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A revised Quarterly Projection Model for South Africa

Shaun de Jager, Michael Johnston and Rudi Steinbach

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Enquiries

Head: Research Department
South African Reserve Bank
P O Box 427
Pretoria 0001

Tel. no.: +27 12 313-3911
0861 12 SARB (0861 12 7272)

Non-technical Summary

Despite the advantages of large-scale macroeconometric models in terms of near-term accuracy and disaggregation, there are significant drawbacks which limit the usefulness of such models for policy analysis and also forecasting over longer term horizons. The disadvantages of using econometric models for policy analysis have been appreciated since the publication of the so-called Lucas Critique (Lucas, 1976). Nevertheless, it has taken decades of progress in macroeconomic theory (and significant improvement in computational resources) to meaningfully address the associated problems. Lucas argued that the parameters of econometric models are based on historical correlations, and these historical correlations depend on both actual policy and what agents expect of future policy; if either policy or expectations of future policy were to change (as they often do), then these correlations will change as well. Yet, the structure of econometric models cannot account for such changes and, as a result, the models are not a suitable tool to analyse the implications of policy changes.

In order to address these fundamental shortcomings, central banks around the world have during the last decade sought to build theoretically-based general equilibrium models that are able to generate macroeconomic forecasts which account for the role of policy and expectations in determining historical and future macroeconomic outcomes. Moreover, these models feature forward-looking rational expectations, in contrast to the backward-looking expectations of econometric models. In general, the philosophy behind the development of the models is markedly different. Large-scale econometric models are typically developed by estimating a large number of individual equations; the behaviour of the system as a whole is often not well-understood, and important concepts like the monetary transmission mechanism may be accordingly opaque. In contrast to this inherently bottom-up philosophy, general equilibrium models are conceived of from the outset as a system with many interlinkages in which it is inherently impossible to assess the quantitative implications of particular parameters in isolation. The top-down philosophy intrinsic to general equilibrium models, whether calibrated or estimated, produces models in which the aggregate behaviour is better understood by design.

As part of this global agenda to develop forward-looking general equilibrium models for policy analysis and forecasting in central banks, De Jager (2007) introduced the Quarterly Projection Model (QPM) as the first theoretical general equilibrium model for quantitative policy analysis at the South African Reserve Bank. This paper provides an update to that research agenda which describes the modifications introduced to enable the use of the model as a quantitative forecasting tool.

A Revised Quarterly Projection Model for South Africa*

Shaun de Jager Michael Johnston Rudi Steinbach

August 6, 2015

Abstract

This paper extends earlier work by De Jager (2007) to construct a semi-structural general equilibrium model for medium-term forecasting and causal policy analysis. It incorporates traditional New Keynesian small open economy structure with a term structure of interest rates, an uncovered interest parity condition which is augmented by the terms of trade and current account, and a world block which describes the evolution of trade-weighted foreign composites.

JEL classification: E52, E47, C51

Keywords: Monetary policy, gap model

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Contents

1 Introduction

Quantitative model-based forecasting begins with the large-scale macroeconometric models of the last century (see Klein (1991) for a survey), a class of models which remains widely used by some practitioners today. This approach typically relies on a system of individually estimated behavioural econometric relationships combined with identities to produce quantitative forecasts which are internally consistent, and can achieve reasonable near-term forecasting performance when estimated frequently (see Klein, 1970 and Coletti, Hunt, Rose, and Tetlow, 1996). The approach has been used in South Africa by the Reserve Bank for a number of decades, continues to receive regular updates (Smal et al., 2007), and is used effectively in conjunction with staff expertise to produce forecasts for the South African economy which are among the most accurate available (SARB, 2013). In response to criticisms of both the theory and practice of monetary policy, policy institutions around the world have sought to build models which are both theoretically and quantitatively viable, and to create macroeconomic forecasts which are effective in accounting for the role of policy and expectations in determining historical and future outcomes. As part of this agenda, De Jager (2007) introduced the Quarterly Projection Model (QPM) as the first theoretical model for quantitative policy analysis at the South African Reserve Bank; this paper provides an update to that research agenda which describes the modifications introduced to enable the use of the model as a quantitative forecasting tool.

Despite the advantages of large-scale macroeconomic models in terms of near-term accuracy and disaggregation, there are significant drawbacks which limit the usefulness of such models for policy analysis and medium-term or long-term forecasting. The disadvantages of using econometric models for policy analysis have been appreciated since publication of the so-called Lucas Critique (Lucas, 1976), although it has taken decades of progress in macroeconomic theory (supported by increasingly cheap computational resources) to meaningfully address the associated problems. Lucas made the case that the stochastic parameter drift which these models seem to exhibit in practice is due to the adaptation of agents' decision rules to a changing environment, making these models worthless for the analysis of long-run questions or the consideration of policy changes; in his own words,

> Given that the structure of an econometric model consists of optimal decision rules of economic agents, and that these rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models.

That is, econometric models are based on historical correlations, and these historical correlations are a function both of actual policy and policy expectations; if either policy or expectations of future policy change, then one should expect these correlations to change as well. While econometric models at the time disagreed with theoretical concepts like the natural rate hypothesis (Friedman, 1968 and Phelps, 1970) in that the econometric models suggested a long-run tradeoff between output and inflation, nothing did more to underscore the importance of theory in quantitative policy evaluation than the widespread policy failures in the 1960s and 1970s which brought about sustained periods of high unemployment and high inflation in a number of countries. From a modelling perspective, this is well summarized by Coletti, Hunt, Rose, and Tetlow (1996):

> The inability of relatively unstructured, estimated models to predict well for any length of time outside their estimation period seemed to indicate that small-sample econometric problems

> were perhaps more fundamental than had been appreciated and that too much attention had been paid to capturing the idiosyncrasies of particular samples. There had been a systematic tendency towards overfitting equations and too little attention to capturing the underlying economics.

The impossibility of incorporating long-run theoretical concepts like the natural rate hypothesis into the large-scale econometric models at the time motivated the development and use of theoretical models for quantitative policy evaluation and forecasting. Through progressions in both economic theory and computational abilities, it has become common practice at many central banks and policy institutions around the world to produce quantitative forecasts from theoretical general equilibrium models. For example, see Kilponen and Ripatti (2006) on AINO at the Bank of Finland; Brubakk et al. (2006) on NEMO at the Norges Bank; Adolfson et al. (2007) on RAMSES at the Riksbank; Christoffel et al. (2008) on NAWM at the European Central Bank; Ratto et al. (2009); Beneš et al. (2009) on KITT at the Reserve Bank of New Zealand; Andrle et al. (2009) on NSM at the Czech National Bank; Erceg et al. (2005) on SIGMA or Chung et al. (2010) on EDO at the U.S. Federal Reserve; Carabenciov et al. (2008) on GPM or Kumhof et al. (2010) on GIMF at the International Monetary Fund; Murchison and Rennison (2006) and Dorich et al. (2013) on ToTEM at Bank of Canada; Castro et al. (2011) on SAMBA at Bank of Brazil; and other examples exist.

Besides addressing the Lucas critique, theoretical models featured forward-looking rational expectations (Muth, 1961), in contrast to the backward-looking adaptive expectations of econometric models (Brayton, Mauskopf, Reifschneider, and Tinsley, 1997). The structure provided an avenue for quantitatively assessing the impact of policy rules on private agents' expectations as well as anticipated deviations from those rules. A large literature uses rational expectations models to analyse alternative monetary policy rules and their consequences for the hypothetical long run behaviour of the economy (see Taylor, 1999; Svensson, 1999; and Khan et al., 2003). In all of this research the role of expectations, including the ability of the central bank to make credible commitments to future behaviour, is paramount.

In general, the philosophy behind the development of the models was markedly different. Large-scale econometric models were typically developed by estimating a large number of individual equations; the behaviour of the system as a whole was often not well-understood, and important concepts like the monetary transmission mechanism were accordingly opaque. In contrast to this inherently bottom-up philosophy, general equilibrium models are conceived of from the outset as a system with many feedback channels in which it is inherently impossible to assess the quantitative implications of particular parameters in isolation. The top-down philosophy intrinsic to general equilibrium models, whether calibrated or estimated, produces models in which the aggregate behaviour is better understood by design.

While general equilibrium models make progress in addressing the Lucas critique in that reduced-form decision rules depend on policy and policy expectations, the inherent complexity of forward-looking models and the associated computational challenges limit the number of variables one can conceivably forecast and the size of the conditioning information sets. As a result, their implementation in policy environments may differ greatly from the prototypical academic exposition. Additional variables can be forecast by projecting non-modelled variables on model variables (as in Schorfheide et al., 2010) and conditioning information sets can be enlarged by adjusting near-term forecasts are typically using some combination of econometric models and expert judgement (Bache et al., 2010; Del Negro and Schorfheide, 2013; and Monti, 2008). By mixing theoretical general equilibrium models with econometrics modellers seek to achieve the best that both classes of models have to offer.

This exposition describes a semi-structural gap model in the spirit of Carabenciov et al. (2008) which is specifically adapted to South Africa and the needs of a small open economy commodity exporter to account for terms of trade fluctuations and various supply-side shocks in explaining inflation dynamics. While DSGE models offer more disaggregation and stock-flow consistency, semi-structural gap models of this kind are easier to construct and use, and make significant progress in addressing the Lucas critique relative to econometric models. Similar semi-structural gap models have been constructed for policy analysis in South Africa previously, including De Jager (2007) for the South African Reserve Bank and Jooste and Marinkov (2012) for National Treasury.

Section 1 describes the data. Section 2 describes the theoretical structure of the model. Section 3 describes the empirical approach used to identify key parameters. Section 4 discusses the simulation properties of the calibrated model. Section 5 concludes.

2 Data

The model is calibrated to match data over the South African inflation targeting period from 2000Q1 through 2013Q4. Uncertainty data are taken from policyuncertainty.com and are constructed by algorithms which analyze the content of news articles over time, as described in Baker, Bloom and Davis (2013). World variables are trade-weighted composites of Global Projection Model (GPM) regional composites. Credit lending standards are taken from the Ernst and Young / BER financial services survey and are normalised to have zero mean and unit variance.

Real GDP and current account data are taken from the National Accounts data produced by Statistics South Africa. Potential output is estimated using a generalized Hodrick-Prescott filter as in Borio, Disyatat, and Juselius (2014). The methodology uses a state space system that accounts for the persistence in estimated output gaps to achieve a better specification with fewer revision problems:

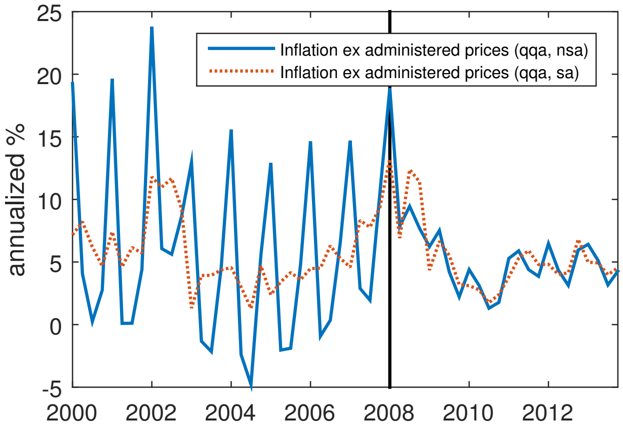
$$y_t - \bar{y}_t = \beta^{kyg} (y_{t-1} - \bar{y}_{t-1}) + \gamma^{kyg} X_t + \varepsilon_t^{kyg} \tag{1}$$

$$\Delta \bar{y}_t = \Delta \bar{y}_{t-1} + \varepsilon_t^{kp} \tag{2}$$

The Hodrick-Prescott filter is a special case in which $\beta^{kyg} = \gamma^{kyg} = 0$. Output gap estimates are adjusted by including credit extension growth and capacity utilisation as covariates in X_t, as described in Anvari, Ehlers, and Steinbach (2014). The relative standard deviations of the shocks ε^{kyg} and ε^{kp} are chosen to produce frequency domain characteristics similar to a standard Hodrick-Prescott filter with a smoothing parameter of 4100.

Interest rate data, including the repo rate and 10-year bond yields, are produced by the South African Reserve Bank, as are real and nominal exchange rates. The real equilibrium interest rate and real equilibrium exchange rate are constructed using the Borio, Disyatat, and Juselius (2014) methodology used to create potential output measures, although neither of these filtered values are adjusted by any covariates.

Figure 1: Changes required to seasonal adjustment pattern in inflation



Headline inflation, inflation in administered prices excluding petrol, and petrol price inflation are all constructed from Consumer Price Index series produced by Statistics South Africa. Quarter-on-quarter inflation measures are seasonally adjusted using X-12-ARIMA seasonal adjustment program (Monsell, 2007); seasonal factors are permitted to change beginning in 2008Q1 to coincide with the change by Statistics South Africa in the methodology used to create the series. Figure (1) illustrates the issue by plotting the raw quarter-on-quarter series for headline inflation excluding administered prices along with the seasonally adjusted series used in this paper.

3 Model

The model fundamentally consists of a few key theoretical relationships which describe the evolution of real activity, the impact of real activity on inflation, and the policy response to deviations of inflation from its target. Because South Africa is a small open economy, there is also a world block with a similar structure to the domestic block which allows variation in real activity abroad to impact both global commodity prices and domestic demand. Nominal exchange rate dynamics are driven by a modified Uncovered Interest Parity (UIP) condition which includes the current account, terms of trade, and long term interest rate differential in addition to the standard interest rate differential. Note that an asterisk ($*$) superscript is used to denote foreign variables.

3.1 Phillips curve

Headline targeted consumer price inflation is modelled in terms of three components (as in De Jager, 2007): Headline excluding administered prices, administered prices excluding petrol prices, and petrol prices. This allows the model to capture stylized facts about the relatively different behaviour of these series, as well as the relatively different off-model information forecasters have about the series when forecasting (for example, the model operator may have good information about future administered price inflation because of announced energy price increases).

Table 1: Inflation summary statistics: 2000Q1:2013Q4

Inflation series (yoy)	*Mean*	*Coefficient of variation*	*Autocorrelation (4)*
Headline ex petrol and admin	5.66	0.39	0.28
Administered prices ex petrol	7.86	0.37	0.32
Petrol	10.82	1.16	-0.33
Food	7.24	0.65	0.12

Figure 2: Inflation excluding administered prices and petrol with the real exchange rate gap

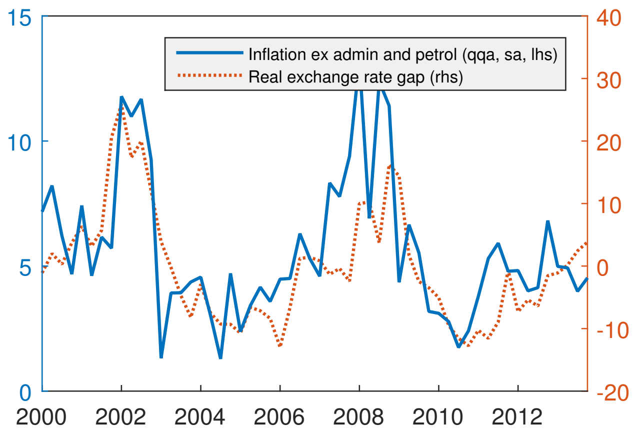
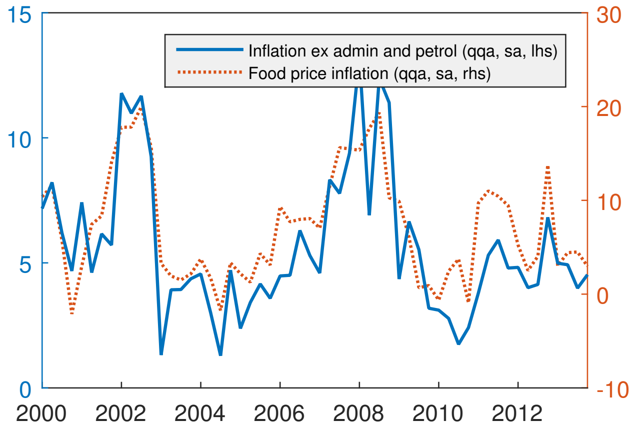


Figure 3: Inflation excluding administered prices and petrol with food price inflation



The key stylized facts are:

1. Petrol price inflation is highly correlated with the world price of oil denominated in rand, but is less volatile.

2. Much of the variation in core inflation is the result of supply shocks like import prices, exchange rate movements, and food prices.

3. Inflation in administered prices excluding petrol is correlated with our measure of core inflation, but is less volatile and has a higher mean (the latter largely due to the inclusion of energy prices).

These stylized facts are broadly captured in Tables (1-2) and Figures (2-4). An identity aggregates the components to create headline inflation.

$$\begin{aligned}\pi_t &= \left(1 - w^{pet} - w^{ad}\right)\pi_t^{core} \\ &+ w^{ad}\pi_t^{ad} + w^{pet}\pi_t^{pet}\end{aligned} \tag{3}$$

It is important to keep in mind that the measure of core inflation used in the model is much broader than the measure of core inflation used by Statistics South Africa. This is a deliberate choice to ensure that there is only one Phillips curve and that the monetary authority in the model controls a sufficiently broad measure of inflation. Narrowing the definition of core would effectively make much of the targeted basket π_t exogenous from the perspective of the authority charged with controlling it. While it is possible to build a model with multiple sectors, each with their own Phillips curve, doing so would eliminate the simplicity associated with the current approach and would require building a DSGE model with a significantly more complicated monetary transmission mechanism.

A Phillips curve for headline CPI excluding administered prices describes the relationship between real activity, as captured by the output gap, and changes in the targeted price level. The relationship is not explicitly micro-founded but describes a semi-structural relationship (Clarida et al., 1999). This relationship is modified by allowing supply side shocks such as the exchange rate, food prices, and oil prices to affect the price level (see Figures (2-3)).

Note that if $\rho^{core} + \sigma^{core} < 1$ then the inflation target implicitly affects inflation expectations. While we allow the announced inflation target to impact inflation expectations, we minimize the quantitative contribution of the target for theoretical reasons (discussed in the next section).

$$\begin{aligned}\pi_t^{core} &= \rho^{core}\pi_{t-1}^{core} + \sigma^{core}E_t\pi_{t+1}^{core} \\ &+ \gamma^{ygap}E_t\left(y_{t+4} - \bar{y}_{t+4}\right) + \gamma^{oil}\pi_{t-1}^{pet} \\ &+ \gamma^{m}\left(\pi_{t-2}^{p*} + \Delta s_{t-2} - \left(\rho^{core}\right)^2\left(\pi_{t-4}^{p*} + \Delta s_{t-4}\right)\right) \\ &+ \gamma^{food}\left(\varepsilon_t^{food} - \rho^{core}\varepsilon_{t-1}^{food}\right) \\ &+ \gamma^{zgap}\left(z_t - \bar{z}_t\right) + \Theta^s(L)\,\varepsilon_t^s + \varepsilon_t^{core}\end{aligned} \tag{4}$$

In the equation above, y_t is (log) real gross domestic product (GDP) and $\bar{y}_t$ is the (log) real potential GDP so that $(y_t - \bar{y}_t)$ describes the percent deviation of output from potential, i.e., the output gap. Lagged petrol price inflation positively influences core inflation through higher input costs (second round effects). The nominal exchange rate shock ε_t^s enters to permit unexpected exchange rate fluctuations to affect core inflation, while $\Theta^s(L)$ represents a lag polynomial which limits the extent to which the exchange rate shock contributes persistently to inflation. Including the food price shock allows the production of shock decompositions which account for food price fluctuations appropriately without necessitating further disaggregation in Equation (3). The moving average structure through which these shocks enter is designed to allow these components to have level effects on the price level without producing persistent inflation in the way that demand-driven inflation would. Rand-denominated foreign wholesale producer price inflation π_t^{p*} enters with a two-quarter lag as domestic retailers seem to be able to hedge foreign price fluctuations for about a half year, a stylized fact which is captured in Table (2) by looking at the correlation between our measure of core inflation and rand-denominated foreign wholesale price inflation at various lags. Lastly, the deviation of the real exchange rate from its equilibrium ($z_t - \bar{z}_t$) enters so that a relatively depreciated real exchange rate will contribute positively to inflation. While most of the variation in the real exchange rate gap will come from nomianal exchange rate movements, this also provides a channel for the transmission of relative productivity shocks or other real shocks in the manner of Balassa-Samuelson and is empirically justified by the relationship observed in Figure (2).

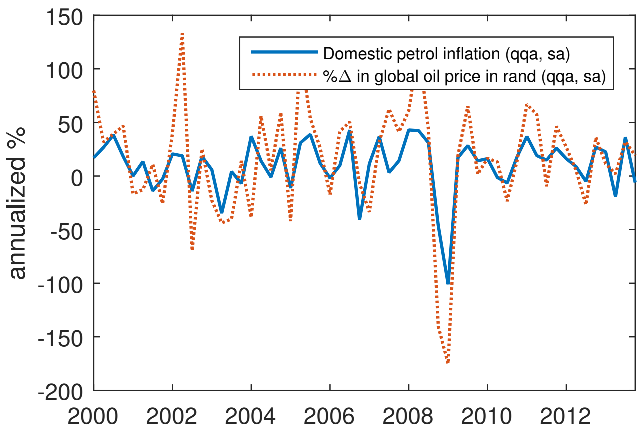
Table 2: Core inflation and rand-denominated foreign wholesale inflation

Horizon (in quarters)	0	1	2	3	4
Correlation	0.21	0.24	0.31	0.33	0.2

Administered prices are modelled as smoothed core inflation. While administered price inflation also differs from core inflation in that it has a higher mean, this adjustment takes place in the measurement equation for administered prices so that the equation below describes the demeaned series.

$$\pi_t^{ad} = \rho^{ad}\pi_{t-1}^{ad} + \left(1 - \rho^{ad}\right)\pi_t^{core} + \varepsilon_t^{ad}$$

Figure 4: Domestic petrol price inflation and global oil price inflation denominated in rand



Petrol prices π_t^{pet} are administered in South Africa and consist of approximately 50% taxes with the implication that the series is smoother than rand denominated oil prices $\pi_t^{*oil} + \Delta s_t$, as illustrated in Figure (4). Over the inflation targeting period, the standard deviation of rand-denominated oil prices is about double that of domestic petrol price inflation, and is modelled by relating the current movement of rand-denominated oil prices to the domestic basic fuel price by a coefficient $0 < \gamma^{*oil} < 1$.

$$\begin{aligned}\pi_t^{pet} &= \rho^{pet}\pi_{t-1}^{pet} + \left(1 - \gamma^{*oil} - \rho^{pet}\right)E_t\pi_{t+1}^{pet} \\ &\quad + \gamma^{*oil}\left[\pi_t^{*oil} + \Delta s_t\right] + \varepsilon_t^{pet}\end{aligned}$$

3.2 IS Curve

An IS curve describes the evolution of real activity, as summarized by the output gap, in relation to expectations of business cycle frequency variation in real interest rates and factor adjustment dynamics. The IS curve is augmented to account for the influence of global real activity on exports, although the decomposition of the national accounts is not explicitly modelled; to do so would require introducing and modelling relative sectoral prices as in multi-sector DSGE models (e.g., Dorich et al., 2013).

$$\begin{aligned}
y_t - \bar{y}_t &= \rho^{ygap}\left(y_{t-1} - \bar{y}_{t-1}\right) + \sigma^{ygap} E_t\left(y_{t+1} - \bar{y}_{t+1}\right) \\
&+ \alpha^{rrgap}\left(r_t - \bar{r}_t\right) + \alpha^{rrgapl}\left(r_t^L - \bar{r}_t^L\right) \\
&+ \alpha^{zgap}\left(z_t - \bar{z}_t\right) + a^{cls} cls_t \\
&+ \alpha^{*ygap}\left(y_t^* - \bar{y}_t^*\right) + \varepsilon_t^{ygap}
\end{aligned}$$

In contrast to more orthodox expositions (Clarida et al., 1999) this framework features a term structure of interest rates, both domestically and abroad; the long-term real interest rate gap affects real activity in addition to the short-term real interest rate gap. Lag terms exist to account for frictions which make adjustment to equilibrium a sluggish process (for example, to account for delays in capital reallocation or labour market matching). Deviations of the real exchange rate from its equilibrium also influence real activity so that, for example, exchange rate depreciation boosts output via increased export demand. Credit lending standards act as a proxy for credit supply. The real interest rate gap $(r_t - \bar{r}_t)$ is used instead of the real interest rate in order to allow the natural rate of interest to fluctuate over time (e.g., because of a trend in the marginal product of capital).

The IS curve above describes the evolution of real activity as an intertemporal substitution problem: the tradeoff is about more consumption this quarter vs. next. High real interest rates increase incentives to save and depress current output. This relationship is similar to Euler equations in DSGE models except that DSGE models will typically contain several Euler equations, each corresponding to a different intertemporal substitution problem.

3.3 Term structure

The term structure of interest rates is based on the expectations hypothesis so that the long rate is the expected average of future short rates plus a term premium. That term premium τ_t is identified as the difference between the expected average of future short rates and the observed long rate.

$$R_t^L = \frac{1}{K}\sum_{j=0}^{K-1} R_{t+j} + \tau_t$$

For simplicity we use 10-year sovereign bond rates and do not explicitly model the entire term structure but instead only two points $\left(R_t, R_t^L\right)$ in it. The term premium follows a stationary autoregressive process. The long-term real rate is the nominal long rate less expected inflation over that period, a long-term analog to the standard Fisher equation $(r_t = R_t - E_t\pi_{t+1})$, as in Andrés, López-Salido, and Nelson (2004).

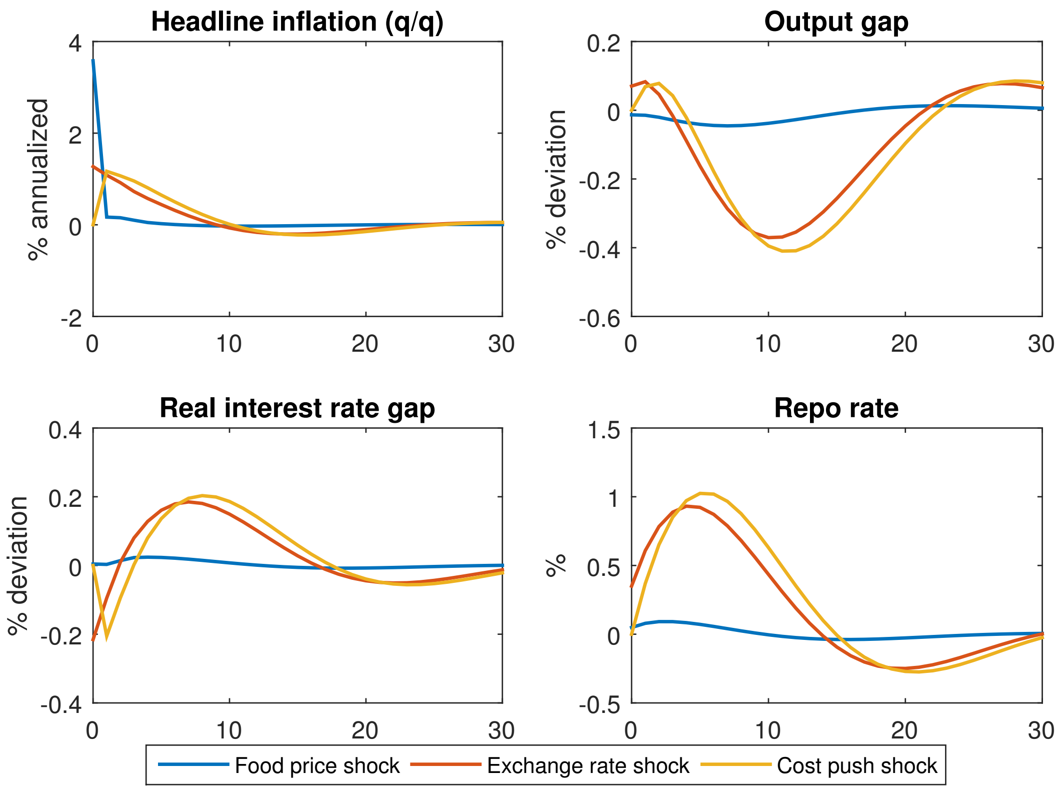
$$r_t^L = R_t^L - \frac{1}{K}\sum_{j=1}^{K} \pi_{t+j}$$

Finally, the real equilibrium short rate follows a persistent but stationary autoregressive process, and the long-term equilibrium real rate is the expected average of future real equilibrium short rates. This implies that both short and long real rates converge to the steady state equilibrium real rate over long periods of time, effectively lowering the elasticity of equilibrium long rates with respect to equilibrium short rates (relative to the case in which the equilibrium real rate follows a non-stationary process).

$$\bar{r}_t^L = \frac{1}{K}\sum_{j=0}^{K-1} \bar{r}_{t+j}$$

The world block contains a term structure of interest rates which is symmetric to the one presented above. It is straightforward to augment both domestic and global term structure to incorporate time-varying risk premia.

Figure 5: Policy response to alternative shocks, normalized by peak year-on-year inflation impact



3.4 Taylor Rule

Monetary policy is described by a Taylor rule (Taylor, 1993) which states that the central bank will respond more than one-for-one in the long run to deviations of inflation from its target. This ensures that if inflation is rising, real interest rates are also rising to lower demand and stabilize the price level.

$$R_t = \rho^R R_{t-1} + \left(1-\rho^R\right)\left[\bar{r}_t + \phi^{\pi} E_t \sum_{j=1}^{4} \pi_{t+j} + \phi^{ygap}\left(y_t - \bar{y}_t\right)\right] + \varepsilon_t^R \tag{5}$$

Although the actual inflation target is technically a band (to maintain inflation between 3% and 6%) we approximate this rule with a point target to avoid complicating the model with non-linearity.

Because of the way the monetary authority sets interest rates based on expected year-on-year inflation five quarters ahead, inflationary components which are expected to be completely transitory will see no policy response; the magnitude of the policy response is related to the expected persistence of the deviation of inflation from its target, as illustrated in Figure (5). As demand-pull inflation is the most persistent type it accordingly warrants the most aggressive policy response; inflation produced by supply side shocks like exchange rate fluctuations or food prices may receive less response because of the moving average structure with which these components enter the Phillips curve, as discussed earlier.

3.5 Uncovered interest parity

Nominal exchange rate movements s_t are described by expected future nominal interest rate differentials relative to the rest of the world. Because the model features a term structure of interest rates, both long-term and short-term interest rate differentials matter; the parameter ψ^s controls the relative importance of the short end of the yield curve.

$$\begin{aligned} s_t &= \rho^s\left(s_{t-1}+\Delta\bar{z}_t+\pi_t-\pi_t^*\right) \\ &\quad +\left(1-\rho^s\right)E_t\left[\begin{array}{c} s_{t+1}+\psi^s\left(R_t^*-R_t\right)+\left(1-\psi^s\right)\left(R_t^{*L}-R_t^L\right)-\xi_t \\ +\chi^{ca}ca_t-\chi^{tot}tot_t \end{array}\right]+\varepsilon_t^s \end{aligned}$$

Because South Africa is a net commodity exporter, adjustments are also made to allow the terms of trade tot_t to affect the currency valuation. The current account ca_t also influences currency valuation, an assumption which can be justified by empirical evidence linking currency crises to current account imbalances (Ferretti and Razin, 2000). The risk premium ξ_t is time varying and follows a stationary first-order autoregressive process. Lastly, the current account is also a stationary first-order autoregressive process; this means that the current account is permitted to affect the value of the currency, but there are no feedback effects from other parts of the model into the current account. This is an important assumption because it means that exchange rate movements do not endogenously affect the current account position in forecasting scenarios.

$$\Delta z_t=\Delta s_t+\pi_t^*-\pi_t$$

The change in the real exchange rate z_t is the change in the nominal exchange rate adjusted for the difference in the rate of change of the price level.

$$\begin{aligned} tot_t-\overline{tot}_t &= \rho^{tot}\left(tot_{t-1}-\overline{tot}_{t-1}\right) \\ &\quad +\lambda^{oil}\left(p_t^{*oil}+s_t\right)+\lambda^{nec}\left(p_t^{*nec}+s_t\right)+\varepsilon_t^{tot} \end{aligned}$$

Terms of trade are positively related to the price of non-energy commodities in rand, and negatively related to the price of oil in rand. The equilibrium terms of trade value $\overline{tot}_t$ follows a random walk.

3.6 World Block

As discussed in the data section, most of the world variables are constructed by trade-weighting Global Projection Model (GPM) regional data or projections. This section outlines the equations which describe the dynamics of those composite variables. The relatively simple structure is designed to permit judgment-free evaluation of the forecasting performance of the domestic portion of the model and is used in constructing shock decompositions; in any actual forecasting exercise the block is effectively shut off by using anticipated shocks to condition on the paths from the GPM.

The global block of the model is similar to the domestic block but simpler in structure. A Taylor rule again describes the monetary policy reaction function, and a Phillips curve captures the relationship between demand pressures and changes in the price level, but both are standard and are omitted for brevity. The IS curve is relates global real activity, as described by a global output gap composite, to short-term and long-term interest rate gaps.

$$
\begin{aligned}
y_t^* - \bar{y}_t^* \quad = \quad & \rho^{*ygap}\left(y_{t-1}^* - \bar{y}_{t-1}^*\right) + \sigma^{*ygap} E_t\left(y_{t+1}^* - \bar{y}_{t+1}^*\right) \\
& \alpha^{*rrgap}\left(r_t^* - \bar{r}_t^*\right) + \alpha^{*rrgapl}\left(r_t^{*L} - \bar{r}_t^{*L}\right) \\
& + \alpha^{*unc} unc_t^* + \varepsilon_t^{*ygap}
\end{aligned}
$$

Elevated economic uncertainty may depress real activity, as captured by the uncertainty term, unc_t^*. This is useful in explaining the protracted recovery following the 2008 financial crisis and is consistent with evidence in Bloom (2013), although other researchers have put forward alternative explanations such as luck (Galí et al., 2012). The world U.S. dollar-denominated prices of oil and non-energy commodities are explained in terms of their relationship to global growth.

$$
\begin{aligned}
\pi_t^{*oil} \quad = \quad & \rho^{*oil}\pi_{t-1}^{*oil} + \sigma^{*oil} E_t \pi_{t+1}^{*oil} \\
& + \varphi^{*\bar{y}} \Delta\bar{y}_t^* + \varphi^{*y} \Delta y_t^* + \varepsilon_t^{*oil} \\
\pi_t^{*nec} \quad = \quad & \rho^{*nec}\pi_{t-1}^{*nec} + \sigma^{*nec} E_t \pi_{t+1}^{*nec} \\
& + \omega^{*\bar{y}} \Delta\bar{y}_t^* + \omega^{*y} \Delta y_t^* + \varepsilon_t^{*nec}
\end{aligned}
$$

Potential output $\bar{y}_t^*$ is included so that gobal commodity prices are cointegrated with global potential output.

4 Calibration

As the primary purpose of a projection model like this is to facilitate decision making on the part of policymakers, there are a number of objectives which extend beyond mere forecasting accuracy. These objectives are not easily incorporated into likelihood-based estimation procedures, and for this reason we opt to calibrate the model (Kydland and Prescott, 1982) by choosing parameters which appropriately balance tradeoffs. Table (3) shows the numerical values of the coefficients chosen while the text and accompanying figures explain the reasoning behind the choices.

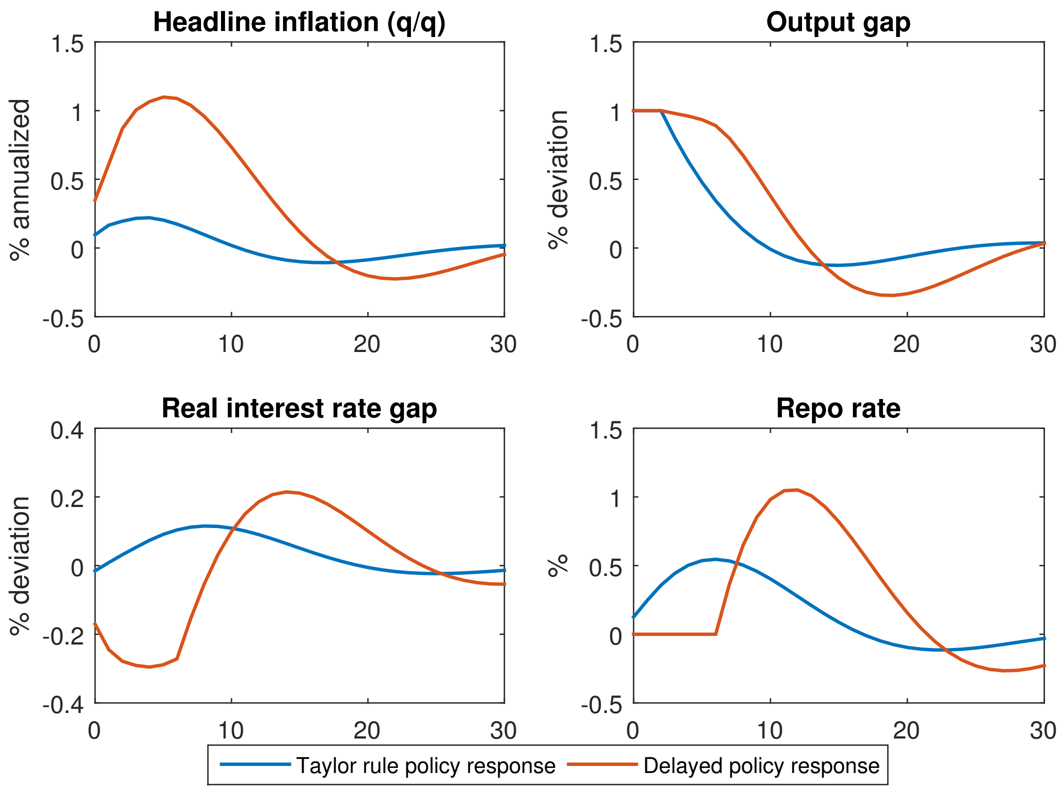
Table 3: Parameters

Parameter name	Symbol	Value
Inflation identity		
Petrol weight	w^{pet}	0.04
Admin ex petrol weight	w^{ad}	0.16
Phillips curve		
Inflation lag	ρ^{core}	0.57
Inflation lead	σ^{core}	0.42
Output gap	γ^{ygap}	0.017
Imported prices	γ^{m}	0.01
Food prices	γ^{food}	0.2
Real exchange rate gap	γ^{zgap}	0.001
Administered price inflation		
AR(1) smoothing	ρ^{ad}	0.7
Petrol price inflation		
AR(1) smoothing	ρ^{pet}	0.15
Rand world oil price	γ^{*oil}	0.15
IS curve		
Output gap lag	ρ^{ygap}	0.7
Output gap lead	σ^{ygap}	0.2
Real short-term interest rate gap	α^{rrgap}	0.3
Real long-term interest rate gap	α^{rrgapl}	0.2
Real exchange rate gap	α^{zgap}	0.001
Credit lending standards	α^{cls}	0.008
Foreign output gap	α^{*ygap}	0.12
Taylor rule		
Interest rate smoothing	ρ^{R}	0.93
Inflation	ϕ^{π}	1.5
Output gap	ϕ^{ygap}	0.15
UIP condition		
Backward looking share	ρ^{s}	0.15
Short-term interest rate differential share	ψ^{s}	0.3
Current account	χ^{ca}	0.12
Terms of trade	χ^{tot}	0.0006
Terms of trade		
AR(1) smoothing	ρ^{tot}	0.12
Dollar-denominated oil price	λ^{*oil}	-0.3
Dollar-denominated non-energy commodity price	λ^{*nec}	1

First, the model should not permit any policy free lunches. For example, consider a persistent positive demand shock which raises inflationary pressures. The Taylor rule will raise nominal rates enough to cause real interest rates to rise, offsetting demand-driven inflationary pressures. If the monetary authority deviates from the Taylor rule and fails to respond to inflationary pressures, real interest rates fall with rising inflation and the policy should add to the demand pressures to the point that the ultimate policy response required is more aggressive than if the monetary authority had simply always followed a Taylor rule. As illustrated in Figure (6), problems which are under the policy authority's control should not solve themselves.

In inflation targeting countries, inflation is statistically likely to return to target following deviations. *Why* this occurs in structural models like ours is critically important. Consider two very different models. In one inflation is inherently unstable, but is brought back to target by aggressive action on the part of the monetary authority. In the other inflation is inherently stable and will return to target regardless of the actions of the monetary authority. If one takes the latter model seriously in considering the projected consequenes of alternative policies, then the policy authority can seemingly avoid raising interest rates to reduce demand and inflation will control itself. Models with properties like this can clearly lead to policy failures if taken literally, so we will focus only on models of the former type in which inflation is only controlled through credible anti-inflationary actions on the part of the policy authority. For this reason we require $(1-\rho^{core}-\sigma^{core})$, the implicit weight on the inflation target in the Phillips curve, to be approximately zero; as calibrated the weight on the target is 0.01.

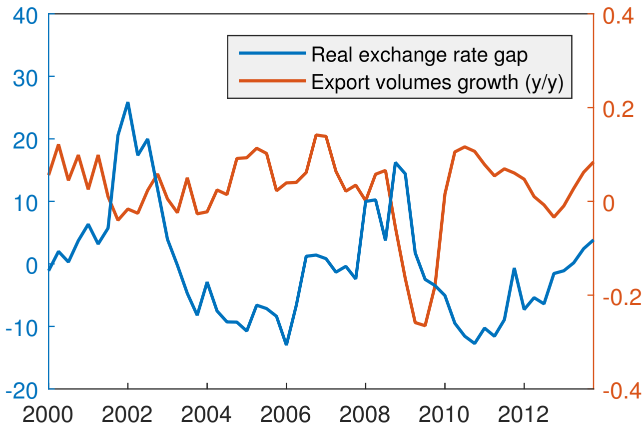
Figure 6: Delayed policy response to inflationary pressures



The IS curve describes the dynamics of the output gap in terms of the incentives real interest rates provide to substitute output intertemporally, while the Phillips curve describes the relationship between aggregate demand and the price level. Secondary and tertiary monetary transmission channels exist as policy influences yields on long-term debt, and both the policy rate and long-term interest rates enter the uncovered interest parity (UIP) condition. Achieving the first objective listed above requires a sufficiently strong link between real interest rates and aggregate demand, and aggregate demand and inflation. This ensures the primary channel for the monetary transmission mechanism is to alter inflationary pressures by using real interest rates to shift aggregate demand. As a result the coefficient in the Phillips curve through which aggregate demand affects inflation γ^{ygap} must be sufficiently large, and the coefficients in the IS curve through which interest rates affect real activity α^{rrgap} and α^{rrgapl} must also be sufficiently large.

Second, the model should capture the relevant frequency-domain characteristics of the data in the sense that the autocorrelation generating functions (ACGF) should be similar, as in Watson (1993). This is essential to capture the business cycle frequency movements and to assess the peak inflation and output impact of monetary policy shocks. It also ensures the model works well as a medium-term forecasting tool.

Figure 7: Real exchange rate gap and real year-on-year export growth



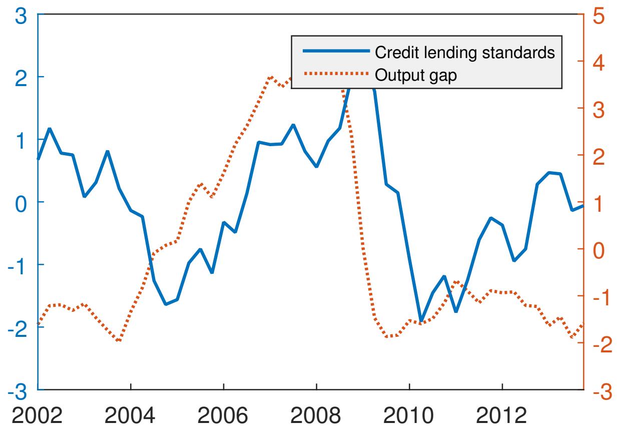
Third, the stories the model tells about history should be plausible in the sense that it is consistent with the views of modelers and policymakers. Many models within the class described here may be empirically plausible from the perspective that they provide reasonably similar forecasting accuracy, but only one structural explanation – as described by the structural shocks which most likely represent history – can be correct. The task of the modeller is to choose parameters which produce an explanation that is intuitively plausible while retaining satisfactory forecasting performance.

Figure (9) plots sequential no-judgment predictions for key macroeconomic variables which start from the current observation and extend six quarters into the future. The ability of the model to capture turning points and the approximate frequency domain characteristics in the data are key inputs into many parameter choices.

The parameter α^{zgap} is almost zero and the model predicts relatively little response of real GDP to exchange rate depreciation. Identification of this parameter is achieved through visual inspection of the sequential predictions for the output gap: periods of exchange rate depreciation are not particularly prosperous periods for the South African economy. One explanation might be that while a depreciated exchange rate makes exports more attractive to the rest of the world, it also hurts the domestic economy through higher energy prices and imported input costs. The contemporaneous correlation between real export growth (year-on-year) and the real exchange rate gap is negative (the point estimate is -0.26), as shown in Figure (7).

Credit lending standards are quantitatively relatively unimportant with a value for α^{cls} of 0.008. It is otherwise difficult to explain the overheating in the domestic economy between 2004 and 2008 and why it persisted so long. The dramatic easing in credit standards following the financial crisis and the weak subsequent growth provide another check on the magnitude of this elasticity. Global economic activity and domestic real interest rates do a much better job of explaining output gap dynamics over the inflation targeting period.

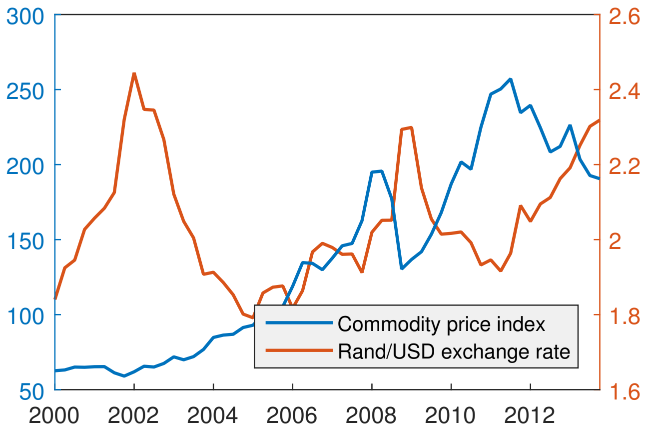
Figure 8: Credit lending standards and the real economy



Parameters in the Phillips curve are selected subject to the constraints discussed earlier in this section, with the aim of capturing the appropriate business cycle spectral characteristics subject to these constraints. The importance of the exchange rate is clear from inspection of Figure (2), where periods of exchange rate depreciation are associated with periods of high inflation. The weight on imported prices γ^m and the weight on the real exhange rate gap γ^{zgap} are chosen to maximize the medium-term fit of sequential inflation forecasts to actual outcomes in Figure (9) and to meet econometric evidence on average pass through of exchange rate movements to headline inflation. In structural models there are many reasons the exchange rate might move, so we choose to measure the average exchange rate pass through in the model by simulating the model using shocks which are bootstrapped over the inflation targeting period. In these simulations the model pass through is 11% which is close to the 13% estimate one would obtain over the same period with a simple regression. This ensures that while the exchange rate affects inflation in multiple ways, the calibrated relationships do not overstate the magnitude of the relationship between the nominal exchange rate and headline inflation. The elasticity of inflation with respect to the output gap γ^{ygap} is determined largely to meet the objective of producing a model without policy free lunches. The sum of the parameters $\{\rho^{core}, \sigma^{core}\}$ is selected to approximately impose the natural rate hypothesis, and their relative weights are determined factors like the speed with which changes in real activity translate to changes in headline inflation.

In calibrating the parameters of the UIP condition we recognize the inherent difficulty in forecasting exchange rates (Kilian and Taylor, 2003) and bias the model towards a random walk rather than try to maxmize in-sample performance. However, we do attempt to capture whether the currency is likely over- or under-valued over the medium term. Because South Africa is a net commodity exporter and commodity prices over the inflation targeting period have risen on average, terms of trade tend to contribute to exchange rate appreciation over the same sample. Since the nominal exchange rate depreciates against the dollar on average in our sample (see Figure (9), it is hard to think this relationship is particularly strong, and this is why the parameter χ^{tot} is small. Over the same period the current account is negative and widening, on

Figure 9: Non-energy commodity prices and currency value: 2000Q1:2013Q4



average, and this partially offsets the effects of improving terms of trade. The parameter χ^{ca} is selected to match key periods over which the currency depreciates, such as the period between the middle of 2004 and the financial crisis. The parameter ρ^{s} must be small or the model forecasts become dominated by recent trends in currency movements rather than fundamentals. Model forecasts are not paricularly sensitive to the choice of the weight on short-term assets in the UIP condition, and the parameter ψ^{s} is small to capture the stylized fact that short term bonds are a small part of the bond market internationally.

The Taylor rule long run reaction coefficient ϕ^{π} of 1.5 is relatively high compared to many estimates for South Africa in the literature. For example, Ortiz and Sturzenegger (2007) estimate a reaction coefficient of 1.11. However, we also use a higher lag parameter ρ^{R} of 0.93 so that the short run reaction is similar. Using a lower long-run reaction worsens the ability of the model to predict inflation since agents anticipate the deviations of inflation from target to be persistent when the monetary authority is expected not to act aggressively. The output gap weight ϕ^{ygap} is also small at 0.15 or it becomes even more difficult to explain why the repo rate was not cut more following the financial crisis (our current calibration already predicts this). The implicit target for inflation excluding administered prices is set at 5.2% and corresponds to an implicit target for headline inflation of 5.75%. This is at the upper end of the target band (to keep inflation between 3% and 6%) but it is empirically difficult to justify lower values. Even with this value the deviations of monetary policy from the Taylor rule contribute, on average, to higher inflation outcomes. Specifically, the Taylor rule would predict a more aggressive response to supply side shocks like the exchange rate depreciation episodes experienced in-sample, and this is captured in both the sequential predictions (Figure (9)) and the shock decomposition of headline inflation (Figure (10)).

5 Simulation results

The model described in Section (3) fits in linear state space form and hence can be easily solved and simulated using linear rational expectations solutions methods (King and Watson, 1998); the solution can accordingly be used with the Kalman filter (Harvey, 1990). It takes the form

$$y_t = Hs_t + Rv_t \tag{6}$$

$$s_t = Ms_{t-1} + Gv_t \tag{7}$$

where y_t is a vector of observable variables, s_t is the state vector, and v_t is a vector of standard Normal independent random variables.[1] The Kalman filter can be used to obtain the minimum mean square estimate of the state vector $\hat{s}_t$ conditional on the model.

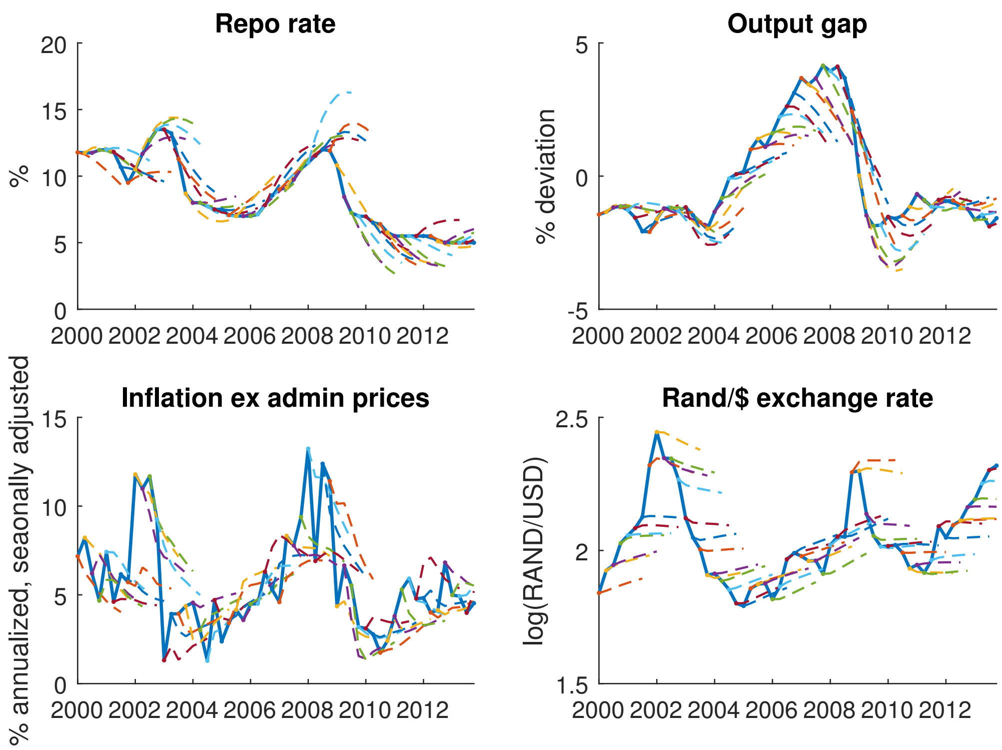
5.1 Sequential forecasts

Conditional on a state estimate $\hat{s}_t$ we can produce forecasts of future observables $E_t y_{t+j}$ for $j > 0$ by iterating on the state equation. Specifically,

$$E_t y_{t+j} = HM^j \hat{s}_t. \tag{8}$$

Figure (9) plots sequential forecasts for key macroeconomic variables where each forecast begins from the state estimate obtained from the Kalman filter.

Figure 10: Sequential no-judgment predictions for key macro variables



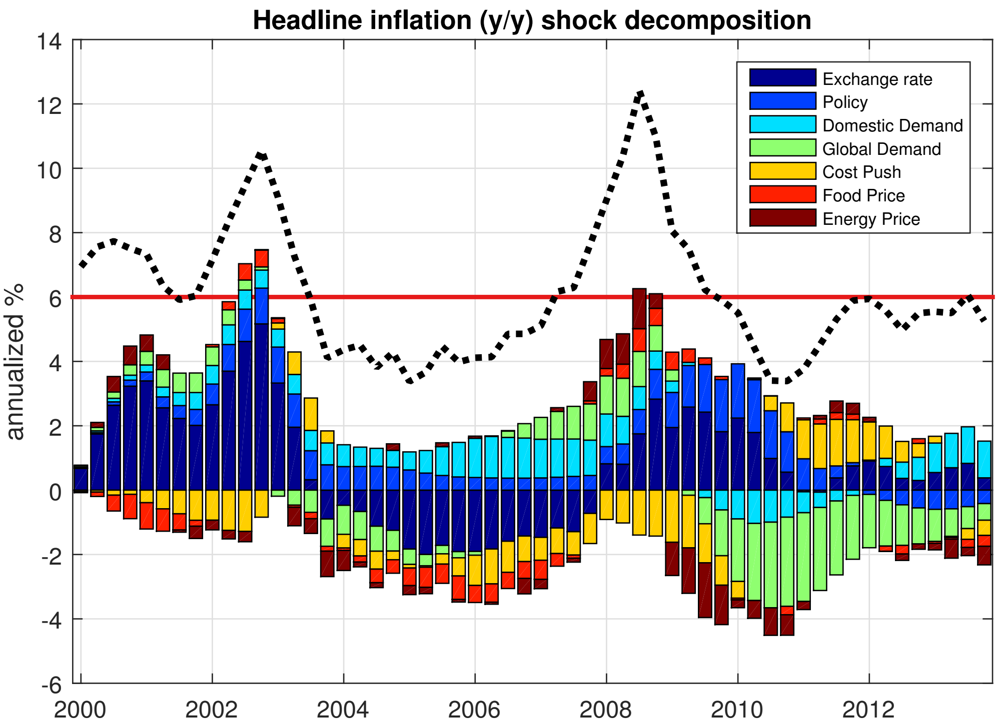
5.2 Shock decompositions

One of the most attractive aspects to using quantitative general equilibrium models is their ability to produce a causal analysis of historical outcomes. The Kalman filter simultaneously produces a time series of state vector estimates $\{\hat{s}_t\}_{t=0}^T$ and shocks $\{\hat{v}_t\}_{t=0}^T$ which replicate the observed historical data $\{y_t\}_{t=0}^T$. Let $\hat{v}_{i,t}$ be the ith element of the K elements in $\hat{v}_t$, and let $\hat{y}_{i,t}$ be the vector of observables obtained by simulating the model with only $\hat{v}_{i,t}$ non-zero and the remaining elements of $\hat{v}_t$ set to zero. Then by linearity $\sum_{i=1}^K \hat{y}_{i,t} = y_t$, for all t, and $\hat{y}_{i,t}$ represents the estimated contribution of shock i to the observed outcomes y_t. Figure (11) plots a shock decomposition of headline inflation where some of the plethora of shocks in the model have

[1] This is equivalent to the way state space systems are normally written for suitable R and G matrices.

been grouped to make things parsimonious.[2] In interpreting the graphs it is important to keep in mind that a shock decomposition is not a decomposition: it describes the contribution of particular stochastic terms to observed outcomes. For example, monetary policy is always active and the contributions in Figure (11) should be interpreted as the consequence of deviating from the Taylor rule in Equation (5).

Figure 11: Headline inflation shock decomposition



The shock decomposition provides a historical explanation for inflation outcomes in South Africa, and indicates that similar outcomes may have very different causal explanations. The first target breach in the inflation targeting period is attributed mostly to exchange rate weakness, although elevated food prices make the problem worse. This is markedly different from the next target breach, where the primary cause is an overheating global and domestic economy and accordingly elevated hard and soft commodity prices. Despite exchange rate weakness and accommodative monetary policy after the financial crisis, inflation outcomes have been low because of persistent weakness in major trading partners.

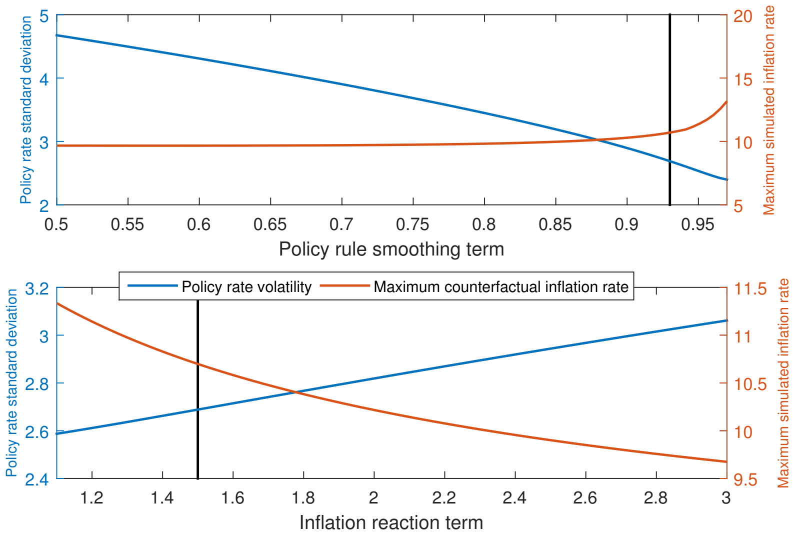
5.3 Alternative policy rules

Since the model provides an account of historial macroeconomic outcomes in a way that controls for policy, a natural counterfactual question concerns the alternative outcomes which might have been obtained had the policy authority used an alternative policy rule. Answering whether the chosen policy is optimal within some class of rules requires having a well-specified objective function which balances tradeoffs between variability in inflation, real activity, and real interest rates. However, because the tradeoffs are often

[2] Exchange rate shocks include the nominal exchange rate shock ε_t^s and real equilibrium exchange rate shock, as well as current account, terms of trade, and non-energy commodity price shocks. Domestic emand shocks include the shock to the IS curve itself ε_t^{ygap} as well as shocks to the term premium and credit lending standards. Energy price shocks include both the shock to the dollar price of oil ε_t^{*oil} and the shock to domestic petrol price inflation ε_t^{pet}. The remaining shocks are not grouped and the names are self explanatory. Contributions from model constants are omitted.

non-linear, it may be instructive to consider whether small changes to policy parameters might give better outcomes with respect to one metric without significantly worsening others. We look at this question by using the structural shocks from the previous section, removing the policy shocks, and simulating the economy under alternative Taylor rule parameters. Figure (12) shows how the inflation reaction coefficient and interest rate smoothing parameter affect the maximum counterfactual inflation rate and nominal interest rate volatility. Obviously responding more quickly or aggressively to perceived inflation threats lowers the maximum observed inflation outcome, but potentially at the cost of a highly variable repo rate. The figure illustrates that although the calibrated policy rule exhibits significant preference for interest rate smoothing, it avoids the worst of the nonlinearities.

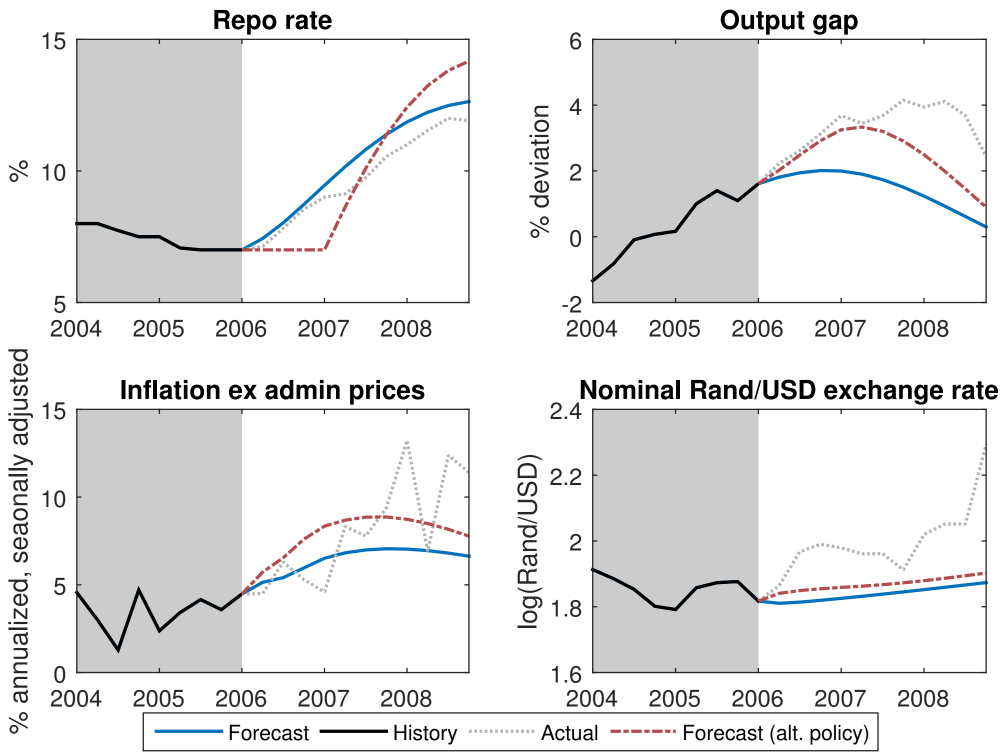
Figure 12: Counterfactual simulations under alternative Taylor rules



5.4 Policy-conditional forecasting

The forecasting equation (8) describes the no-judgment forecast under which the expectation of future structural shocks is zero, but can be modified to account for deviations from model behaviour (Beneš, 2011). For example, it is possible to solve for structural shocks $\{\varepsilon^R_{t+i}\}$ which fix a particular path for the nominal interest rate R_t in a way that is anticipated by agents and is still consistent with rational expectations. For example, Figure (13) shows a hypothetical forecasting scenario which begins in 2006Q1. The shaded area represents history, and the remaining portion of the graphs shows two policy-adjusted projections along with the actual outcome. In one forecast we condition on monetary policy following the Taylor rule; while in the other we condition on the nominal interest rate not changing for one year, after which the nominal interest rate once again follows the Taylor rule. This illustrates how the model can be used to discuss intertemporal considerations in policy decisions. While the monetary authority can temporarily raise near-term growth prospects, doing so exacerbates inflationary pressures and necessitates more aggressive future policy actions to bring inflation back to target.

Figure 13: Policy-conditional no-judgment forecasts



6 Conclusion

We build on work in De Jager (2007) to construct a theoretical model of South Africa which can be used for medium-term forecasting and causal policy analysis. The model augments a traditional New Keynesian structure with features necessary to describe the dynamics of the macroeconomy in South Africa over the inflation targeting period. It includes a term structure of interest rates (both domestically and abroad) which make the model useful in analyzing the effects of alternative monetary policies such as quantitative easing or regulatory changes, in addition to providing a more nuanced monetary transmission mechanism. It also features a modified interest parity condition which accounts for the impact of terms of trade movements and current account imbalances on currency valuation.

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