time-varying price elasticity of demand, and acts as a mark-up, or cost-push, shock following the autoregressive process in equation (11).

The final-goods-producing firm then seeks to maximize its profits by choosing

$$Y_t(i) = \left[\frac{P_t(i)}{P_t}\right]^{-\theta_t} Y_t$$

for all i, which confirms that θ_t measures the time varying elasticity of demand for each intermediate good. The final-goods-producing firm's profit is driven to zero in equilibrium through competition, thereby determining P_t as

$$P_t = \left(\int_0^1 P_t(i)^{1-\theta_t} di\right)^{1/(1-\theta_t)}$$

for all t.

IV: Equilibrium Conditions

In equilibrium, the intermediate-goods-producing firms make identical choices, so that $Y_t(i)=Y_t$, $h_t(i)=h_t$, $D_t(i)=D_t$ and $P_t(i)=P_t$ for all i and t. Additionally, the market-clearing conditions $M_t=M_{t-1}+T_t$ and $B_t=B_{t-1}=0$ must hold in equilibrium for all i and t. Now, with these conditions imposed, equations (5), (7) and (9) can be used to solve for W_t/P_t (real wages), h_t (hours worked) and D_t/P_t (real profits). Defining $\pi_t = P_t/P_{t-1}$, the gross inflation rate for all t, the representative household's budget constraint (3) can be rewritten as

$$Y_t = C_t + \frac{\phi}{2}\left(\frac{\pi_t}{\pi} - 1\right)^2 Y_t \tag{12}$$

the Euler equation (6) can be rewritten as

$$\frac{a_t}{C_t} = \beta\, r_t E_t\left(\frac{a_{t+1}}{C_{t+1}}\frac{1}{\pi_{t+1}}\right) \tag{13}$$

and (11), the intermediate-goods-producing firm's first order conditions, can be written as

$$\theta_t - 1 = \theta_t \frac{C_t}{a_t}\left(\frac{Y_t}{Z_t}\right)^{\eta-1}\frac{1}{Z_t} - \phi\left(\frac{\pi_t}{\pi} - 1\right)\frac{\pi_t}{\pi} + \beta\phi E_t\left[\frac{a_{t+1}}{a_t}\frac{C_t}{C_{t+1}}\left(\frac{\pi_{t+1}}{\pi} - 1\right)\frac{\pi_{t+1}}{\pi}\frac{Y_{t+1}}{Y_t}\right] \tag{14}$$

V: The Output Gap and Efficient Allocations

Firstly, consider a social planner's problem. During each period the social planner allocates $n_t(i)$ of labour to produce $Q_t(i)$ of each intermediate good, which is then used to produce Q_t of the final good. Production takes place using the same production technologies noted above.

The social planner therefore chooses Q_t and $n_t(i)$ so as to maximize the household's welfare, which is measured by

$$E\sum_{t=0}^{\infty}\beta^t\left[a_t\ln(Q_t)-\frac{1}{\eta}\left(\int_0^1 n_t(i)di\right)^{\eta}\right]$$

subject to

$$Z_t\left(\int_0^1 n_t(i)^{(\theta_t-1)/\theta_t}di\right)^{\theta_t/(\theta_{t-1})}\geq Q_t$$

The first order condition for this problem defines Q_t as

$$Q_t = a_t^{1/\eta}Z_t$$

Therefore, the efficient level of output increases through a positive technology or preference shock, and does not depend on the cost-push shock. The output gap, x_t, can be calculated as

$$x_t = (1/a_t)^{1/\eta}(Y_t/Z_t) \qquad (15)$$

which is the ration between the efficient and actual level of output.

VI: Linearization

Equations (4), (8), (11) and (12)-(15) quantify the behaviour of the five endogenous variables C_t, Y_t, r_t, π_t and x_t, as well as the exogenous shocks a_t, Z_t and θ_t. Because both output, Y_t, and consumption, C_t, inherit a unit root from equation (8), these variables are stochastically detrended to achieve stationarity. Therefore, $y_t=Y_t/Z_t$ and $c_t=C_t/Z_t$, as well as the output gap x_t are stationary. The growth rate of output is defined as

$$g_t = Y_t/Y_{t-1} \qquad (16)$$

The economy converges to a steady state where all stationary variables are constant over time and amounts to the removal of the t subscript from all stationary variables.

Define the percentage deviation of each variable from its steady state as

$$\hat{u}_t = \ln(u_t / u)$$

with $u = y, c, \pi, r, x, g, a, \theta, z$ and $u_t = y_t, c_t, \pi_t, r_t, x_t, g_t, a_t, \theta_t, z_t$ respectively.

Now, equation (12) implies that $\hat{y}_t = \hat{c}_t$, while equations (4), (8), (11) and (13)-(16) become

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{at} \tag{17}$$

$$\hat{e}_t = \rho_e \hat{e}_{t-1} + \varepsilon_{et} \tag{18}$$

$$\hat{z}_t = \varepsilon_{zt} \tag{19}$$

$$\hat{x}_t = E_t \hat{x}_{t+1} - (\hat{r}_t - E_t \hat{\pi}_{t+1}) + (1-\omega)(1-\rho_a)\hat{a}_t \tag{20}$$

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \psi \hat{x}_t - \hat{e}_t \tag{21}$$

$$\hat{x}_t = \hat{y}_t - \omega \hat{a}_t \tag{22}$$

$$\hat{g}_t = \hat{y}_t - \hat{y}_{t-1} + \hat{z}_t \tag{23}$$

The new parameters ω and ψ in (20), (21) and (22) are defined as $\omega = 1/\eta$ and $\psi = \eta(\theta - 1)\phi$ and assist in the empirical exercise. The cost-push shock is transformed and defined in equation (21) as $\hat{e}_t = (1/\phi)\hat{\theta}_t$ so that $\rho_e = \rho_\theta$ in (18) and the serially uncorrelated, zero-mean disturbance ε_{et} has standard deviation $\sigma_e = (1/\phi)\sigma_\theta$.

In this system, equations (22) and (23) define output growth and the output gap, while equations (17)-(19) govern the behaviour of the three exogenous shocks. Equation (20) is the so-called expectational IS curve, while equations (21) is the New Keynesian Philips curve.

VII: The Central Bank

The central bank conducts monetary policy following a modified Taylor (1993) rule

$$\hat{r}_t - \hat{r}_{t-1} = \rho_\pi \hat{\pi}_t + \rho_g \hat{g}_t + \rho_x \hat{x}_t + \varepsilon_{rt} \tag{24}$$

with $\hat{r}_t$, $\hat{\pi}_t$, $\hat{g}_t$ and $\hat{x}_t$ denoting percentage deviations from steady state of the short-term nominal interest rate, inflation, output growth and the output gap respectively. The central bank adjusts the short-term nominal interest rate in response to movements in the variables on the right hand side of equation (12). The central bank therefore takes responsibility for choosing the steady state level of inflation, π. It is unclear whether it is more appropriate to depict the central bank as responding to movements in the output gap or output growth and therefore both are included in this policy rule. The serially uncorrelated, zero-mean disturbance ε_{rt} is normally distributed with standard deviation σ_r.

4.3 Econometric Strategy and Empirical Results

Equations (17)-(24) now form a system in two unobservable variables (detrended output and the output gap), three observable variables (output growth, inflation and the short-term nominal interest rate) and four unobservable shocks (preference shock, technology shock, desired mark-up or cost-push shock and monetary policy shock). Ireland (2004) utilizes a modification of the Blanchard-Kahn (1980) procedure to solve the system. Kalman filtering algorithms are then used to estimate the model's parameters via maximum likelihood and to explore the behaviour of the model's unobservable variables based on data contained in the three observable series.

The econometric exercise uses quarterly data on South African variables for the period 1981Q1 to 2005Q4[9]. Quarterly changes in seasonally adjusted, real GDP per capita serve to measure output growth, while quarterly changes in the GDP deflator provides a measure of inflation. The short term nominal interest rate is constructed using the 91-days Treasury Bill rate, converted to a quarterly rate.

The main aim of this exercise is to determine the role played by the various shocks in driving fluctuations in both the observable and unobservable variables in the model. To that end equations (20) and (21) are modified by adding lagged output gap and inflation terms

$$\hat{x}_t = \alpha_x \hat{x}_{t-1} + (1-\alpha_x) E_t \hat{x}_{t+1} - (\hat{r}_t - E_t \hat{\pi}_{t+1}) + (1-\omega)(1-\rho_a)\hat{a}_t \qquad (25)$$

$$\hat{\pi}_t = \beta\left[\alpha_\pi \hat{\pi}_{t-1} + (1-\alpha_\pi) E_t \hat{\pi}_{t+1}\right] + \psi \hat{x}_t - \hat{e}_t \qquad (26)$$

with α_x and α_π both lying between 0 and 1. This modification ensures that estimates of the forward looking specification do not falsely attribute dynamics in the data to serial correlation in the shocks when these dynamics are more accurately modelled through additional frictions that give rise to backward looking behaviour on the part of agents. If the data prefers the original forward looking specification to this more general specification, α_x and α_π are free to take on a value of 0.

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[9] See Data Appendix for a complete description of the data, sources and the construction of the data series used in the empirical excercise

Among the parameters in the model, π and z serve only to pin down the steady state values of inflation and output growth. Therefore, π is set equal to 1.026829, which is equal to the average inflation rate in the data, and translates to 11.17% when annualised. The parameter z is set equal to 1.000234, matching average output growth in the data, and translates to 0.0935% when annualised.

In steady state, the short-term nominal interest rate is determined as $r = \pi(z/\beta)$, which translates into a value for β of 0.995. This ensures that the short-term nominal interest rate is equal to 1.032341 which matches the average in the data and translates to 13.78% when annualised.

The final calibration step involves the coefficient on the output gap in (24), ψ. This parameter is set equal to 0.1, the same value used in Ireland (2002, 2004). This value is chosen since initial estimation exercises by Ireland resulted in unreasonably small estimates of ψ. Gali and Gertler (1999) show that in simpler NK models, a setting of $\psi = 0.1$ translates into a situation where individual goods prices are reset every 3.74 quarters (or a little more frequently than once a year).

With the above mentioned parameters held fixed, Table 1 below displays the results of the estimation exercise.

Table 1 - Maximum Likelihood Estimates and Standard Errors

Parameter	Estimate	Standard Error
ω	0.0000	0.0842
α_x	0.1103	0.1414
α_π	0.0000	0.0986
ρ_π	0.0914	0.0182
ρ_g	1.4937	0.3122
ρ_x	0.3977	0.2312
ρ_a	0.9207	0.0361
ρ_e	0.0000	0.0984
σ_a	0.0470	0.0189
σ_e	0.0110	0.0010
σ_z	0.0162	0.0039
σ_r	0.0096	0.0022

Now, looking at the individual parameters, the estimate of ω implies a very large estimate of η since $\omega = 1/\eta$ and indicates very inelastic labour supply in the theoretical model. However, in the empirical model with $\psi = \eta(\theta - 1)/\phi = 0.1$ fixed, ω serves to determine, through (22), the extent to which the preference shock impacts on the efficient level of output and through this the output gap (Ireland, 2004: 928). The small estimate of ω therefore implies that the data prefers a model where the preference shock has a negligible influence on the efficient level of output.

The small and statistically insignificant estimate of α_x, and an estimate of α_π of close to zero, is evidence for the purely forward-looking specification of the IS- and Phillips-curves. The large and statistically significant estimates of ρ_g = 1.4937 and ρ_x = 0.3977 imply that the Reserve Bank of South Africa has, at least over the sample period, responded strongly to output growth and the output gap, while the smaller estimate ρ_π = 0.0914 implies that it has paid much less attention to inflation movements when setting monetary policy. The estimates for ρ_a and ρ_e imply that, like the model's technology shock, the preference shock is highly persistent while the cost-push shock is not persistent at all.

Finally, the estimates for σ_a = 0.0470, σ_e = 0.0110, σ_z = 0.0162 and σ_r = 0.0096 all appear relatively large compared to their standard errors, implying that all four shocks, and not just the technology shock, play an important role in explaining movements in the data.

The discussion above shows that although the RBC type technology shock plays a role in the model dynamics, the other shocks – preference, cost-push and policy shocks – also play an important role in the movement of the variables. Figures 1.1 and 1.2 show the impulse responses of key variables to a one-standard-deviation shock.

A 1-standard-deviation preference shock leads to a increase in output growth of slightly more than 16 basis points, or 0.16%, and the annualised inflation rate increases by approximately 7 basis points but then falls sharply. Under the dynamics of the model these movements push the short-term nominal interest rate 200 basis points above steady state, while the output gap increases as well.

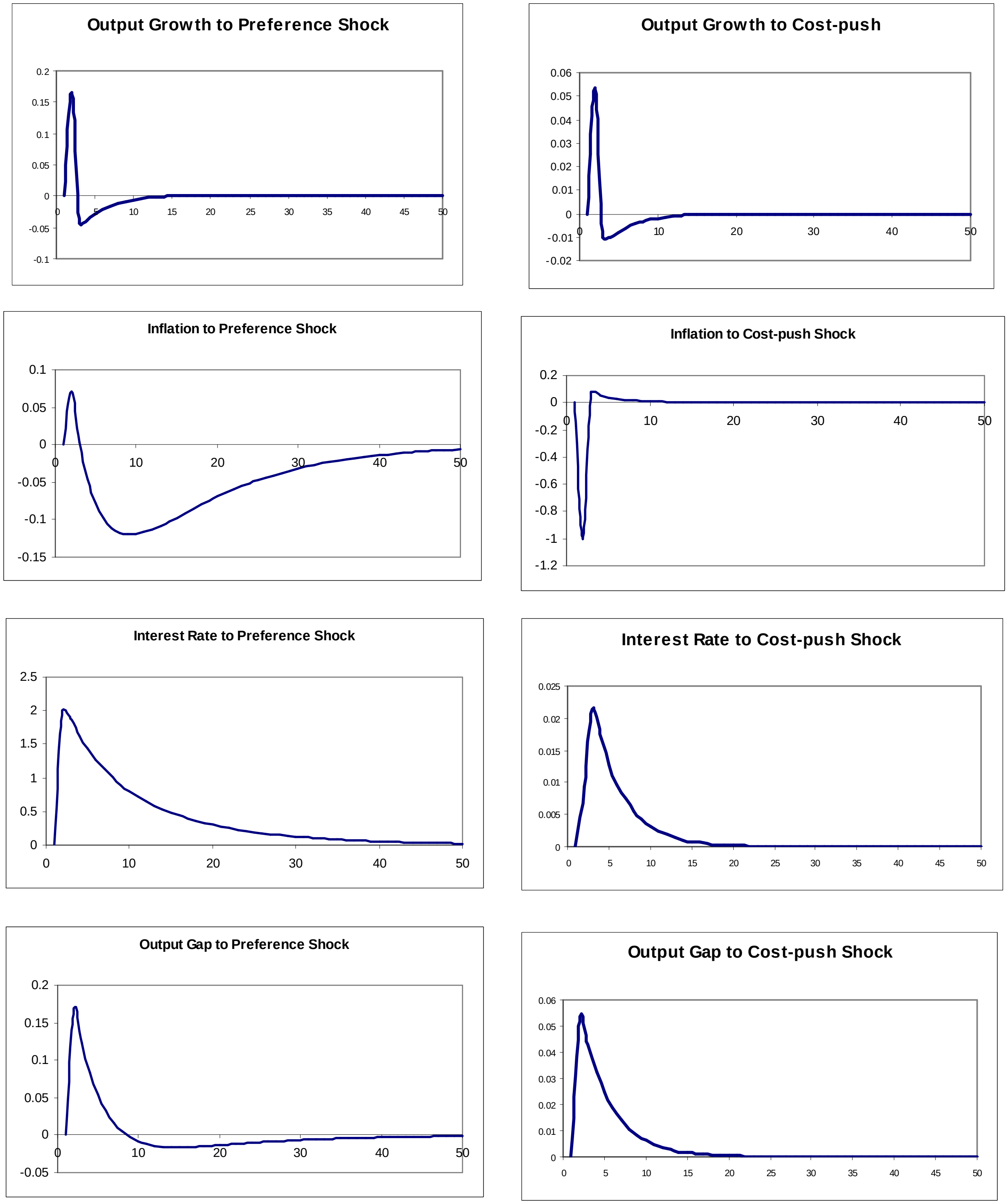
A one-standard-deviation cost-push shock increase output growth by 5.5 basis points and reduces inflation by 100 basis points. This leads to an increase in the short-term nominal interest rate of approximately 2.2 basis points. The output gap increases by 5.5 basis points.

Figure 1.2 shows that a one-standard-deviation technology shock leads to a increase in output growth and a decrease in inflation of about 35 and 100 basis points respectively. The short-term interest rate decreases by 45 basis points and the output gap also decreases.

A one-standard-deviation policy shock leads to a decrease in output growth and inflation of about 50 and 65 basis points respectively. The short-term interest rate decreases by 19 basis points and the output gap also decreases.

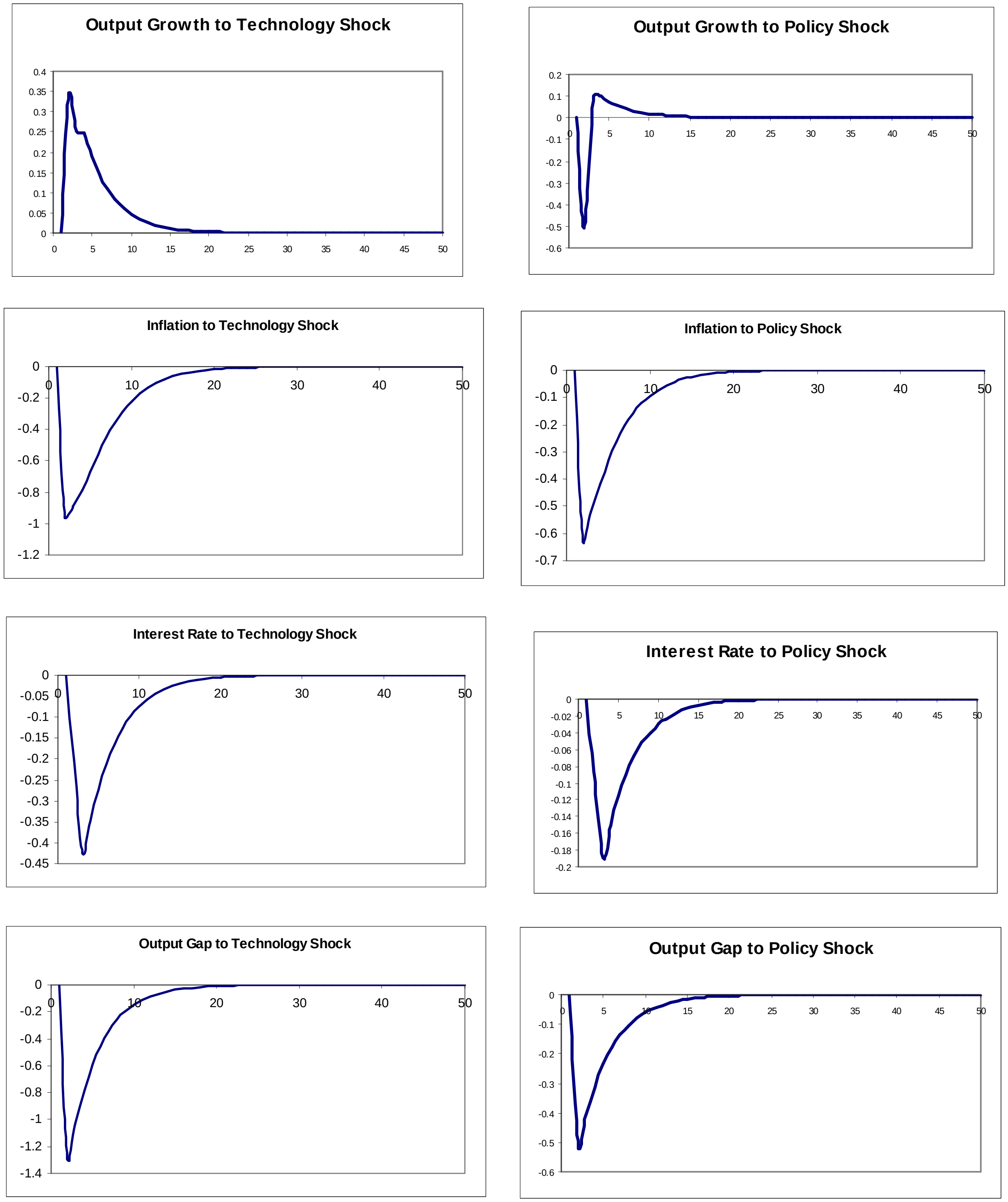
These impulse response functions give an idea of how the various shocks are identified in this estimation of the NK model. Both the preference and cost-push shocks lead

Figure 1.1 – Impulse Responses: Preference and Cost-push Shocks



Note: Each figure shows the percentage-point change in each of the variables in response to a 1-standard-deviation shock. Inflation and interest rate expressed in annualised terms

Figure 1.2 – Impulse Responses: Technology and Policy Shocks



Note: Each figure shows the percentage-point change in each of the variables in response to a 1-standard-deviation shock. Inflation and interest rate expressed in annualised terms to an increase in the short-term nominal interest rate, with output growth increasing and inflation decreasing in each case.

Figures 1.1 and 1.2 show that different shocks differ in importance in terms of explaining the fluctuations in these key variables. Technology shocks dominate movements in output growth and the output gap, whereas cost-push shocks dominate movements in inflation. Preference shocks make their largest contribution in explaining movements in the short-term nominal interest rate.

Table 2 decomposes the forecast error variances for output growth, inflation, the short-term interest rate and the output gap into components attributable to each of the four exogenous shocks.

These variance decompositions verify the findings in the above discussion. These decompositions show that technology shocks make their largest contribution in output growth and the output gap, approximately 48% and 85% respectively, as is evidenced in Figures 1.1 and 1.2. However, for output growth we see that policy shocks account for almost the same amount of variation as technology shocks. In all, the variance decompositions verify the impulse response analysis in that cost-push shocks dominates in explaining movements in inflation, while preference shocks are most important in driving changes in the short-term nominal interest rate.

These results therefore indicate that preference shocks, cost-push shocks and policy shocks, in addition to technology shocks, play an important role in explaining the movements in key economic variables and that it is unreasonable to assume that technology shocks alone can account for the greatest part of the movement in macroeconomic variables.

4.4 Some Caveats

Although the empirical exercise in the previous sections provide some valuable insight into the functioning of the South African economy, some issues deserve mentioning.

The sample size used in the exercise was, due to data restrictions, relatively small. Some data series, especially for the 91-days Treasury Bill rate, were only available from 1981 to 2005, and hence the sample was restricted to this period. Additionally, the fact that the three series used in the exercise were constructed using other available series[10], mean that the data used is only a rough approximation of the true values. As the parameter estimates were no doubt influenced by these data restrictions, it is necessary to continue the search for longer, more accurate series (or at least better approximations) in order to facilitate more accurate estimation and evaluation.

The estimation procedure itself may also be slightly inaccurate.

[10] See Data Appendix

Table 2 - Forecast Error Variance Decompositions

Quarters Ahead	Preference Shock	Cost-push Shock	Technology Shock	Policy Shock
		Output Growth		
1	6.93	0.70	28.61	63.76
4	5.47	0.52	46.35	47.66
8	5.18	0.49	49.40	44.93
12	5.14	0.49	49.71	44.66
20	5.14	0.49	49.74	44.63
40	5.14	0.49	49.74	44.63
∞	5.14	0.49	49.74	44.63
		Inflation		
1	0.03	77.49	19.43	3.05
4	0.04	61.76	33.02	5.18
8	0.20	59.14	35.15	5.51
12	0.36	58.78	35.32	5.54
20	0.54	58.64	35.29	5.53
40	0.61	58.60	35.26	5.53
∞	0.62	58.60	35.26	5.53
		Interest Rate		
1	97.08	0.00	2.52	0.40
4	89.52	0.02	9.05	1.42
8	91.37	0.01	7.45	1.17
12	92.36	0.01	6.59	1.03
20	93.04	0.01	6.01	0.94
40	93.25	0.01	5.83	0.91
∞	93.26	0.01	5.82	0.91
		Output Gap		
1	1.45	0.15	85.07	13.33
4	1.24	0.15	85.25	13.36
8	1.13	0.15	85.34	13.38
12	1.14	0.15	85.34	13.38
20	1.18	0.15	85.31	13.37
40	1.20	0.15	85.29	13.37
∞	1.20	0.15	85.29	13.37

Note: Forecast error variance in each variable at each forecast horizon is decomposed into percentages due to each shock

Because of time restrictions, the necessary tests to determine whether the value for the maximized likelihood function was indeed the global maximum could not be carried out. Again, further research is required to ensure that the global maximum is reached and accurate parameter estimates obtained. A future exercise may also want to investigate the stability of the parameter estimates over different sample periods. Ireland (2004) shows that for US data, parameter estimates vary substantially over sample periods. In the case of South Africa, however, such tests could only be carried out if larger and more accurate samples were available.

Ireland (2004) also argues that the basic New Keynesian model estimated in this paper ignores capital accumulation which is an important propagation mechanism for technology shocks. Incorporating capital accumulation could influence results dramatically and remains a task for the future. Furthermore, it could be argued that the additional shocks introduced in the model (the preference, cost-push and policy shocks) serve only to "soak up" the specification error in the model. Both these arguments do not, however, detract from the main conclusion: specifications that go beyond the original RBC models can possibly better account for movement in macroeconomic variables than models which feature technology shocks alone.

5. Conclusion

Traditional MEM's proved invaluable in the development of macroeconomics as a science and provided a framework for policy analysis that had not existed before the 1940's. The fundamental flaws that were identified in this approach should in no way detract from the contribution these models made to our understanding of the economy.

The main goal of this paper was to explore the "next generation" models that emerged in the aftermath of the Lucas and Sims critiques. VARs, RBC models and DSGE models addressed some of the concerns voiced by Lucas and Sims, providing a new, solid framework for exploring the driving forces behind economic fluctuations and evaluating economic policy. DSGE models in particular hold much promise for the future of macroeconomic research and are increasing in popularity among academics and modellers alike. There is still much room for improvement and continued research in this field is required.

A secondary goal of this paper was to provide an example of an estimated DSGE model for the South African economy. The New Keynesian model developed by Ireland (2004) was re-estimated using South African data for the period 1981Q1 to 2005Q4. Four exogenous disturbances – shocks to household preferences, firms' desired mark-ups, productivity and the central bank's monetary policy rule – compete to provide explanations for economic fluctuations. The model was estimated using maximum likelihood estimation and the estimated model was used to gauge the relative importance of each of these disturbances in driving economic fluctuations in South African data. It was found that the link between the New Keynesian model and its predecessors, the RBC models, was weakened.

The empirical exercise showed that, apart from technology shocks, various other shocks play an important role in explaining the movements in key economic variables. In particular it was shown that technology shocks and monetary policy shocks played an equal role in explaining movements in output growth, whereas movements in inflation and the short-term nominal interest rate was largely explained by cost-push shocks and preference shocks respectively. These results show that relying solely on changes in productivity to explain movements in South African data cannot be condoned, and that the other shocks contained in the model provide valuable insight into the functioning of the South African economy.

It is important to note, once again, the restriction faced during this exercise. The relatively small sample size and restricted access to accurate data may have influenced the estimation procedure, which may have resulted in inaccurate conclusions. It is therefore imperative that research in this context should continue in an attempt to improve on the accuracy and content of the conclusions drawn in this paper.

DSGE models, such as the one explored in this paper, hold the key to the development of macroeconomics and our understanding of the functioning of the economy. It is imperative that research in this field must continue in a persistent attempt at improving our understanding of the economy.

DATA APPENDIX

All data series were obtained from the South African Reserve Bank (SARB) website.

Quarterly changes in seasonally adjusted, real GDP per capita was constructed as follows: annual series on seasonally adjusted real GDP and real GDP per capita were used to construct yearly estimates of the South African population. Annual growth rates in the population were calculated and converted to effective quarterly rates. These rates were used to construct a series for quarterly population figures, which were then used to construct a series for seasonally adjusted, quarterly real GDP per capita.

Quarterly figures for seasonally adjusted, nominal and real GDP were used to construct the GDP deflator. Quarterly changes in this deflator was used as a measure of inflation. The 91-days Treasury Bill discount rate was used to construct a series for the short-term interest rate. The effective annual discount rate was averaged over quarters and converted to an effective quarterly rate.

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