A STRUCTURAL DECOMPOSITION OF THE SOUTH AFRICAN BUSINESS CYCLE

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Abstract

Empirical econometric literature in South Africa has explored a wide range of topics related to the business cycle. There are, however, fewer instances of dynamic general equilibrium models developed to look at the underlying structure of the South African business cycle. Importantly, it has not been well-established how alternative specifications affect the estimated structure and dynamics of the business cycle, which has important implications for policy analysis. This paper evaluates the consistency of model estimations in the extant literature and tests the sensitivity of alternative models tailored to the South African economy. We find that both parameter estimates and model dynamics are sensitive to model specification. Our findings suggest that a three-equation New-Keynesian model and a traditional open economy model provide qualitatively and quantitatively similar results to the benchmark medium-scale New-Keynesian model with sticky prices and wages, habit formation and investment adjustment costs. However, significant differences from the benchmark New-Keynesian specification are revealed once financial frictions are included. In addition, the types of exogenous shocks included in the model are key determinants for the variation of results.

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1 Introduction

South African business cycle dynamics have been fairly well-documented within the empirical econometric literature (see, e.g., Moolman (2004), du Plessis (2004), du Plessis (2006), du Plessis et al. (2008), Burger (2008), Burger (2010), du Plessis and Kotzé (2010), Bosch and Ruch (2013), Venter (2017), Vermeulen et al. (2017)). While econometric models can be used effectively to delineate the determinants of movements in the business cycle, theoretically-derived dynamic general equilibrium models can provide more detailed underlying structural dynamics of an economy (Ohanian et al., 2009). Indeed, over the last two decades, dynamic stochastic general equilibrium (DSGE) models became the most widely adopted methodological approach in macroeconomic policy-making (Tovar (2009); Lindé et al. (2016)). This family of models, most notably, allows for more intricate characterisations of economic decision-making through the establishment of rigorous microfoundations.[1]

A theoretical framework that embraces microfoundations has a number of unique benefits. First, it allows the researcher to decompose variables into the likely factors driving their evolution over time. These factors include both endogenous frictions and exogenous shocks. Second, it paves the way for causal inference, allowing macroeconomic relationships to be generated from microeconomic principles. Finally, it opens up the possibility for welfare analysis, affording practitioners the ability to make informed judgements surrounding the implications of a particular policy or policy rule.

DSGE models typically form part of a suite of methodologies in the toolkit of policymakers—especially central banks (Tovar, 2009). These central bank models rely heavily on the benchmark New-Keynesian DSGE framework for policy analysis and forecasting (see, e.g., Lindé et al. (2016) and Botha et al. (2017)). While DSGE models have a greater degree of theoretical coherence, econometric models often showcase greater empirical coherence (Wren-Lewis, 2018).[2] As such, it is not the explicit goal of this chapter to forecast future values of key indicators. Instead, we focus on reproducing and detailing conditions of the South African business cycle environment.

Documenting the business cycle dynamics in South Africa using modern techniques of dynamic stochastic general equilibrium (DSGE) models has recently become more popular (see Steinbach, Mathuloe, and Smit (2009); Alpanda, Kotzé, and Woglom (2010); Steinbach, du Plessis, and Smit

[1]In particular, microfoundations relay the ability of these models to incorporate forward-looking, policy invariant and heterogeneous agent behaviour (see, e.g., Ohanian et al., 2009). However, these models are not without their drawbacks. In the next section a discussion is undertaken to describe the current role for these type of models and the extensions that need to be incorporated to keep them relevant to the underlying economic environment.

[2]The role for DSGE models in providing accurate forecasts of macroeconomic indicators is not so clear cut. Although DSGE models can be used in conjunction with other macroeconometric tools, this is not its strong suit, and traditional econometric models might perform better in this regard. See, for example, the discussion in Blanchard (2018) about the relevance of DSGE models when it comes to predicting events or the path of macroeconomic indicators.

(2014); Paetz and Gupta (2016); Hollander, Gupta, and Wohar (2018))[3], but is still in its infancy compared to more traditional econometric methods. The various DSGE models developed for the South African economy primarily include features that have become standard in the small open-economy literature. Generally, these frictions attempt to reproduce empirical regularities built-up from microfounded motivations, such as: staggered price- and wage-setting; price- and wage-indexation to past inflation; habit formation in consumption; incomplete international risk-sharing through asset diversification; incomplete exchange rate pass-through to domestic inflation; and Taylor-type rules to describe monetary policy. Financial frictions (i.e., financial sector components in DSGE models) are another important dimension that has experienced increased attention in the domestic literature. In addition, a number of models (including hybrid DSGE-VARs) have been used explicitly for forecasting purposes (Liu and Gupta (2007), Liu et al. (2009), Alpanda et al. (2011), Gupta and Steinbach (2013), Balcilar et al. (2015), Balcilar et al. (2017)) or explicitly for fiscal and monetary policy analysis (e.g., Jooste et al. (2013) and Liu (2013))—although relatively little attention has been paid to fiscal rules.[4]

The specific goal of this chapter is to unify the important contributions in the literature through the use of nested macroeconomic DSGE models. In particular, we first consider the benchmark closed economy New-Keynesian DSGE (NKDSGE) model, as presented by Smets and Wouters (2003, 2007). This benchmark model is then extended along two dimensions. First, in order to address criticisms launched against the DSGE modelling paradigm in the wake of the financial crisis, financial frictions are incorporated through a non-trivial financial sector (see, e.g., Gerali et al., 2010). Specifically, we incorporate a role for monopolistically competitive retail banking, bank balance sheet management and stock market wealth effects (Hollander and Liu, 2016a,b). Second, open economy features are introduced to more accurately reflect the prevailing economic conditions in the South African economy (see, e.g., Adolfson et al., 2007; Steinbach et al., 2009; Hollander et al., 2018). Incorporating these non-trivial, yet tractable, extensions will help the model capture important business cycle moments. South Africa is, for example, particularly exposed to movements in international markets and therefore it is important to present a small open economy dynamic stochastic general equilibrium (SOE-NKDSGE) model. In the next section we frame the debate among macroeconomists as to the theoretical and empirical relevance of DSGE models.

[3]Kotzé's (2014) PhD thesis provides a detailed discussion and application of DSGE approaches similar to the objective of this chapter.

[4]Works-in-progress incl. Kotzé (2017) and Kemp (PhD).

2 The DSGE Framework as a Modelling Paradigm

Kuhn (1996) argued that for a paradigm shift to occur there needs to be a core failure in the prevailing paradigm and that a persuasive new path must clearly emerge. The failure of New-Keynesian DSGE models to accurately predict the financial crisis has generated sharp criticism of the consensus model, with several pundits unequivocally pronouncing the demise of this modelling framework (Korinek, 2017; Stiglitz, 2017). As a result of this perceived failure, it is argued that macroeconomic modelling is now primed for a paradigm shift.[5] Taking these criticisms into consideration, we discuss the role that DSGE models have played in the past and possible extensions that would allow it to become a core component of the new path for macroeconomic modeling following the financial crisis.

2.1 The current state of DSGE

The two decades preceding the Great Financial Crisis (GFC) were marked by an unprecedented consensus on the intellectual and institutional framework for macroeconomic policymaking (Bernanke, 2012). At the heart of the consensus is the dynamic general equilibrium framework, which was pioneered by Leeper and Sims (1994) and Schorfheide (2000). It was then further propelled into the mainstream by the seminal contributions of, among others, Woodford (2003), Smets and Wouters (2003, 2007) and Christiano et al. (2005). This macroeconometric modelling paradigm has been implemented universally by policymakers, who were able to utilise the models successfully to understand the consequences of policy actions better, and thereby achieve macroeconomic stability. However, these models were not equipped to forestall financial market failure.

Economics, as a discipline, has developed with the use of theoretical frameworks that often ignore knotty real-world frictions in order to remain tractable and computationally feasible (De Walque et al., 2010). Theorists make assumptions that reduce complex real-world interactions into digestible mathematical equations. Some of these assumptions have been questioned in the wake of the international financial crisis. A particular concern is the idea that financial markets are perfect and complete, with the implication that financial shocks are irrelevant to real economic outcomes (Roger and Vlcek, 2012). There was a commonly held belief that finance, in the first approximation, was irrelevant to business cycle movements (Woodford, 2003). However, owing to recent events, it has been acknowledged that the financial crisis originated from a collapse of financial intermediation, which has cemented the idea that credit market frictions have real implications (Ahn and Tsomocos, 2013). The shortcomings of macroeconomic models revealed during the crisis have led many critics,

[5] According to Krugman (2018) the big new idea that will reshape macroeconomics has not yet arrived. Many ideas have been forwarded, but none are taking the profession by storm.

such as Kirman (2010), Caballero (2010), Stiglitz (2011), Krugman (2011), DeLong (2011), Kay (2012), Romer (2016), Korinek (2017) and Stiglitz (2017) to question the underlying assumptions of DSGE models.

This leads one to question whether the entire DSGE modelling framework needs to be rebuilt from scratch or simply restructured. Fortunately, as argued by Wright (2018) and Vines and Wills (2018), most macroeconomists side with the idea that DSGE models only need moderate modifications. Blanchard (2018) points out that there is broad-scale agreement on a few specific propositions when it comes to DSGE modelling. He emphasises that while DSGE is about general equilibrium modelling, it is important to acknowledge partial equilibrium models, those without general equilibrium closure. These models can provide significant understanding of particular mechanisms. Once these dynamics are understood, they can be incorporated, in an almost modular fashion, into broader general equilibrium frameworks.[6] For example, Wright (2018) argues that monetary search models that bring together the interaction of money and financial markets in a partial equilibrium setting need to be incorporated into a DSGE framework and would address many of the current shortcomings in monetary economics.

While the lack of financial frictions are usually forwarded as the most severe shortcoming in the current DSGE setup, other important shortcomings have also been identified. The most important of these, as listed in a recent survey by Vines and Wills (2018), are the development of better microfoundations that relax the focus on rational expectations (e.g., bounded rationality) and the introduction of heterogeneous agents. In this chapter we extend the core DSGE framework to include financial market components, but refrain from addressing the multitude of extensions proposed above as little consensus exists at present on the how to incorporate these components. It is exciting to postulate the possible directions that macroeconomics might take in the immediate future, but for the purpose of exposition we will only focus on financial frictions, as this literature is significantly more mature and would allow us to better model key features of the business cycle.

3 The Benchmark DSGE Model Framework

In this section, we introduce a stylized New-Keynesian framework that embodies all the core features of the models used in this chapter (Christiano et al., 2005; Smets and Wouters, 2007). The model consists of a number of frictions to both real and nominal variables and seven exogenous shocks. These features are primarily included to match empirical regularities observed in the data and to provide a non-negligible role for monetary policy (Fuhrer, 2000; Smets and Wouters, 2003;

[6] Blanchard (2018) compares DSGE models to a Meccano set, a platform that can easily integrate new elements developed outside the general equilibrium setting.

Christiano et al., 2005).[7] The key feature of New-Keynesian models is that of monopolistic markets in price and wage setting, the so-called “nominal rigidities” or “sticky prices and wages”.[8] The stochastic components of the DSGE framework allows for deviations from a deterministic steady-state growth path.[9] The model is therefore only concerned with deviations of variables from their steady-state, where these deviations are generated by exogenous stochastic components. As such, we are concerned with estimating and evaluating a structural decomposition of the South African business cycle.

Following Smets and Wouters (2003, 2007), all models incorporate the implied flexible price and wage (“efficient”) equilibrium conditions to derive a model-consistent output gap. The output gap is important for identifying the dynamic inefficiencies of demand shocks for policy evaluation. In this setting, the goal of policy is to stabilize (or smooth) the business cycle fluctuations arising from inflation and output gap variability. Importantly, when we extend the model to an open economy setup, with incomplete and rigid import price adjustment and exchange rate pass-through, the stabilisation of domestic prices (total headline inflation) may no longer be optimal (Smets and Wouters, 2002). Additionally, we find that the effect of monetary policy is severely constrained by introducing a risk premium on borrowing. This raises serious identification issues for macroeconomic policy analysis in a strict interest rate targeting framework—and even more so when the model is extended to include credit frictions and financial wealth effects.

3.1 The household sector and equilibrium conditions

Households maximize utility subject to a budget constraint. Utility is modelled to exhibit a constant elasticity between current and future consumption (i.e., a constant coefficient of relative risk aversion) and to include external habit formation so that households change consumption gradually over time.[10] Household preferences are separable in consumption $C_{j,t}$, labour $N_{j,t}$ and real money

[7]That is, the model extends directly from the real business cycle (RBC) framework.

[8]The distinction between Calvo-type (fixed probability of adjustment) and Rotemberg-type (quadratic adjustment costs) price setting is unimportant at first-order approximation (Ireland, 2004, 2007), and therefore our discussions in this paper will limit the details of alternative modelling approaches that deliver similar first-order outcomes. There are, however, important non-linear effects on adjustment dynamics and welfare (see, e.g., Leith and Liu (2016)).

[9]Again, at a first-order approximation, the distinction of a deterministic (constant) growth or level steady-state is unimportant for our business cycle analysis here. Although, estimations will be sensitive to the specification and treatment of observational variables in the estimation of models (see Pfeifer (2018) on “A Guide to Specifying Observation Equations for the Estimation of DSGE Models.”).

[10]For tractability, we simplify the model as much as possible and therefore ignore the more complex intertemporal modelling of internal habit formation (see Fuhrer, 2000). Again, the distinction between internal (time non-separable) and external (exogenous) habit formation becomes important for higher-order approximations (e.g., uncertainty) or regime changes.

balances $\mathcal{M}_{j,t}/P_t$, such that each household j maximises their discounted lifetime utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_{j,t} - \phi C_{t-1})^{1-\sigma_c}}{1-\sigma_c} - \frac{(N_{j,t})^{1+\sigma_n}}{1+\sigma_n} + \frac{a}{1-\sigma_m} (\frac{\mathcal{M}_{j,t}}{P_t})^{1-\sigma_m} \right], \tag{1}$$

where β^t is the household's discount factor. Utility depends positively on the consumption of goods and negatively on the supply of labour hours, N_t. The coefficient of relative risk aversion σ_c measures the curvature of the household's utility function with respect to its argument $C_{j,t} - \phi C_{t-1}$, where external habit formation is parameterized by ϕ. It also measures the inverse of the intertemporal elasticity of substitution in consumption. σ_n is the inverse of the elasticity of hours worked to the real wage. Households derive direct value from the liquidity services of real money holdings, where σ_m is the interest elasticity of money demand.

Households have access to two types of assets: money $\mathcal{M}_{j,t}$ and bonds $B_{j,t}$, where bonds pay a gross nominal rate of return $(1 + i_t^b)$. Notably, we assume that each household j owns an equal portion of all firms in the economy, and the household outsources its labour decision to labour unions who determine their wage rate. The representative household j therefore allocates periodic income from wages (W_t), bonds, dividends and cash balances to current consumption and new financial wealth holdings:

$$P_t C_{j,t} + Q_t B_{j,t} + \mathcal{M}_{j,t} \leq B_{j,t-1} + \mathcal{M}_{j,t-1} + W_t N_{j,t} + \Pi_{j,t}^H + T_{j,t}, \tag{2}$$

where Q_t is the discount on one-period bond purchases such that the pay-off at maturity is the short-term nominal interest rate $I_t^b \mu_t^b$. The stochastic disturbance term μ_t^b represents the domestic risk premium (spread) over the monetary policy rate. $\Pi_{j,t}^H$ are dividends/profits received from domestic firms, and $T_{j,t}$ represents lump-sum net transfers from government.

3.1.1 Consumption and savings behaviour

Households optimize their consumption-savings decision by maximizing Eq. 1 subject to Eq. 2. The aggregated first-order conditions for bonds gives the standard Euler equation governing intertemporal consumption dynamics:

$$1 \quad = \quad \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \frac{P_t}{P_{t+1}} I_t^b \mu_t^b \right] . \tag{3}$$

where $\Lambda_t = (C_t - \phi C_{t-1})^{-\sigma_c}$ is the marginal utility of consumption and the Lagrangian multiplier of the budget constraint. The first-order condition for money follows as

$$\frac{\Lambda_{m,t}}{\Lambda_t} = 1 - \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \frac{1}{\Pi_{t+1}} \right] , \tag{4}$$

where $\Pi_{t+1} = P_{t+1}/P_t$ is gross inflation, $\Lambda_{m,t} = a(\mathcal{M}_t/P_t)^{-\sigma_m}$ is the liquidity services from holding real money balances. Eq. 4 captures the household's demand for real money balances. In equilibrium, the money supply process is such that seignorage revenue equals lump-sum net transfers: $\mathcal{M}_t - \mathcal{M}_{t-1} = T_t$.

3.1.2 Labour supply decisions and the wage setting equation.

Monopolistically competitive unions determine the optimal wage for households for a given labour demand schedule. There is a continuum of unions, and each union represents workers of a certain type τ. The labour demand schedule that each household type τ faces is determined by

$$N_t^\tau = \left(\frac{W_t^\tau}{W_t} \right)^{-\xi_t^w} N_t \ , \tag{5}$$

where ξ_t^w is the stochastic wage elasticity of substitution across different types of households.

Following Calvo-type price-setting, only a random fraction $(1-\theta_w)$ of unions have the opportunity to reset their wages $(\tilde{W}_t)$ each period. Whereas those unions that cannot reset their wages simply index to the lagged wage rate. The aggregate wage index is given by:

$$W_t^{1-\xi_t^w} = \theta_w (\Gamma_t W_{t-1})^{1-\xi_t^w} + (1-\theta_w)(\tilde{W}_t)^{1-\xi_t^w} \ , \tag{6}$$

where $\Gamma_t = \Pi_{t-1}^{\gamma_w} = (P_{t-1}/P_{t-2})^{\gamma_w}$ and γ_w is the degree of wage indexation. The re-optimizing union's problem is to therefore choose $\tilde{W}_t$ to maximize the consumption-weighted wage income:

$$\max_{\tilde{W}_t} E_t \sum_{i=0}^{\infty} (\theta_w \beta)^i \left[\frac{\Gamma_{t+i} \tilde{W}_t N_{t+i}^\tau}{P_{t+i}(C_{t+i} - \phi C_{t-1+i})^{\sigma_c}} - \frac{(N_{t+i}^\tau)^{1+\sigma_n}}{1+\sigma_n} \right] , \tag{7}$$

subject to the labour demand schedule in Eq. 5. Solving and linearizing the optimization problem and combining it with Eq. 6 gives the forward-looking New-Keynesian wage-setting equation.

3.2 Decision problems of firms and equilibrium conditions

The domestic goods-producing sector is made up of a continuum of infinitely lived firms indexed by $j \in [0,1]$. The decision problem can be characterised by two stages. First, firm j minimizes the total cost of production subject to the production constraint. Second, each firm j maximizes its profit function subject to a domestic demand schedule. Following Calvo (1983), all firms face a probability θ_p of not being able to optimally adjust prices. In this market, final goods producers are monopolistically competitive.

Various alternative approaches can be taken where, for example, households also rent physical capital to intermediate goods producing firms which earns a rate of return equal to its marginal product. They may also own firms but there exists a separate physical capital producing sector (see, e.g., Bernanke et al., 1999). We, however, treat investment and capital goods production as a wholly-separate competitive sector with an implied "shadow" value (Iacoviello, 2005).

3.2.1 Capital goods producers

The representative capital goods producing firm chooses a path for investment (V_t) that maximises the present value of its profits:

$$\max_{K_{t+1},V_t} E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left[R^k_{t+i} K_{t+i} - V_{t+i} - \Phi\left(\frac{V_{t+i}}{K_{t+i}}\right) K_{t+i} \right] \tag{8}$$

subject to the capital accumulation equation given by

$$K_{t+1} \leq (1-\delta)K_t + \xi^v_t V_t \ , \tag{9}$$

where δ measures the depreciation rate of capital, and K_t represents the physical capital stock at the beginning of period t. ξ^v_t is an investment-specific efficiency shock. R^k_t is the gross (real) return on rented capital holdings, and $\Phi(\cdot)$ captures the adjustment cost of capital installation.[11] We assume that the prices of consumption goods and investment goods coincide ($P_t = P^V_t$). $\Lambda_{t,t+i}$ denotes the consumption-based relevant discount factor for real profits, i-periods ahead, given by $\Lambda_{t,t+i} \equiv \beta^i(\Lambda_{t+i}/\Lambda_t)$.

The first order conditions for the capital goods producer problem are:

$$Q^k_t = E_t\left\{\Lambda_{t,t+1}\left[R^k_{t+1} + Q^k_{t+1}(1-\delta) + \Phi^v_{t+1}V_{t+1} - \Phi_{t+1}\right]\right\} \tag{10}$$

$$\xi^v_t Q^k_t = 1 + \Phi^v_t K_t \ , \tag{11}$$

where $\Phi^v_t = (\kappa_v/\delta)(V_t/K_t - \delta)(1/K_t)$ and Q^k_t is the marginal value of an additional unit of capital. That is, Q^k_t is the "shadow value" of the capital accumulation constraint (11) and equals the present

[11] $\Phi' > 0$, $\Phi'' < 0$, $\Phi'(\delta) = 0$, $\Phi(\delta) = 0$. Specifically, $\Phi(V_t/K_t)K_t = (\kappa_v/2\delta)(V_t/K_t - \delta)^2 K_t$.

discounted value of the marginal profits of an additional unit of capital (10).

3.2.2 Intermediate goods producers

In the intermediate goods production stage, each firm j combines factor inputs, labour ($N_{j,t}$) and capital ($K_{j,t}$), to produce intermediate goods for final good production with the following Cobb-Douglas production technology: $Y_{j,t} = \xi_t^a (K_{j,t})^{\alpha} (N_{j,t})^{(1-\alpha)}$, where α captures the share of physical capital in production and ξ_t^a represents total factor productivity that follows an auto-regressive stochastic process of order one (the technology shock). The decision problem is to therefore select the optimal combination of factor inputs—labour and capital—to minimize the total cost of production, taking prices as given:

$$\min_{\{N_{j,t},K_{j,t}\}} TC_{j,t} + \lambda_t (Y_{j,t} - \xi_t^a (K_{j,t})^{\alpha} (N_{j,t})^{(1-\alpha)}) \ , \tag{12}$$

where $TC_{j,t} = \frac{W_t}{P_t^h} N_{j,t} + R_t^k K_{j,t}$ is the total real cost of production. The aggregate first order efficiency conditions for labour and capital are:

$$\frac{W_t}{P_t} = \lambda_t \frac{\partial Y_t}{\partial N_t} = (1-\alpha)\lambda_t \frac{Y_t}{N_t} \tag{13}$$

$$R_t^k = \lambda_t \frac{\partial Y_t}{\partial K_t} = \alpha \lambda_t \frac{Y_t}{K_t} \ , \tag{14}$$

where λ_t is the real marginal cost of production and the Lagrangian multiplier of the production function.

3.2.3 Final goods sector

In the final goods (retail) production stage, each firm j is monopolistically competitive in its intermediate good $Y_{j,t}$. The firm is able to brand and sell its retail good at a markup P_t over marginal cost, taking into account their individual demand curves from consumers. We assume that only a random fraction $(1-\theta_p)$ of firms can adjust their retail price in each period. Therefore, each firm j faces the following decision problem:

$$\max_{\{\tilde{P}_t\}} E_t \sum_{i=0}^{\infty} \theta_p^i \Lambda_{t,t+i} \left[\left(\frac{\Pi_{t+i-1}^{\gamma_p} \tilde{P}_{j,t}}{P_{t+i}} - \lambda_{t+i} \right) Y_{j,t+i} \right] \tag{15}$$

subject to the consumer demand schedule for goods

$$Y_{j,t+i} = \left(\frac{\tilde{P}_{j,t}}{P_{t+i}} \right)^{-\xi_t^p} Y_{t+i}, \tag{16}$$

where ξ_t^p is the stochastic price-elasticity of demand for intermediate good Y_t. $\tilde{P}_t$ denotes the optimal price set by firms who are able to adjust the price in period t, and λ_t is the real marginal cost of production. The aggregate price level is determined by

$$(P_t)^{1-\xi_t^p} = \theta_p \left(\left[\frac{P_{t-1}}{P_{t-2}} \right]^{\gamma_p} P_{t-1} \right)^{1-\xi_t^p} + (1-\theta_p)(\tilde{P}_t)^{1-\xi_t^p}, \tag{17}$$

where γ_p determines the degree of price indexation for non-optimizing retailers. Solving and linearizing the optimization problem and combining it with Eq. 17 gives the forward-looking New-Keynesian Phillips curve.

3.2.4 Government and market clearing

The short-term interest rate is determined by a Taylor-type reaction function that describes monetary policy decisions:

$$I_t = (I_{t-1})^{\rho_i} \left(\frac{\Pi_t}{\Pi^{target}} \right)^{\kappa_\pi(1-\rho_i)} \left(\frac{\Delta Y_t}{Y} \right)^{\kappa_y(1-\rho_i)} \xi_t^i \ , \tag{18}$$

where ρ_i is the weight on the lagged policy rate, κ_π is the weight on inflation, and κ_y is the weight on output growth, $\Delta Y_t = Y_t / Y_{t-1}$. ξ_t^i captures exogenous innovations to the short-term interest—typically identified as independent and identically distributed monetary policy shocks. The short-term nominal interest rate therefore rises (falls) whenever inflation and output growth rise above (fall below) their average, or steady-state. All markets clear and, in the symmetric equilibrium, all representative agents make identical decisions. To close the model we include the aggregate resource constraint:

$$Y_t = C_t + V_t + \xi_t^g \ , \tag{19}$$

where the final goods market is in equilibrium if production equals demand for consumption and investment plus an exogenous expenditure component, ξ_t^g, which captures both government spending and the trade balance.[12]

3.2.5 Exogenous shocks

There are 7 exogenous shocks in the benchmark Smets and Wouters (2007) framework that follow AR(1) processes with independent and identically distributed standard deviations. The three core

[12] Given that Y_t, C_t and V_t are observed data inputted into the model for estimation, the AR(1) stochastic process ξ_t^g is included, as in Smets and Wouters (2007), to avoid stochastic singularity and to reduce estimation bias toward the other structural shocks.

New-Keynesian shocks are the technology shock (ξ_t^a), the price mark-up shock (ξ_t^p) and the monetary policy shock (ξ_t^i).[13] The supply-side of the real economy includes a wage mark-up shock (ξ_t^w) which distorts the labour market. On the demand side, we have an investment-specific efficiency shock (ξ_t^v), a risk premium shock (ξ_t^b) and, as mentioned in the previous section, an exogenous expenditure component (ξ_t^g) in the aggregate resource constraint.

4 The Linearized System of Equilibrium Conditions

In addition to the benchark New-Keynesian model based on Smets and Wouters (2007) (*SW-NK* hereafter), we develop three alternative models. First, a "naive" New-Keynesian model of the 3-equation type based on Ireland (2011) (*Naive-NK* hereafter): an IS-curve, a Phillips curve, and a monetary policy rule. Second, a standard small open economy New-Keynesian model based on Hollander, Gupta, and Wohar (2018) (*SOE-NK* hereafter), and third, a New-Keynesian model extended to include a retail and wholesale banking sector and a role for equity in household wealth, firm creditworthiness and bank capital dynamics, based on Hollander and Liu (2016a) (*FF-NK* hereafter). Appendices A, B and C give the complete list of linearized equilibrium conditions.

As far as possible, we stick to the canonical approach adopted in Smets and Wouters (2003, 2007) for each of the four models described. That is, we synchronize the structural framework, structural shocks and estimation procedures as far as possible to ensure an appropriate evaluation and comparison of the results from each model. Here, we show the core New-Keynesian framework and highlight the key equations for each extended version of the nested model. In what follows, lower-case variables with a hat, $\hat{x}_t$, represent log-deviations from a steady-state or trend.

4.1 The core New-Keynesian specification

We begin with Ireland's small-scale model:

$$\text{IS curve} \quad : \quad \hat{y}_t = \frac{1}{(1+\phi)}\hat{y}_{t+1} + \frac{\phi}{(1+\phi)}\hat{y}_{t-1} - \frac{(1-\phi)}{\sigma_c(1+\phi)}(\hat{i}_t - E_t[\hat{\pi}_{t+1}]) \tag{20}$$

$$\text{NK Phillips curve} \quad : \quad \hat{\pi}_t = \frac{\gamma_p}{(1+\gamma_p\beta)}\hat{\pi}_{t-1} + \frac{\beta}{(1+\gamma_p\beta)}E_t[\hat{\pi}_{t+1}] + \tilde{\kappa}\tilde{y}_t \tag{21}$$

$$\text{Monetary policy rule} \quad : \quad \hat{i}_t = \rho_i\hat{i}_{t-1} + (1-\rho_i)(\kappa_\pi\hat{\pi}_t + \kappa_y\Delta\hat{y}_t) + \epsilon_t^i \tag{22}$$

[13] ρ_i in the monetary policy rule (18) captures the persistence of innovations to ξ_t^i. In this context, it captures the degree of interest rate smoothing by the monetary authorities.

where $\tilde{y}_t = (\sigma_c/(1-\phi)+\sigma_n)\hat{y}_t + (\sigma_c\phi)/(1-\phi)\hat{y}_{t-1} + (1+\sigma_n)\hat{\xi}^a_t$ is the real marginal cost of production, $\Delta\hat{y}_t = \hat{y}_t - \hat{y}_{t-1}$, and $\tilde{\kappa} = (1-\theta_p)(1-\theta_p\beta)/(\theta_p(1+\gamma_p\beta))$.[14] For expositional reasons we ignore the slightly different specifications for the shock variables across the models. The key reason being that the technology shock and price markup shock are collinear in a *Naive-NK* model as presented above. On the aggregate supply side, Ireland (2011) distinguishes a price markup shock in the New-Keynesian Phillips curve from the technology shock to the *growth rate* of output. On the demand side, in addition to the monetary policy shock, Ireland's model includes a preference shock that has an analogous role as the risk-premium shock in the benchmark Smets and Wouters model (see Section 6.1).

The Smets and Wouters model presented in Section 3 (*SW-NK* hereafter) extends the *Naive-NK* model to include labour market frictions and capital goods market frictions, namely: sticky wage-setting and adjustment costs to physical capital accumulation. These two frictions generate imperfect adjustment in factor inputs for production and hence help replicate empirical features observed in the data. The investment schedule with adjustment costs follows as:

$$\hat{v}_t - \hat{k}_t = \beta E_t(\hat{v}_{t+1} - \hat{k}_{t+1}) + \frac{\beta R^k}{\kappa_v} E_t(\hat{r}^k_{t+1}) + \frac{\sigma_c}{\kappa_v}(\hat{c}_t - \hat{c}_{t+1}) \ , \tag{23}$$

where $R^k = 1/\beta - (1-\delta)$. And the nominal wage inflation process follows from the optimal (real) wage setting equation of unions as:

$$\hat{\pi}^w_t - \gamma_w\hat{\pi}_{t-1} = \beta E_t\hat{\pi}^w_{t+1} - \theta_w\beta\gamma_w\hat{\pi}_t + \Omega^*(\hat{mrs}_t - \hat{w}_t) \ , \tag{24}$$

where $\Omega^* = \frac{(1-\theta_w)(1-\theta_w\beta)}{\theta_w(1+\xi^w\sigma_n)}$ and $\hat{mrs}_t = \frac{\sigma_c}{1-\phi}(\hat{c}_t - \phi\hat{c}_{t-1}) + \sigma_n\hat{n}_t$.[15]

[14] Ireland (2011) assumes log preferences ($\sigma_c = 1$) and linear disutility of hours worked ($\sigma_n = 0$). In addition, to enrich the dynamics of the model, habit formation is endogenous to the representative household (internal). This specification is shown in Appendix A. Note that the 3-equation New-Keynesian model presented here follows very similarly to the 3-equation model specification for the foreign economy in Hollander, Gupta, and Wohar (2018).

[15] Log-linearizing the optimality condition for wage-setting and solving for $\tilde{w}_t$ gives the optimal reset wage equation:

$$\tilde{w}_t = \frac{(1-\theta_w\beta)}{(1+\xi^w\sigma_n)} E_t \sum_{i=0}^{\infty} (\theta_w\beta)^i \left(\chi mrs_{t+i} + \xi^w\sigma_n w_{t+i} + p_{t+i} - \gamma_w\pi_{t+i-1}\right) \tag{25}$$

where $\chi \equiv \frac{W}{MRS^s\mu^w}$. Combining (25) with the log-linearized wage index equation gives the aggregate sticky real wage ($\hat{w}_t = w_t - p_t$) equation:

$$\begin{aligned} \hat{w}_t \quad = \quad & \Omega\beta E_t\hat{w}_{t+1} + \Omega\hat{w}_{t-1} + \Omega\Omega^*(\hat{mrs}_t - \hat{w}_t) \\ & + \Omega\beta E_t\hat{\pi}_{t+1} - \Omega\hat{\pi}_t - \Omega\theta_w\beta\gamma_w\hat{\pi}_t + \Omega\gamma_w\hat{\pi}_{t-1} \ , \end{aligned} \tag{26}$$

where $\Omega = \frac{1}{(1+\beta)}$. Eq. 26 can be re-written in nominal wage inflation form as Eq. 24.

4.2 Extending the model to the open economy

It is straightforward to extend the described New-Keynesian framework to include open economy dynamics. Here, we follow the approach of the small open economy models of Steinbach, Mathuloe, and Smit (2009), Alpanda, Kotzé, and Woglom (2010) and Hollander, Gupta, and Wohar (2018) applied to the South African economy. These models all incorporate access to a foreign-currency denominated asset, domestic importing retailers (sticky import price setting) and deviations from purchasing power of parity, which captures short-run incomplete nominal exchange rate pass-through observed in the data (Burstein and Gopinath, 2014).[16] As such, exchange rate overshooting is an outcome of the model where international risk sharing in consumption allows for asset markets to clear, and therefore interest rates to adjust, more rapidly than price adjustments in the goods sector.

Specifically, complete international consumption risk sharing implies complete international asset markets. The optimality conditions for domestic- and foreign-currency denominated assets therefore gives the standard uncovered interest parity (UIP) condition:

$$\hat{i}_t^b = \hat{i}_t^{b*} + E_t[\Delta\hat{\varepsilon}_{t+1}] + \hat{\Phi}_t \ , \tag{27}$$

where $\hat{i}_t^b$ and $\hat{i}_t^{b*}$ are the domestic and foreign short-term nominal interest rates, $\hat{\varepsilon}_t$ the nominal effective exchange rate (direct quoting) and $\hat{\Phi}_t$ is the prevailing stochastic risk premium for the domestic economy ($\hat{\mu}_t^b - \hat{\mu}_t^{b*}$). A positive shock to $\hat{\Phi}_t$, equivalent to a negative demand shock, raises the return on domestic currency bonds relative to foreign currency bonds and reduces current consumption (Smets and Wouters, 2007; Steinbach et al., 2009). The *nominal* exchange rate is therefore the market clearing price for domestic and foreign asset demand derived optimally from the domestic household's consumption Euler equations.

The evolution of the *real* exchange rate (RER) represents a measure of trade competitiveness: the value of a basket of domestic goods in terms of a similar basket of foreign goods. It is rising in the domestic real interest rate ($i_t - E_t[\pi_{t+1}]$) and falling in the foreign real interest rate ($i_t^* - E_t[\pi_{t+1}^{f*}]$). A positive shock to the prevailing stochastic risk premium ($\hat{\Phi}_t$) reduces the real exchange rate of the domestic economy. The assumption here is that purchasing power parity must either hold in steady-state (if import price mark-ups are zero), or revert to a constant level. Any *long-run* deviations from PPP, as a result of productivity differentials or changes in the structure of the non-tradable goods sector, are therefore not accounted for by the model.

[16] For a given exchange rate, domestic importing retailers are import "price-takers", but face a downward sloping domestic demand curve.

This implies that the *real* exchange rate adjusts to consumption dynamics between the domestic and foreign sectors.[17] Specifically, we can combine the definition of the real exchange rate: $rer_t \equiv \hat{\varepsilon}_t + \hat{pr}^{f*}$, where $\hat{pr}^{f*} = \hat{p}_t^{f*} - \hat{p}_t$ is the foreign-domestic relative price level, with the UIP condition (27) to describe the equation of motion for the relative purchasing power parity condition (i.e., the real exchange rate):

$$\hat{rer}_{t+1} = \hat{rer}_t + E_t[\Delta\hat{\varepsilon}_{t+1}] + \hat{\pi}_{t+1}^{f*} - \hat{\pi}_{t+1} \ . \tag{28}$$

The terms-of-trade follows as the price of imports relative to the price of domestically produced goods (denominated in domestic currency). The assumption here is that domestic firms cannot price discriminate across markets and that the l.o.p holds for domestic export prices. This also implies that the share of domestic goods in the foreign economy consumption bundle is negligible. A first-order approximation expresses the terms-of-trade as the difference between the relative prices of foreign and domestic goods: $\hat{s}_t = \hat{pr}_t^f - \hat{pr}_t^h$, where $\hat{pr}_t^i = \hat{p}_t^i - \hat{p}_t$ for $i = h, f$. The trade balance follows as the difference between exports ($\hat{x}_t$) and imports ($\hat{m}_t$): $\hat{x}_t = \hat{y}_t^* - \xi^{f*}(\hat{pr}_t^h - \hat{rer}_t)$ and $\hat{m}_t = \hat{c}_t^f$, where $\hat{y}_t^*$ is foreign demand and ξ^{f*} is the foreign (export) price elasticity of demand for domestic goods[18], and $\hat{c}_t^f$ is the consumption of foreign goods.

4.3 Extending the model to the financial sector

Our financial model is based on Hollander and Liu (2016a) (*FF-NK* hereafter) which incorporates the monopolisitcally competitive banking sector structure of Gerali et al. (2010) (sticky interest rate adjustment) with the equity price channel developed in Hollander and Liu (2016b). In this model, households have access to credit as well as savings. Their savings portfolio is allocated between "safe-assets" and investment in the equity market. The price of equity is determined by households' demand for equity investment. Both banks and firms issue equity, and as a result, the value of equity influences credit spreads through both the bank capital channel and the financial accelerator channel (Hollander and Liu, 2016b,a). For example, an equity price collapse reduces borrower creditworthiness, which puts upward pressure on retail credit spreads from the demand side. On the supply side, a fall in the bank capital-to-assets ratio, due to the equity price collapse, induces financial distress in over-leveraged banks. As a result, interbank spreads widen and net interest margins between funding (short-term) and lending (long-term) rates narrow to the extent that interest rate pass-through is incomplete. Figure 1 highlights this relationship between the bank capital-to-asset ratio of South African deposit-taking institutions and both the retail (term)

[17] i.e., RER equates the marginal utilities of consumption between the domestic and foreign households.

[18] i.e., the change in foreign demand for domestic goods given the foreign price of domestic goods relative to the foreign price of foreign goods can be expressed as: $\hat{pr}_t^{h*} - \hat{pr}_t^{f*} = \hat{pr}_t^h - \hat{rer}_t$.

spread and the interbank spread. Over the period 1995:01−2018:05, the term spread (top panel) is strongly positively correlated (0.57), and the interbank spread (bottom panel) is strongly negatively correlated (-0.50).[19]

Banks operate in both the commercial (retail) and investment (wholesale) sectors. In the monopolistically competitive retail sector, they supply credit to both households and firms. Retail loan rate setting is symmetric for households and firms ($z = h, f$) and is described by the following retail credit spread between the retail loan rate and the interbank loan rate:

$$\begin{aligned} \hat{i}_t^z - \hat{i}_t^c &= \frac{\kappa_z}{\kappa_z^*}\hat{i}_{t-1}^z + \frac{\beta_B\kappa_z}{\kappa_z^*}E_t\hat{i}_{t+1}^z + \frac{(1+\nu_B)(\varepsilon^z-1)-(1+\beta_B)\kappa_z}{\kappa_z^*}\hat{i}_t^c \\ &+ \frac{(1-\nu_B)(\varepsilon^z-1)}{\kappa_z^*}\mu_t^z, \end{aligned} \tag{29}$$

where μ_t^z is the stochastic process for retail rate markups imposed by commercial banks, and $\kappa_z^* = (1-\nu_B)(\varepsilon^z-1)+(1+\beta_B)\kappa_z$. Equation (29) shows that household and firm loan rate setting depends on the stochastic markup, past and expected future loan rates, and the wholesale interbank funding rate ($\hat{i}_t^c$), which depends on the policy rate and the balance sheet position of the bank. A positive adjustment of the interbank rate puts upward pressure on retail loan rates. As $\nu_B \to 1$, the influence of the interbank rate over retail rate setting increases, while the influence of the stochastic markup decreases. In contrast, a higher adjustment cost (κ_z) smooths the adjustment of retail loan rates and hence retail credit spreads.

In the competitive wholesale sector, the interbank credit spread between the interbank loan rate and the policy rate follows as:

$$\hat{i}_t^c - \hat{i}_t = -\kappa_k\tau^3(\hat{k}_t^B - \hat{l}_t - \hat{\tau}_t) \tag{30}$$

where $\hat{k}^B$ is the total bank capital which accumulates gradually through common equity stock valuation changes and retained earnings.[20] Market clearing in the credit market ensures that $\hat{l}_t$ equals the aggregate of household and firm loans. The coefficient κ_k captures the adjustment cost of contemporaneous deviations of the capital-to-assets ratio from a target capital requirement ratio, which we assume to follow an exogenous stochastic process: $\hat{\tau}_t = \ln(\tau_t) = (1-\rho_\tau)\ln\tau + \rho_\tau \ln\tau_{t-1} +$

[19] Recent empirical evidence suggests that bank capital adequacy ratios in South Africa are procyclical (see, e.g., Akinsola and Ikhide (2017) and Maredza (2015)). For now, we abstract from measuring the extent of this endogenous procyclicality by requiring banks to target a non-binding capital-asset ratio that is subject to precautionary/regulatory shocks.

[20] Adrian and Shin (2010, 2013) show that banks (in the U.S.) tend to actively manage their capital-assets ratios through debt rather than equity. As such, bank capital accumulation is persistent (for a more-detailed discussion see, e.g., Hollander, 2017). In addition, we assume that the market value of bank equity influences the book value of common (or tier 1) bank equity. (Adrian and Shin, 2010, 2013)

$\epsilon_{\tau,t}$. This banking sector setup allows for procyclical interbank credit spread variability based on aggregate bank balance sheet adjustments. That is, bank leverage drives a wedge between the policy rate and other market rates. To the extent that leverage is procyclical (Adrian and Shin, 2010, 2013) the effectiveness of monetary policy over longer-term retail rates declines (Hollander and Liu, 2016a). For example, during stress episodes the interbank credit spread immediately widens with a deterioration of bank capital-asset positions. Thereafter, the interbank credit spread narrows as banks accumulate larger capital buffers and the capital-to-assets ratio converges on the target τ_t.

The bank capital accumulation is as follows

$$\hat{k}_t^B = (1-\delta_B)\hat{k}_{t-1}^B + \delta_B \hat{\pi}_{\psi,t-1}^B + \phi_\psi(\hat{q}_t^{\psi,b} - \hat{q}_{t-1}^{\psi,b}) - (1-\phi_\psi)\hat{\pi}_t \ , \tag{31}$$

$\hat{q}_t^{\psi,b}$ is the equity price and ϕ_ψ measures the pass-through effect of equity price changes on total bank capital and δ_B is the bank capital depreciation rate, capturing management costs for banks.[21] Retained earnings ($\hat{\pi}_{\psi,t-1}^B$) are bank profits net of dividend payments. Eq. 31 therefore provides a role for the market capitalization of bank equity in the formation of total bank capital, which, in turn, influences the feasible supply of credit. This reflects both the recent regulatory emphasis on common equity as a buffer to bank balance sheet shocks and the recent observed rise in the ratio of bank capital to assets in South Africa (see Figure 1). From January 2008 to June 2017 regulatory tier 1 bank capital to risk-weighted assets (of which common equity forms the majority) rose steadily from 8.9% to 13.5%, and total capital adequacy ratios rose from 11.8% to 16.5%. Prior to the global financial crisis, tier 1 capital adequacy ratios rose in two successive waves from 6.5% (March 1994) to 9.5% at the end of 2007, peaking twice in May 2001 (9.5%) and January 2005 (10.6%).

Households and firms are credit constrained by their creditworthiness (Hollander and Liu, 2016a). This generates a financial accelerator mechanism that propagates, not only financial sector disturbances, but demand (nominal) and supply (real) shocks originating outside of the financial sector (Bernanke et al., 1999; Kiyotaki and Moore, 1997). Creditworthiness depends on household wealth (wage income and equity assets) and firm assets and net worth (physical capital and equity). Factor inputs in production (labour and physical capital) therefore serve as a measure of creditworthiness for loans. The equity price channel, in addition, provides a distinct dynamic interaction between asset prices (wealth and net worth) and credit limits. The first order approximations of

[21] We assume that the stock of equity shares are fixed, thus $\hat{\psi} = \hat{\psi}^b + \hat{\psi}^f = 0$.

these two constraints follow as:

$$\hat{l}_t^f = \frac{\phi_k}{R^f}(\hat{q}_t^k + \hat{k}_{t-1}) + \frac{(1-\phi_k)}{R^f}\hat{q}_t^{\psi,f} - \hat{i}_t^f + \frac{1}{R^f}\hat{\nu}_t^f \ , \quad (32)$$

$$\hat{l}_t^h = \frac{\phi_w}{R^h}(\hat{w}_t + \hat{h}_t) + \frac{(1-\phi_w)}{R^h}q_t^{\psi,h} - \hat{i}_t^h + \frac{1}{R^h}\hat{\nu}_t^h \ . \quad (33)$$

where $\phi_k \in (0,1)$ is the weight on physical capital stock. $\hat{q}_t^k$ is the real price of physical capital, $\hat{\nu}_t^f$ is a stochastic loan-to-value (LTV) ratio, and $\hat{i}_t^f$ is the nominal interest rate on firm loans $(\hat{l}_t^f)$. The market value of physical capital $(\hat{q}_t^k + \hat{k}_{t-1})$ and firm equity $(\hat{q}_t^{\psi,f} + \hat{\psi}_{t=0}^f)$ serve as a measure of creditworthiness. In other words, they serve as a market-based signal for firm's net worth and hence collateral. The equity market is introduced into the production sector in such a way that it has an impact on the firm's resource allocation and, in turn, the productivity of the economy. The household's wage income together with its investment in the equity market represent her creditworthiness and serve as collateral, where $\phi_w \in (0,1)$ is the weight on wage income. $\hat{\nu}_t^h$ is a stochastic LTV ratio and, correspondingly, in cases of default $1-\hat{\nu}_t^h$ can be interpreted as the proportional transaction cost for the bank's repossession of the borrower's collateral. Following the literature (e.g., Iacoviello, 2005), we assume that the size of shocks is small enough that the borrowing constraint is always binding.

Equity prices follow a standard consumption-based asset pricing equation from the households optimality condition for equity investment (ψ_t):[22]

$$\begin{aligned}\hat{q}_t^\psi &= E_t[\hat{q}_{t+1}^\psi - \frac{\sigma_c}{1-\phi}(\hat{c}_{t+1} - \phi\hat{c}_t)] + \frac{\sigma_c}{(1-\Gamma_\psi)(1-\phi)}(\hat{c}_t - \phi\hat{c}_{t-1}) \\ &+ \frac{\Gamma_\psi}{1-\Gamma_\psi}(\hat{\lambda}_t^h + \hat{\nu}_t^h) - \hat{\xi}_t^\psi, \quad (34)\end{aligned}$$

where the Lagrangian multiplier, $\hat{\lambda}_t^h$, is the marginal utility of an additional unit of loans, and $\Gamma_\psi = ((1/R^h) - \beta_h)\nu_h(1-\phi_w)$. Arbitrage ensures that $q_t^\psi = q_t^{\psi,i} \ \forall \ i = h, b, f$ (see, e.g., Hollander, 2017, for a more-detailed exposition). Figure 2 highlights the procyclicality of the equity price.

We introduce six shocks in the financial sector. On the supply side of credit, we have two retail loan rate mark-up shocks to household loans $(\hat{\mu}_t^h)$ and firm loans $(\hat{\mu}_t^f)$. On the demand side of the credit market, household loans and firm loans are subject to loan-to-value ratio shocks $(\hat{\nu}_t^h$ and $\hat{\nu}_t^f)$. Households' demand for safe-asset holdings are subject to an exogenous shock $(\hat{\xi}_t^b)$—which replaces the risk premium shock in the *SW-NK* model. Therefore, this safe-asset demand shock

[22] We do not distinguish between saver and borrower households as in Hollander and Liu (2016b) which allows for a demand and supply interaction for equity investment. Instead, we follow Hollander and Liu (2016a) and the problem simplifies to a dynamic asset-pricing equation (see, e.g., Cochrane, 2008).

captures the aggregate demand for monetary aggregates with respect to intertemporal consumption decisions of households. Finally, an equity price shock ($\hat{\xi}_t^{\psi}$) simultaneously affects consumption, production and bank lending activities through the equity price channel as described in Hollander and Liu (2016b,a).

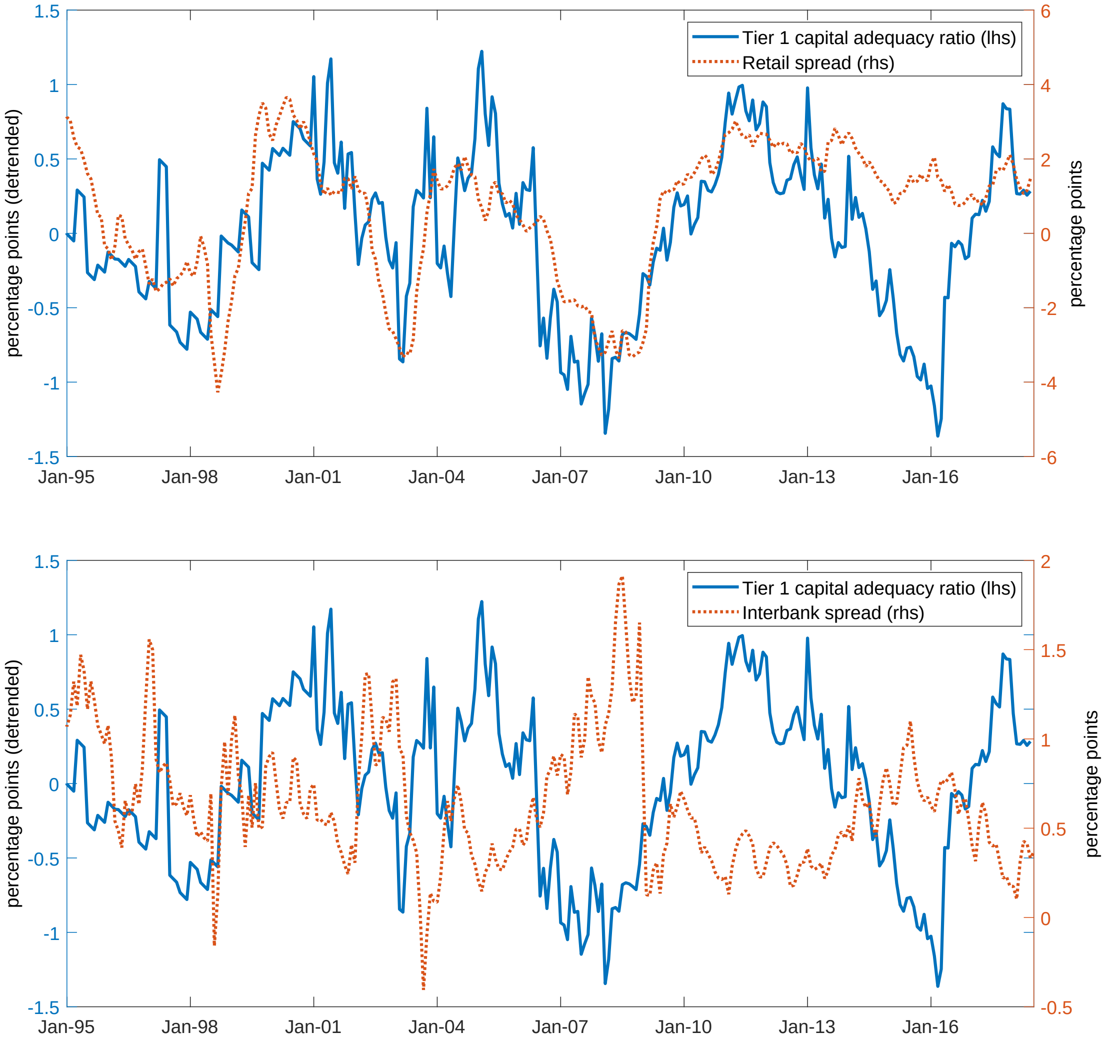

Figure 1: Correlation between linearly detrended tier 1 bank capital adequacy ratio for South African deposit-taking institutions and interest rate spreads. The term spread is the difference between 10-year and 3-month treasury bonds (top panel). The interbank spread (bottom panel). The interbank spread is the difference between 3-month negotiable certificates of deposit and the 3-month treasury bill rate.

5 Estimation

This section discusses the estimation methodology and results. First, we describe the estimation procedure and the parameter restrictions we adopt before taking the model to the data. We then

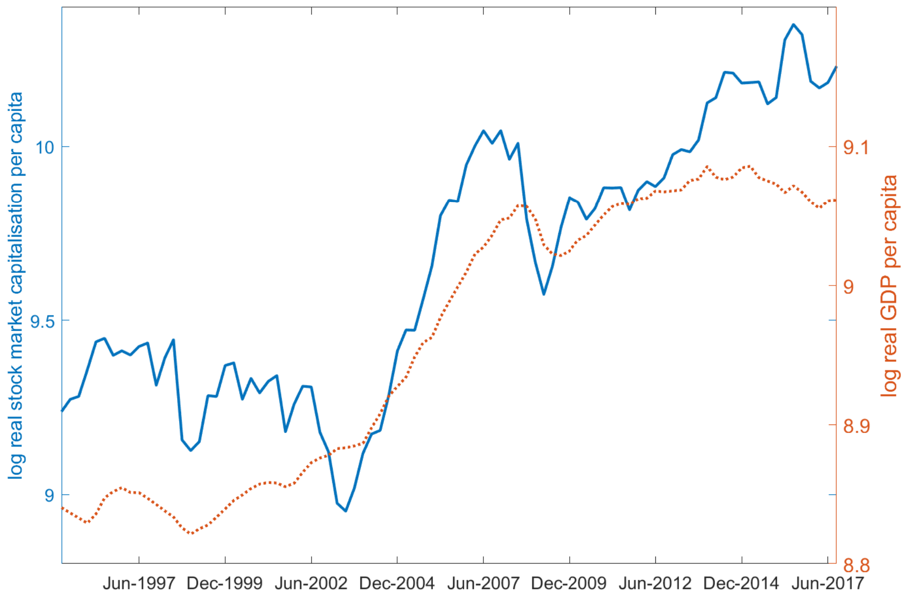

Figure 2: Correlation between log real stock market capitalisation per capita (left axis) and log real GDP per capita (right axis).

discuss estimation results of the structural parameters and structural shocks, with specific emphasis on the plausibility of the parameters and economic implications. We also test for weak identification and evaluate the empirical performance against alternative South African-based DSGE model estimations. In this sense, we care about model uncertainty whereby probabilities are prespecified but outcomes are unknown—i.e., "inside uncertainty" or "risk within a model" (Hansen, 2014, 2017).

In order to distinguish between relevant model specifications we estimate our three alternative models in addition to the benchmark New-Keynesian model (*SW-NK*) based on Smets and Wouters (2007). As a reminder, our "naive" New-Keynesian model (*Naive-NK*) contains an IS-curve, a Phillips curve, and a monetary policy rule. We then extend the *SW-NK* model in two directions: first, to a standard small open economy New-Keynesian model (*SOE-NK*) based on Hollander, Gupta, and Wohar (2018); second, to a model with a detailed financial sector (*FF-NK*) based on Hollander and Liu (2016a), that includes a retail and wholesale banking sector and a role for the equity market in financial wealth, borrower creditworthiness and bank capital dynamics. Here, model specification is important for discriminating between different business cycle models, their estimated responses to identified structural shocks, and the inferences we make regarding their policy responses (Nakamura and Steinsson, 2018)—what Hansen (2014, 2017) refers to as "outside uncertainty" or "ambiguity about a model [among a family of alternatives]". We specifically look at the robustness of model specification in Section 6.[23]

5.1 Estimation Methodology

The model is estimated using Dynare, a MATLAB pre-processor that allows for Bayesian estimation of dynamic stochastic general equilibrium (DSGE) models (http://www.dynare.org/). The estimation procedure use the Metropolis-Hastings (MH) Markov-Chain Monte Carlo (MCMC) algorithm with 200,000 draws for three chains (with a burn-in of 0.5). To ensure that the tails of the posterior mode are identified, the scale used for the jumping distribution is adjusted to ensure an acceptance rate of approximately 25%.[24]

We estimate the benchmark model, and the respective extensions, using data over the period 1995Q1−2017Q2. The sample size of 90 observations covers the post-Apartheid period of South Africa and conforms with reasonable sample sizes used in Bayesian estimation of DSGE models (An and Schorfheide, 2007; Steinbach et al., 2009). There are seven key macroeconomic variables: real gross domestic product (GDP), real consumption, real investment, headline consumer price index (CPI) inflation, real wages, employment, and the nominal interest rate.[25] For the *FF-NK* model (which develops a richer financial sector) we include observable variables for household assets, household loans, firm loans, the aggregate bank capital adequacy ratio, as well as the stock market index for South Africa.[26] For the *SOE-NK* model we calculate the foreign economy macroeconomic data using a trade-weighted average for the U.S., U.K., Euro area and Japan. Combined, we have the foreign GDP, the foreign total CPI inflation, and the foreign 3-month treasury bill (government securities) rate. All data are log-differenced except interest rates—which are in quarterly terms. All quantity variables, except employment, are expressed in per capita terms.[27]

The choice of the prior distribution can have significant implications for the estimated models. Our focus is to align our parameter restrictions with that of the existing literature, whilst ensuring the initial conditions and restrictions are as consistent as possible across all model estimations. We

[23] A third component of uncertainty relates to potential model *mis*specification (Hansen, 2014, 2017).

[24] See An and Schorfheide (2007) for a review of Bayesian methods for evaluating DSGE models.

[25] See the appendix for data and sources.

[26] Aggregate tier 1 bank capital adequacy ratio data is used to proxy regulatory/precautionary capital requirement shocks (τ_t). Quarterly tier 1 capital adequacy data can be compiled from the SARB's BA700 and DI400 bank statistics for the entire sample period. This measure therefore includes the risk-adjusted exposure of banks and describes the contemporaneous regulatory/precautionary "target". Due to data constraints, we have not included aggregate retail interest rates to households and firms. For households, the predominate mortgage rate is benchmarked to prime lending rates which tracks the short-term rate very closely. Interestingly, we obtain a very similar result if we derive the effective rate from the aggregate bank income statement statistics collected by the SARB. For firms, there is no immediate way to weight corporate bonds listed on the JSE. It is likely, however, that long-term corporate yields are benchmarked to the 10-year government bond rate, but this requires a stricter assumption of the role of monetary policy over the term structure in our model setup (see Hollander and Liu, 2016a).

[27] For a useful guide on the treatment of observational variables in the estimation of DSGE models see Pfeifer, J., (2018), "A Guide to Specifying Observation Equations for the Estimation of DSGE Models," mimeo.

therefore calibrate relatively few parameters to allow for flexibility when estimating the alternative model specifications (see Table D.1). Notably, the household discount factor β is normalized to be 0.99 across all models, which implies an annualized real rate of return of 4% for safe-assets. The capital-output share α is set to 0.30, and the physical capital depreciation rate δ is set to 0.03. A steady-state price elasticities of demand for retail goods (ξ^p) and for different types of labour (ξ^w) are 11 and 5, which imply steady-state gross mark-ups of 10% ($\xi^p/(\xi^p-1)$) and 25% ($\xi^w/(\xi^w-1)$). We use the value of ρ_g from Steinbach et al. (2014), who separately estimate and then fix the exogenous spending persistence parameter. Remaining parameters follow directly from the models implied steady-state, and in a few cases are calibrated to the averages of South African macroeconomic data.

5.2 Parameter Estimates

Tables 1 and 2 provide the means, standard deviations and shapes that describe the prior and posterior marginal distributions for the estimated parameters from the benchmark *SW-NK* model. In this section, we focus the discussion of our results in terms of the extant literature. Table 3 compares the estimated parameters from the *SW-NK* model to the estimations from the five recent South African-based NK-DSGE models identified: Steinbach, Mathuloe, and Smit (*SMS09*); Steinbach, du Plessis, and Smit (*SPS14*); Alpanda, Kotzé, and Woglom (*AKW10*)—which includes *SMS09* replication; Paetz and Gupta (*PG16*)—which includes a nested NK model; and the nested Hollander, Gupta, and Wohar (*HGW18*) model without oil. The parameter estimates for each alternative model specification (i.e., *Naive-NK*, *SOE-NK* and *FF-NK*) are shown in Table 4.[28]

For the preference parameters, a value of 0.795 for the degree of habit formation is analogous to the estimated value found in *SPS14*, and is only slightly above the calibrated value of 0.70 often adopted in the literature. Similarly, at 1.20, the coefficient of relative risk aversion follows closely to the estimates in *SMS09* and *AKW10-SMS*, which also corresponds to the log-utility specifications ($\sigma_c = 1$) in *SPS14*, *PG16* and *PG16-NK*. In contrast, *AKW10* and *HGW18* find values of 0.58 and 3.92. Both of these models extend the *SW-NK* framework to a small open economy. *AKW10* attribute their *stronger* response of aggregate consumption to the real interest rate (i.e., where the inter-temporal (interest) elasticity of consumption is $1/\sigma_c$) to their incomplete international risk sharing specification and the inclusion of the nominal exchange rate as an observable variable in estimation (*AKW10*, pp. 175-178). Whereas, in *HGW18*, inter-temporal consumption decisions of households are more muted but falls within the range of plausible estimates in the international

[28] The respective prior and posterior distribution statistics for the alternative models—as well as convergence statistics—reported in the technical appendix are available upon request.

literature. Both papers note that the burden of adjustment falls on σ_c estimates to capture movements in the data—especially since the other two key preference parameters, ϕ and σ_n, are fixed. Another consideration is that the sample periods and observable variables of these models do not fully coincide. That said, it is evident from Table 4—comparing *SW-NK*, *Naive-NK*, *SOE-NK* and *FF-NK*—that household preference parameters σ_c and ϕ are robust to the specification of alternative models given consistent priors—in other words, the restrictions on certain parameters and different exogenous shocks not related to the core household sub-block. Similarly, the elasticity of labour supply ($1/\sigma_n$) is consistent with calibrated values in the literature, but also appears sensitive to model specifications—most notably, *FF-NK* (the consequences of which are clearly evident in Section 6, Figure 13).

Domestic prices and wages tend to be adjusted every 2-4 quarters ($1/(1-\theta)$). This implies a sticky price- and wage- setting parameter (θ_p and θ_w) range of 0.5 to 0.75. For closed economy models in particular, θ_p estimates tend to imply that prices are set yearly which is consistent with what we find in *SW-NK*. For open economy model estimates, prices tend to be adjusted more frequently—usually between 2 and 4 quarters. Our results correspond closely to that of *PG16* and *PG16-NK*, which is in line with the calibration approach in the literature. That is, with the exception of *SMS09* (which informed the calibrated parameters in *AKW10*), the weight applied to historical inflation (i.e., indexation parameters γ_p and γ_w) tends to be 50% or less. Firm-specific physical capital adjustment costs exhibit the weakest consistency across models. Such high capital/investment adjustment costs—that imply an elasticity of investment of approximately 0.1-0.15 in response to a 1% change in the price (shadow value) of installed capital (see Eq. A.10)—is generally inconsistent with the international literature. *HGW18* (p. 8, ft. 7) provide some motivation for fixing κ_v when identification may be an issue, which is addressed further in the identification section below.[29]

Turning to the monetary policy reaction function, the majority of model estimates (both from the literature in Table 3 and from the alternative specifications in Table 4) find a larger weight on inflation stabilisation than that on output. This not only corroborates the South African Reserve Bank's (SARB's) official commencement of its inflation targeting monetary regime in February 2000,[30] but is consistent with the SARB's policy trajectory as described by the Taylor rule specification from the 1970s through to 2006 (see, e.g., Ortiz and Sturzenegger, 2007): that is, a fairly

[29] Nakamura and Steinsson (2018) note how, in such cases, moments estimated from microeconomic data can "help to discipline models" (p. 62). In our analysis, the investment sub-block of the DSGE model does not have an outsized influence on the dynamics of the model. This, however, should not be brushed under the rug. As micro data informs parametrization of the Phillips curve for monetary policy analysis, investment/capital price elasticities should inform calibration of country specific estimations where investment adjustments are applicable to the question at hand.

[30] The official announcement came in August 1999.

strong and consistent anti-inflation bias and a more recent emphasis on output deviations.[31]

The persistence of shocks vary somewhat across the models. Most consistently, is that technology shocks are more persistent than estimated supply side shocks to prices and wages. With the introduction of a broad set of financial frictions (FF-NK), however, the persistence of "traditional" supply side shocks drop considerably. Demand-side persistence parameters seem to be more sensitive to alternative specifications (for example, ρ_b) and sample size ($PG16$ and $PG16 - NK$). Section 6 evaluates the contribution of the structural shocks in more detail.

Figure 3 provides a visual representation of the posterior estimates. For a number of parameters, the prior and posterior distributions are quite similar. This may indicate that the priors drive the posterior results and that the data is uninformative for estimating that parameter (see, e.g., Canova, 2007). It could also be the case that the prior is a good initial approximation of the possible distribution of parameter values. This is often the case, as we've just discussed, for parameters such as κ_π and κ_y—the weights on inflation and output in the monetary policy reaction function (for a similar comparison, see *SPS14*, Fig. 3, pp. 42-44). That is, in some situations, one would question more-carefully the empirical result that did not conform to the prior which rests on a substantial body of literature (e.g., the value of κ_y for *PG16* in Table 4, or more generally the variability in κ_v across models). This logic follows when comparing across model specifications with the same given prior (SW-NK vs FF-NK in Figure 3). Figure 3 shows the greatest variation between the two model specifications for the exogenous shock processes, which suggests that the core New-Keynesian model blocks are robust to additional model features.[32] On the surface, this result reiterates a general finding in the literature that the magnitude and persistence of shocks (see exogenous process in Tables 2, 3 and 4) tend to be the main factors adjusting, and therefore explaining, business cycle variation over time, rather than estimated changes to structural parameters (Stock and Watson, 2003; Sims and Zha, 2006; Smets and Wouters, 2007; Ireland, 2011; Hollander and Liu, 2016a). The following Section 5.3 looks into identification and model sensitivity.

[31] For the period 1995Q4−2005Q3, specifically, (Ortiz and Sturzenegger, 2007, p. 671) find: $\kappa_\pi = 1.36$ $[1.02, 1.67]$; $\kappa_y = 0.42$ $[0.18, 0.65]$; $\rho_i = 0.68$, $[0.59, 0.77]$. The authors also find negligible relevance for any 'fear of floating' bias (interest rate reactions in response to nominal exchange rate fluctuations) but admit that the Taylor rule specification likely understates the relative importance of controls on capital flows or forward market interventions, pre-2000.

[32] Figure D.3 shows the prior and posterior distributions for the remaining FF-NK parameters not corresponding to SW-NK.

Table 1: Structural parameters

Parameter	Description	Prior distribution			Posterior distribution			
		Type	Mean	Std.dev	Mean	Median	90% HPD int.	
Preferences								
ϕ	Habit formation	Beta	0.70	0.10	0.795	0.798	0.735	0.858
σ_c	Relative risk aversion	Inv.Gam	1.50	0.50	1.197	1.182	0.893	1.489
σ_n	Inverse elasticity of lab.	Inv.Gam	1.50	0.50	2.616	2.275	1.010	4.342
Firms & Price setting								
κ_v	Phys. capital adj. costs	Inv.Gam	5.00	0.50	6.469	6.398	5.232	7.697
θ_p	Sticky price adjustment	Beta	0.70	0.10	0.810	0.811	0.763	0.856
γ_p	Domestic price indexation	Beta	0.30	0.10	0.231	0.226	0.110	0.345
θ_w	Sticky wage adjustment	Beta	0.70	0.10	0.647	0.650	0.542	0.753
γ_w	Wage indexation	Beta	0.30	0.10	0.342	0.338	0.178	0.503
Monetary policy rule								
κ_π	Weight on inflation	Gam	1.50	0.10	1.521	1.518	1.366	1.671
κ_y	Weight on output	Gam	0.50	0.10	0.502	0.497	0.349	0.652

Table 2: Exogenous processes

	Parameter	Prior Distribution			Posterior distribution			
		Type	Mean	Std.dev	Mean	Median	90% HPD interval	
AR coefficients								
ρ_a	Technology	Beta	0.50	0.10	0.897	0.898	0.865	0.931
ρ_b	Risk premium	Beta	0.50	0.10	0.565	0.567	0.481	0.653
$\rho_{g,y}$	Cross-corr. w/ tech.	Beta	0.50	0.10	0.453	0.451	0.295	0.608
ρ_v	Investment specific	Beta	0.50	0.10	0.539	0.539	0.412	0.664
ρ_i	Monetary policy	Beta	0.50	0.10	0.849	0.849	0.825	0.872
ρ_p	Price mark-up	Beta	0.50	0.10	0.465	0.466	0.343	0.591
ρ_w	Wage mark-up	Beta	0.50	0.10	0.409	0.408	0.280	0.550
Standard deviations								
ϵ_a	Technology	Inv.Gam	0.01	Inf	0.010	0.010	0.008	0.011
ϵ_b	Risk premium	Inv.Gam	0.01	Inf	0.002	0.002	0.001	0.002
ϵ_g	Exogenous spending	Inv.Gam	0.01	Inf	0.030	0.029	0.026	0.033
ϵ_v	Investment specific	Inv.Gam	0.01	Inf	0.006	0.006	0.005	0.007
ϵ_i	Monetary policy	Inv.Gam	0.01	Inf	0.002	0.002	0.002	0.002
ϵ_π	Price mark-up	Inv.Gam	0.01	Inf	0.005	0.005	0.004	0.006
ϵ_w	Wage mark-up	Inv.Gam	0.01	Inf	0.008	0.007	0.006	0.009

Table 3: Estimated parameter comparisons from alternative South African-based DSGE models

	Posterior Estimates							
	SW-NK	*SMS09*	*SPS14*	*AKW10*†	*AKW10-SMS*	*PG16*	*PG16-NK*	*HGW18*
Data sample	95Q1−17Q4	90Q1−07Q4	00Q1−12Q4	90Q1−07Q4	90Q1−07Q4	71Q1−13Q1	71Q1−13Q1	95Q1−17Q2
Preferences								
ϕ	0.80	0.70*	0.81	0.70*	0.70*	-	-	0.70*
σ_c	1.20	1.03	1*	0.58	0.99	1*	1*	3.92
σ_n	2.62	3*	5*	3*	3*	1.90	1.45	3*
Firms & Price setting								
κ_v	6.47	-	10.5	-	-	-	-	0.25*
θ_p	0.81	0.54	0.70	0.46	0.49	0.81	0.79	0.50
γ_p	0.23	0.25*	0.50	0.25*	0.25*	0.43	0.45	0.55
θ_w	0.65	0.50*	0.69*	0.50*	0.50*	0.64	0.65	0.75*
γ_w	0.34	0.70	0.50*	0.70	0.70	0.39	0.46	0.50*
Monetary policy rule								
κ_π	1.52	1.39	1.73	1.48	1.37	1.24	1.19	1.41
κ_y	0.50	0.63	0.25	0.48	0.59	1.19***	1.43***	0.73
AR coefficients								
ρ_a	0.90	0.73	0.77	0.74	0.81	0.74	0.75	0.862
ρ_b**	0.57	0.64	0.70	0.65	0.65	0.83	0.83	0.867
ρ_g	0.815*	-	0.815*	-	-	0.65	0.67	-
$\rho_{g,y}$	0.45	-	-	-	-	-	-	-
ρ_v	0.54	-	0.79	-	-	-	-	-
ρ_i	0.85	0.73*	0.83	0.73*	0.73*	0.41	0.39	0.85
ρ_p	0.47	0.74	0.65	0.75	0.80	0.53	0.51	0.63
ρ_w	0.41	0.80*	0.49	0.80*	0.80*	0.43	0.41	-
Standard deviations								
ϵ_a	0.010	0.015	0.015	0.008	0.008	0.025	0.017	0.014
ϵ_b**	0.002	0.005	0.001	0.006	0.005	0.056	0.045	0.003
ϵ_g	0.030	-	?	-	-	0.005	0.005	-
ϵ_v	0.006	-	0.003	-	-	-	-	-
ϵ_i	0.002	0.004	0.001	0.004	0.004	0.003	0.003	0.002
ϵ_p	0.005	0.020	0.006	0.016	0.017	0.001	0.002	0.015
ϵ_w	0.008	0.014	0.004	0.009	0.009	0.015	0.002	-
Obs. var.	7	6	15	7	6	8	8	6
# est. shocks	7	9	12	6	5	10	10	7
# est. param.	24	24	40	17	15	29	27	26

* fixed (calibrated) parameters. ** either risk premium or preference shock. *** output gap, not output growth, used in MP-reaction function.
† posterior mode "similar" to posterior mean (p. 177). List of parameters only include those corresponding to *SW-NK*.

Table 4: Alternative model parameter estimates

	Posterior Distribution Means					Posterior Distribution Means			
	SW-NK	*Naive-NK*	*SOE-NK*	*FF-NK*		*SW-NK*	*Naive-NK*	*SOE-NK*	*FF-NK*
Marginal density	2088.04	1050.22	2939.0	2597.79					
Preferences					*AR coefficients*				
ϕ	0.795	0.611	0.792	0.726	ρ_a *	0.897	1.000	0.673	0.487
σ_c	1.197	-	1.197	1.246	ρ_b **	0.565	0.808	0.598	0.896
σ_n	2.616	-	2.885	0.501	ρ_g	-	-	-	-
Firms & Price setting					$\rho_{g,y}$	0.453	-	0.367	0.537
κ_v	6.469	-	0.305	9.049	ρ_v	0.539	-	0.610	0.580
θ_p	0.810	0.586	0.709	0.858	ρ_i	0.849	0.853	0.854	0.860
γ_p	0.231	0.376	0.315	0.158	ρ_p	0.465	0.452	0.667	0.384
θ_w	0.647	-	0.777	0.748	ρ_w	0.409	-	0.394	0.185
γ_w	0.342	-	0.203	0.185	ρ_e	-	-	-	0.699
Monetary policy rule					ρ_h	-	-	-	0.702
κ_π	1.521	2.101	1.559	1.527	ρ_{ν^h}	-	-	-	0.874
κ_y	0.502	1.856	0.546	0.565	ρ_{ν^e}	-	-	-	0.600
Credit demand					ρ_ψ	-	-	-	0.813
ϕ_w	-	-	-	0.969	*Standard deviations*				
ν^h	-	-	-	0.871	ϵ_a	0.010	0.010	0.016	0.012
ϕ_k	-	-	-	0.596	ϵ_b **	0.002	0.019	0.014	0.028
ν^f	-	-	-	0.784	ϵ_g	0.030	-	0.012	0.005
Credit supply & bank balance sheet					ϵ_v	0.006	-	0.012	0.003
κ_k	-	-	-	0.784	ϵ_i	0.002	0.003	0.002	0.002
κ_f	-	-	-	0.339	ϵ_p	0.005	0.008	0.068	0.005
κ_h	-	-	-	6.698	ϵ_w	0.008	-	0.012	0.018
ϕ_ψ	-	-	-	1.070	ϵ_f	-	-	-	0.068
ν_B	-	-	-	0.499	ϵ_h	-	-	-	0.099
					ϵ_{ν^h}	-	-	-	0.032
					ϵ_{ν^f}	-	-	-	0.076
					ϵ_ψ	-	-	-	0.049
					ϵ_τ	-	-	-	0.033
Obs. var.	7	3	10	12					
# shocks	7	4	10	13					
# param.	24	12	41	46					

$*$ *Naive-NK* estimates a growth-rate shock to output. Table 4 excludes open economy parameters.
$**$ *Naive-NK* = preference shock. *FF-NK* = safe-asset demand shock.

5.3 Identification and Model Sensitivity

This section provides a discussion on the comparison of the prior and posterior statistics and performs a formal identification analysis of the benchmark *SW-NK* model. Instead of shutting off each friction individually, as in Smets and Wouters (2003), we look at identification tests of pairwise collinearity to infer the importance of specific structural parameters. This procedure allows us to identify which endogenous frictions are empirically important.

We follow Ratto (2008) and Ratto and Iskrev (2011) to perform the identification analysis for

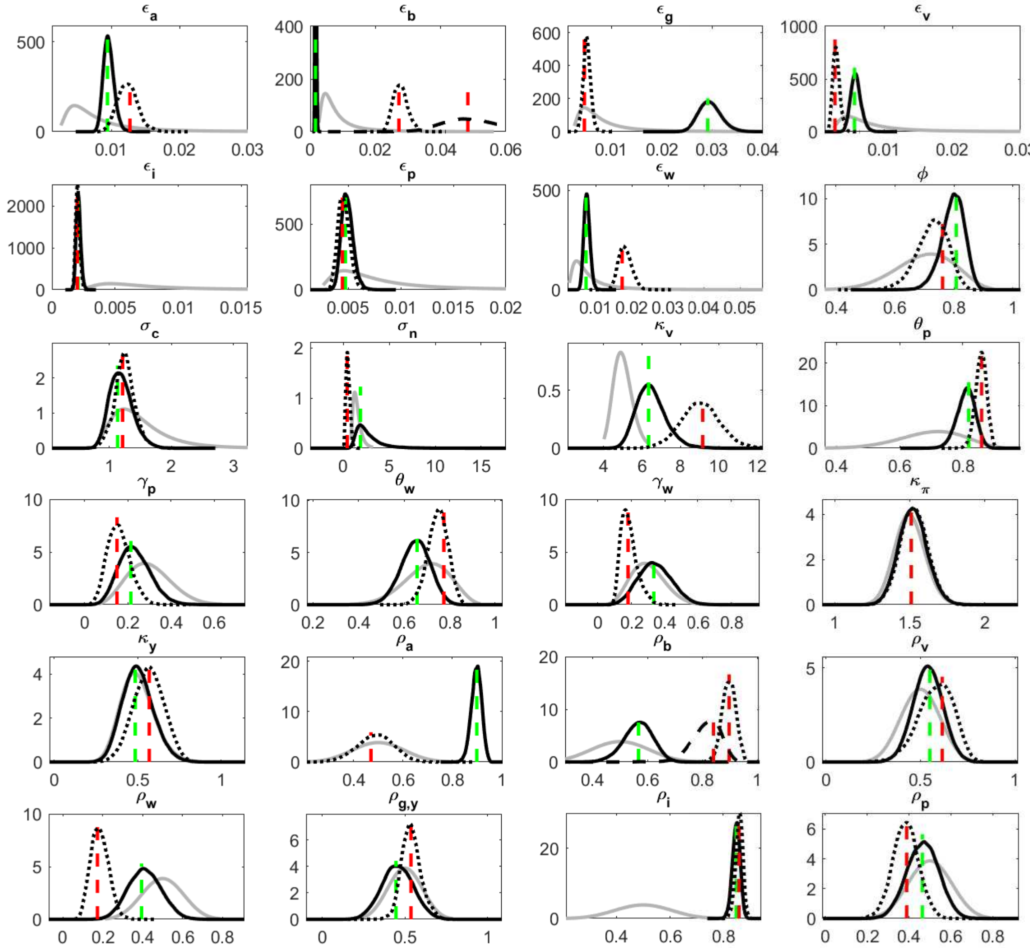

Figure 3: Prior (grey), *SW-NK* posterior (solid black) and *FF-NK* posterior (dotted black) distribution statistics with posterior modes (dashed green and red vertical lines). Distrubitions for ϵ_b and ρ_b includes equity price ψ (dashed black).

the baseline *SW-NK* model.[33] Weak identification implies that changes in a particular parameter are compensated for by linear combinations of one or more other parameters (Iskrev, 2010); or changes in a particular parameter have a negligible effect on the moments of the model (Andrle, 2010). Identification patterns are shown by taking the singular value decomposition of the Jacobian matrix and displaying the eigenvectors corresponding to the smallest (or highest) singular values (see Ratto and Iskrev, 2011, p.34). The smallest singular value indicates the particular parameter with the weakest identifiable pattern.

Our identification analysis, from Figures 4, 5, and 6, shows that all parameters are identified in the model at the posterior mean. Specifically, Figure 5 plots the identification strength at the posterior mean. Parameters are ranked in increasing order of identification strength. From the top panel in Figure 5, we see that all parameters are identified. The bottom panel suggests that all parameters have a non-negligible effect on the first- and second-order moments. However, we observe a desirable outcome that the relatively weaker identified parameters have a lesser effect on the moments of the model.

Figure 4 identifies weakest patterns for σ_n and κ_v. Given that we highlight these two parameters in the previous section as being the most sensitive across alternative model estimations, it is not surprising. This finding, however, does not appear to raise any serious identification issues. Firstly, as shown in Figure 3, the data provides non-negligible information of the mean and/or distribution of at least 17 of the 24 estimated parameters. The parameters that exhibit very similar prior and posterior means and distributions are: $\{\sigma_n, \gamma_w, \kappa_\pi, \kappa_y, \rho_v, \rho_{g,y}, \rho_\pi\}$. With the exception of σ_n, it is clear that the identification of persistence parameters have a trade-off with the identification of structural parameters. For example, price stickiness and price indexation help identify persistence in inflation data that would otherwise arise from estimating a highly persistent Markov process.[34] In contrast, and as already mentioned, parameters in the monetary policy reaction function (κ_π and κ_y) are already well established and it is not likely that we would expect significant deviations from well-informed priors.

Based on collinearity patterns (Figure 7), the identification analysis suggests that adjusting the prior distribution of σ_n will likely be offset by changes in θ_w and ρ_w (wage stickiness and the persistence of the wage markup shock process). In other words, the sensitivity of the labour supply schedule to wage changes is weakly identified by parameters identifying other processes in the labour market. We observe this clearly when these parameters or shocks are fixed or excluded in the models from Tables 3 and 4. For the capital installation adjustment cost parameter (κ_v), we

[33]This is easily implemented in Dynare using the `identification` command.

[34]Information on collinearity patters showing this is observable in Figure 7. Similar relationships are found with the other parameters.

observe pairwise collinearity patterns with ρ_v (0.84) and multicollinearity patterns with σ_c and ρ_p (0.95), where both ρ_v and σ_c directly affect the investment schedule.

Finally, the posterior density estimates (Figures D.1 and D.2) show that there is no clear indication of a problem with the optimizer.[35] As such, posterior means estimated to be close to their prior means do not necessarily imply that the priors drive the results. It could be, firstly, that the priors are well-specified—which should not be surprising given that several of the priors are updated to reflect estimations in the international as well as South African literature. Secondly, if the prior and posterior means are the same, this does not mean the distributions are the same. Figure 3 shows that the second-, third- and fourth-moments of the parameters are quite different at times. Moreover, the consistency of the prior distributions and posterior estimations across alternative models suggests that the posterior estimates are robust.

Such diagnostics, as discussed in its entirety above, will be particularly useful for model extensions not established in the literature, and should guide researchers to weaknesses in their model specifications that may need to be addressed or help researchers to identify entirely erroneous specifications. For example, perfect collinearity occurs when both a technology shock to output (not *output growth* as in *Naive-NK*) and a mark-up (price) shock to marginal cost is included in the foreign economy block of the *SOE-NK* model (see Eqs. A.26 to A.29).

6 What Structural Shocks Drive the South African Economy?

In this section we evaluate the individual contribution of important structural shocks that may be used to explain behaviour of key variables in the South African economy. We also look at the property of robustness by comparing "identified moments" from our nested models (Nakamura and Steinsson, 2018); that is, we identify the consistency (or not) of estimated responses to identified structural shocks. In doing so, we draw particular attention to monetary policy inference and the selection of exogenous shocks under alternative model specifications.

6.1 Impulse Response Analysis

Figures 8, 9, 10, 11, 12 and 13 plot the impulse responses for the different models. Figure 8 indicates the impact of a positive technology (or productivity) shock. This positive supply side innovation results in the standard hump-shaped increase in output, consumption and investment,

[35] Figures D.1 and D.2 show the log-posterior likelihood functions and log-likelihood kernels. If the estimated mode is the local mode, it should be at the maximum of the posterior likelihood. We also look at the Markov-Chain Monte-Carlo diagnostics from the Metropolis-Hastings algorithm of the corresponding parameters. Here, we observe convergence of the estimates which eliminates bimodal or poorly identified parameter distributions (see Figures D.4, D.5 and D.6 on the multivariate and univariate convergence diagnostic statistics (Brooks and Gelman, 1998)).

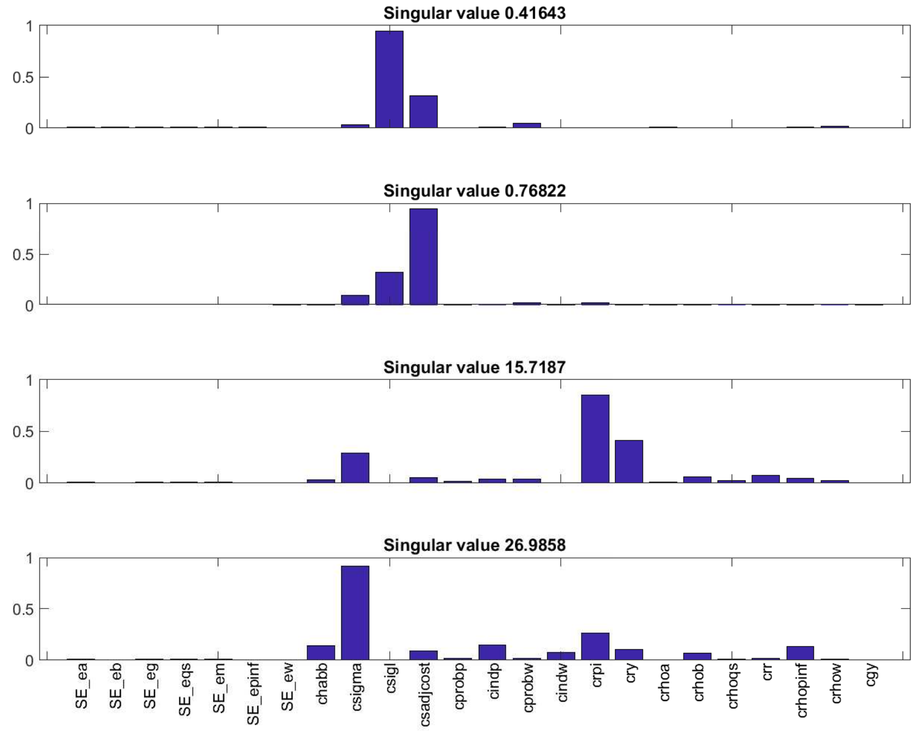

Figure 4: Identification patterns at posterior mean (lowest singular value).

while bringing about a significant reduction in inflation. In reaction to the generated disinflation and widening output gap the reaction function of the central bank prompts a decrease in the interest rate. The quantitative impact of this shock is felt most strongly in the macroeconomic indicators related to the sticky prices and wages model. The accommodative monetary policy response has a persistent effect on consumption and investment, significantly greater than that of the *FF-NK* model and *SOE-NK* model, which sees the affected variables taking longer to return back to their steady states. Notably, in the financial frictions model with sticky retail interest rate adjustment, the monetary policy response is to tighten credit conditions by raising the short-term nominal interest rate. The fall in employment (labour) as a result of the productivity shock is consistent with evidence in the literature.

The price mark-up shock observed in Figure 9 leads to a decrease in output, consumption, investment and labour. Inflationary pressure created by this price shock generates similar interest rate increases for all four of the models, which leads to a quick convergence of inflation back to the steady state at the expense of a prolonged recovery to real economic activity. Regarding output, consumption, investment and labour, the *FF-NK* model again appears to be the significant outlier—especially with respect to labour. Two important mechanisms are at play. On the one hand, the financial frictions model predicts a more prolonged contraction due to monopolistic competition in

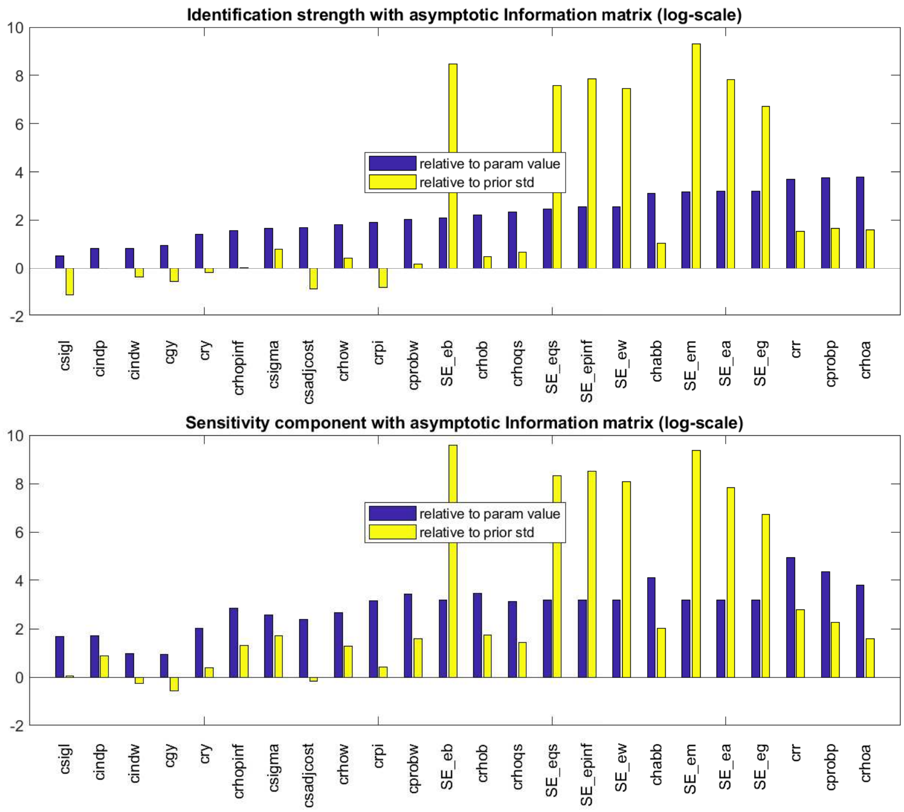

Figure 5: Identification strength at posterior mean.

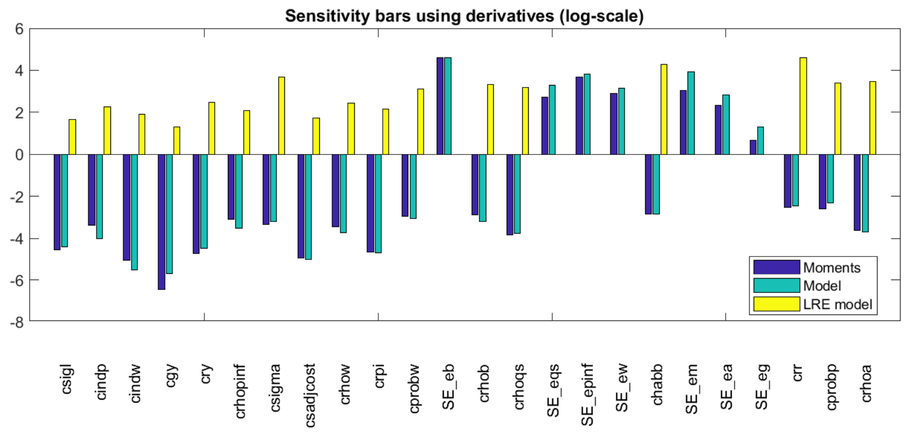

Figure 6: Sensitivity analysis at posterior mean.

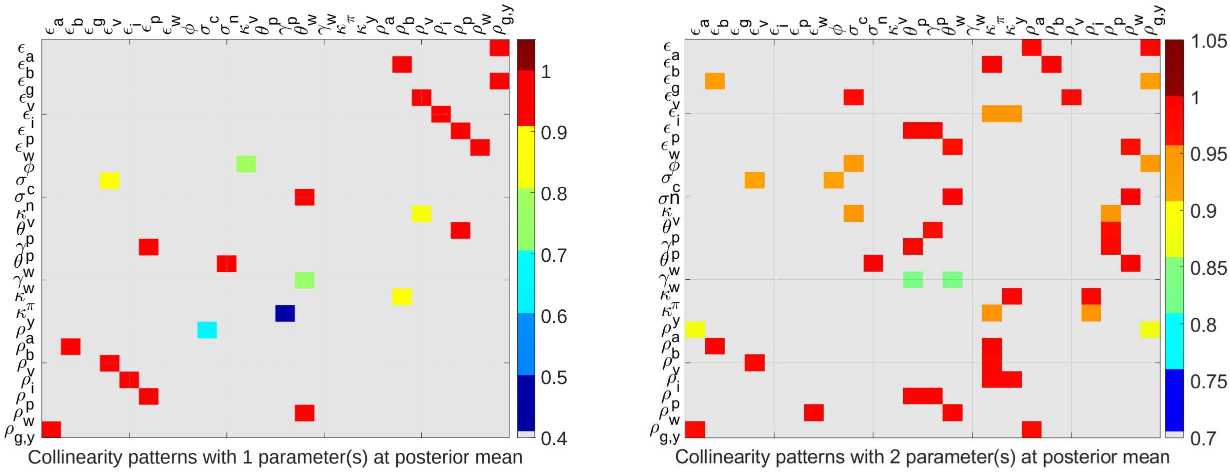

Figure 7: Collinearity patterns with parameter(s) for *SW-NK* at posterior mean.

the banking sector that generates a persistent tightening of credit conditions. On the other hand, the income effect of the initial wage increase on household wealth and creditworthiness offsets the cost-push effect on firm input costs, profits and therefore inflation. The lack of a clear trade-off between nominal wages and labour reflects high labour market rigidities. However, the response of nominal wages is barely significant and it is difficult to make definitive statements in this regard. As such, we briefly turn to the wage mark-up shock in Figure 13 which more clearly bares witness to this second channel in the *FF-NK* model: here, we observe qualitatively similar results to that of the price mark-up shock, where, instead, the positive effect on wages is much more pronounced. As a result, the income effect of the wage increase on household wealth and creditworthiness far outweighs the cost-push effect on firm input costs, profits and therefore inflation.

Figure 10 represents the typical demand shock relevant for policy analysis. One can see that disturbances to the monetary policy reaction function (or, monetary policy 'surprises') are largest in the case of the small open-economy model and weakest in the model that incorporates financial frictions. This contractionary policy shock results in a persistent decline across output, consumption, investment and labour—where, again, we see the clear effect of sticky retail interest rate adjustment. Notably, the response of inflation is quite varied, unlike the supply-side shocks, and ranges between 0 and 1.25 percentage points. The *Naive-NK* model in this instance shows the greatest inflation response, with inflation in all models returning to steady state within 10 quarters. The effectiveness of the monetary policy transmission is clearly dampened by the presence of additional demand shocks in the *SW-NK*, *SOE-NK* and *FF-NK* models. For example, greater aggregate demand from a decline in the risk premium on domestic assets, as presented in Figure 11, reveals a typical pro-cyclical demand shock. The impact of this shock, together with demand-and supply-side factors and disturbances in the *FF-NK* model, disrupt the monetary transmission mechanism which warrants cautious interpretation of interest rate policy in a stylized 3-equation New-Keynesian model.

Figure 11 includes both the safe-asset demand shock and the equity price shock from the *FF-NK* model. As we will see in Section 6.2, the equity price shock has a far larger and more persistent influence on all of the key variables. Specification of the sources of financial shocks (as opposed more traditional "demand shocks") appears crucial to understanding demand side stabilisation policies. In this light, it is also important to note that the more-credible a central bank becomes (or is), the less likely we would observe 'surprises' to the rule specifying their policy reactions. That is, we may well observe that fluctuations to the short-term nominal interest rate coincide with increasingly stronger mean reversion of inflation to the target set by monetary authorities. Such an experience seems to be true for the South African Reserve Bank (SARB) (Ortiz and Sturzenegger, 2007). In fact, Table 3 suggests a stronger anti-inflation bias when comparing models estimated over different sample periods. This implies that the *Naive-NK* model, and even the *SW-NK* model, likely overstate the "effectiveness" of the demand shock relevant for policy analysis. This does not, however, automatically imply that any model with financial frictions, including the *FF-NK* model here, is better specified or more useful for forecasting and counterfactual policy analysis.

Figure 12 captures demand-side factors (so-called, exogenous spending shocks) in the aggregate resource constraint not captured by the model framework—where *Naive-NK*, instead, includes the preference shock following Ireland (2011).[36] Ireland (2011) finds a strong role for demand-side preference shocks (to the household's discount factor) in the Great Recession episode of the U.S. On the one hand, the *Naive-NK* model is useful to tease-out the heuristics of the business cycle in a transparent manner. But clearly, there exists a trade-off with the selection of shocks that generate business cycle fluctuations and the adequate interpretation thereof. Comparing the *SOE-NK* model IRFs to the *SW-NK* model shows how including open economy dynamics dampens the general importance of exogenous spending shocks (as expected) and brings into question their interpretation. For example, the response of output is largest in the *SOE-NK* model which means that most of the persistence is attributable to the exogenous shock process and not the internal propagation mechanisms of the model. This is possibly due to the additional foreign economy data and model parameters used in estimation (see Table 4). An obvious shortcoming is to include the trade balance (or the real exchange rate) as an observable variable in the estimation of the open

[36] As noted in Section 3.2.4, following Smets and Wouters (2007) and Steinbach et al. (2014), the measurement error is included to avoid stochastic singularity in the aggregate resource constraint given that output, consumption and investment are all observable variables. The models therefore exclude government and net exports (with the exception of *SOE-NK*), as well as genuine measurement errors from the data.

economy model. This would require either relaxing the restrictive assumption of complete asset markets (international risk sharing in consumption) or introducing trade frictions (see, e.g., Canova and Ravn, 1996; Obstfeld and Rogoff, 2000; Eaton et al., 2016a,b).

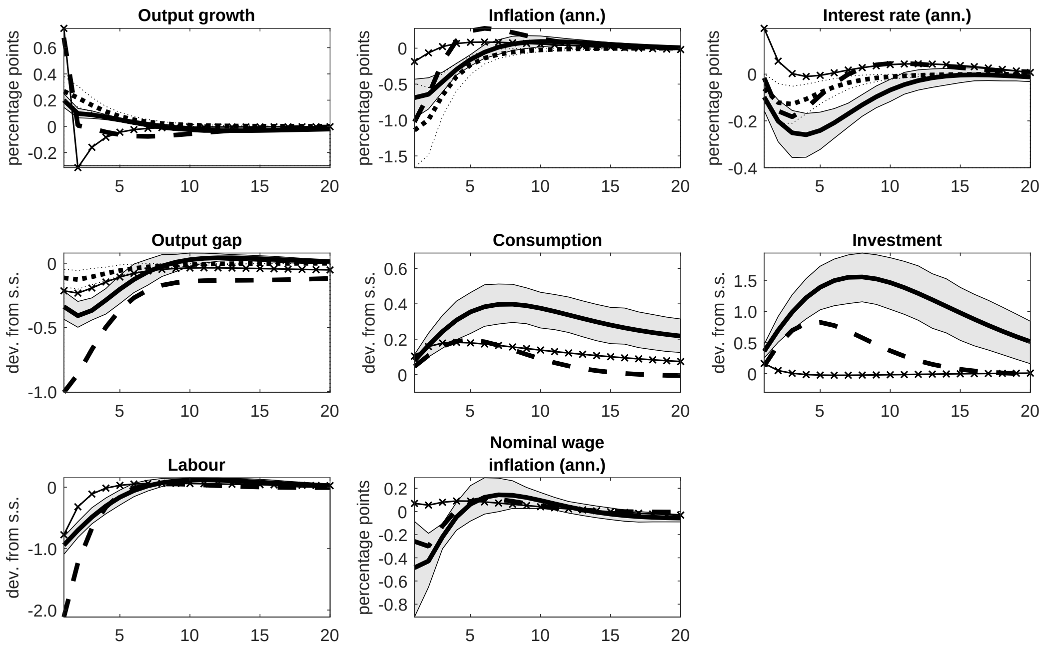

Figure 8: IRF to a technology shock. Solid line: Sticky prices and wages (*SW-NK*) model. Dotted line: 3-equation New-Keynesian (*Naive-NK*) model. Dashed line: Small open economy (*SOE-NK*) model. Cross-marker line: Financial frictions (*FF-NK*).

6.2 Variance Decomposition

Table 5 reports the forecast error variance decomposition (FEVD) results from the benchmark *SW-NK* model. This shows the contribution of the structural shocks' innovations to the variance of gross domestic product (output) per capita, headline CPI (total) inflation and the short-term nominal interest rate. We also include the decomposition of the model implied output gap measure. We compare these results to the literature, as well as the *FF-NK* model, to highlight how model specification and the selection of exogenous sources of variation affect our understanding of business cycle fluctuations. The short-run is defined as 1-quarter to 1-year, the medium-run 2-years, and the long-run 5-years.

Output variability is driven mainly by supply-side factors in the long-run. Most notably, technology makes up 30.53% after 5-years. In the short-run, we observe over two-thirds contribution from the risk premium and exogenous spending shocks after 1-quarter. The effect of ϵ_g dampens

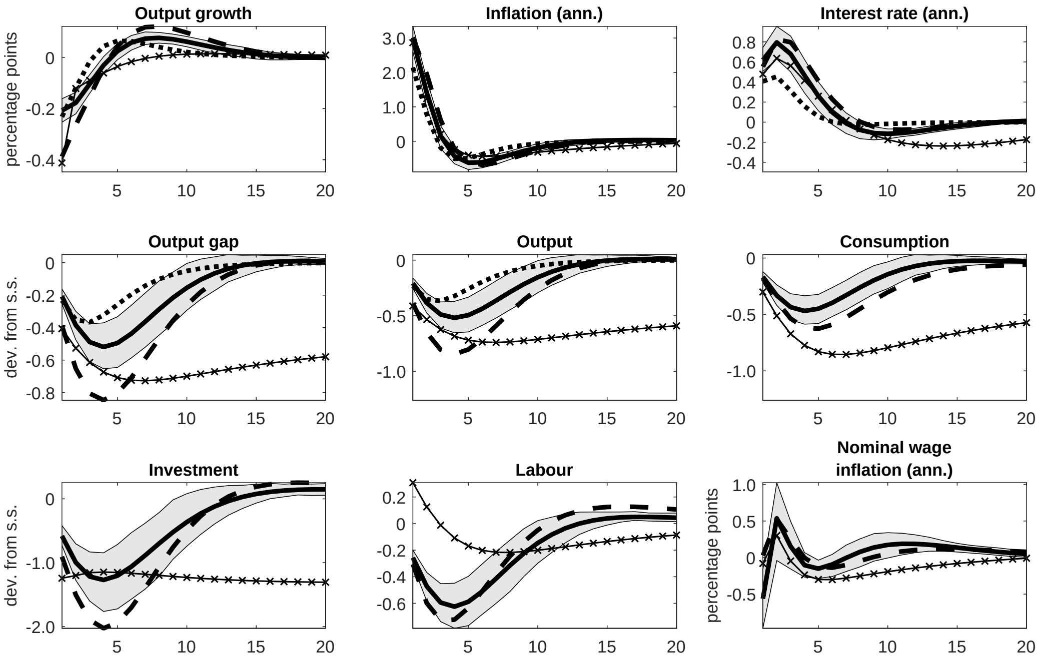

Figure 9: IRF to a price mark-up shock. Solid line: *SW-NK* model. Dotted line: *Naive-NK* model. Dashed line: *SOE-NK* model. Cross-marker line: *FF-NK* model.

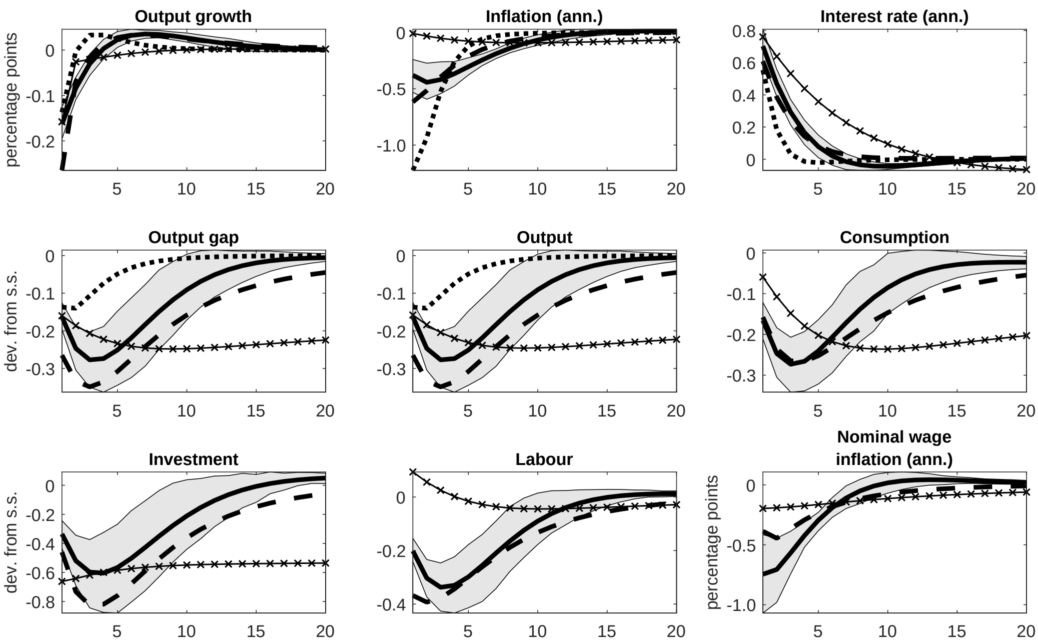

Figure 10: IRF to a monetary policy shock. Solid line: *SW-NK* model. Dotted line: *Naive-NK* model. Dashed line: *SOE-NK* model. Cross-marker line: *FF-NK* model.

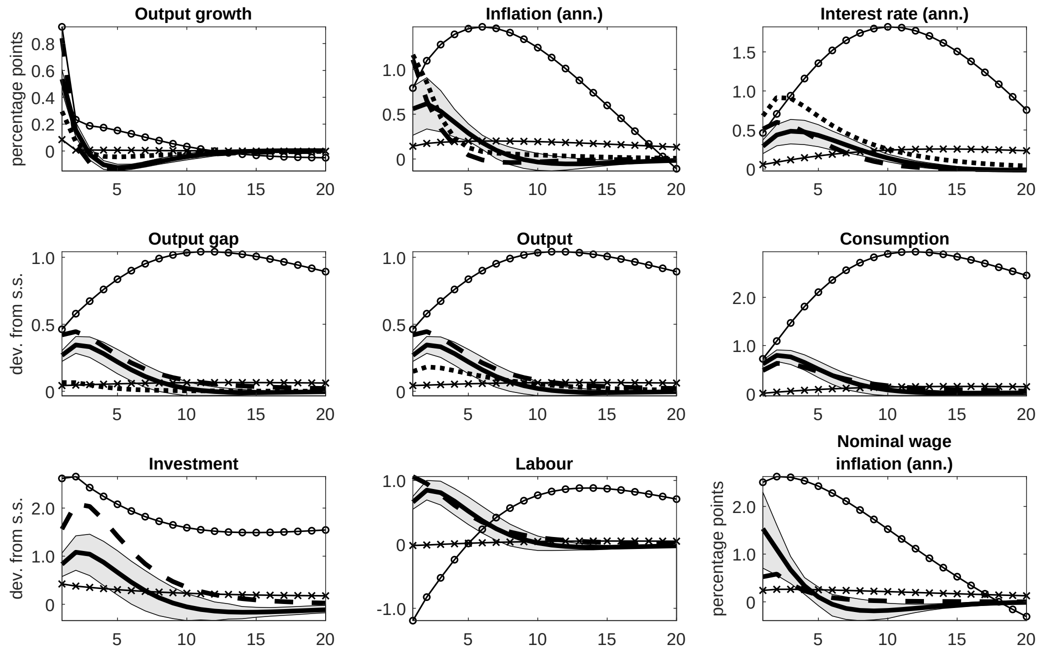

Figure 11: IRF to a risk-premium shock. Solid line: *SW-NK* model. Dotted line: *Naive-NK* model (preference shock). Dashed line: *SOE-NK* model. Cross-marker line: *FF-NK* model (safe-asset demand shock). Circle-marker line: *FF-NK* model (equity price shock).

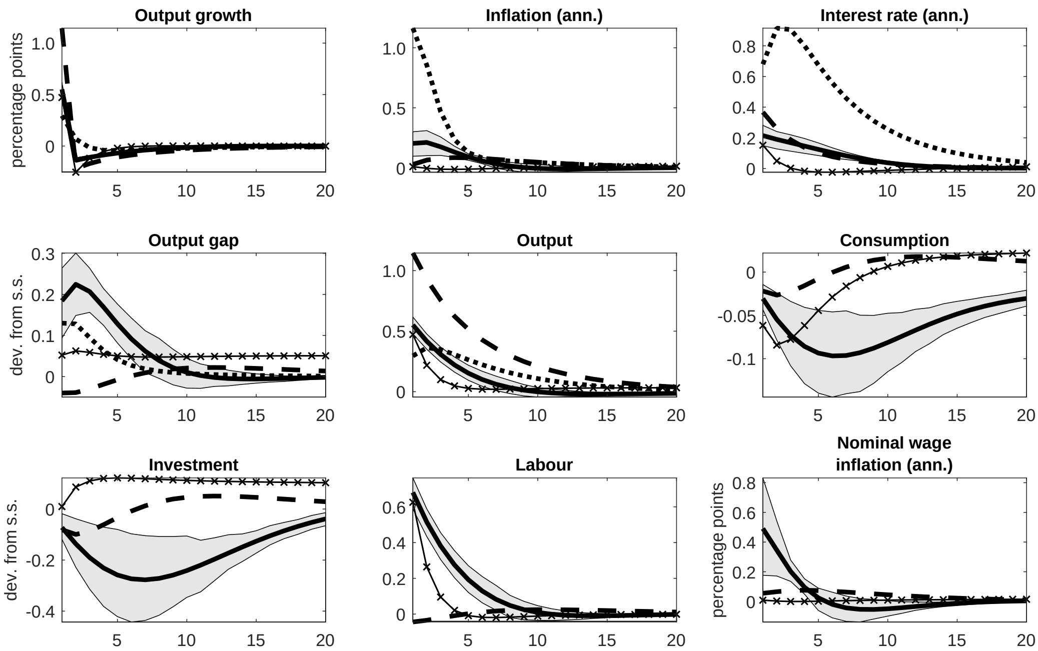

Figure 12: IRF to an exogenous spending shock. Solid line: *SW-NK* model. Dotted line: *Naive-NK* model (preference shock). Dashed line: *SOE-NK* model. Cross-marker line: *FF-NK* model

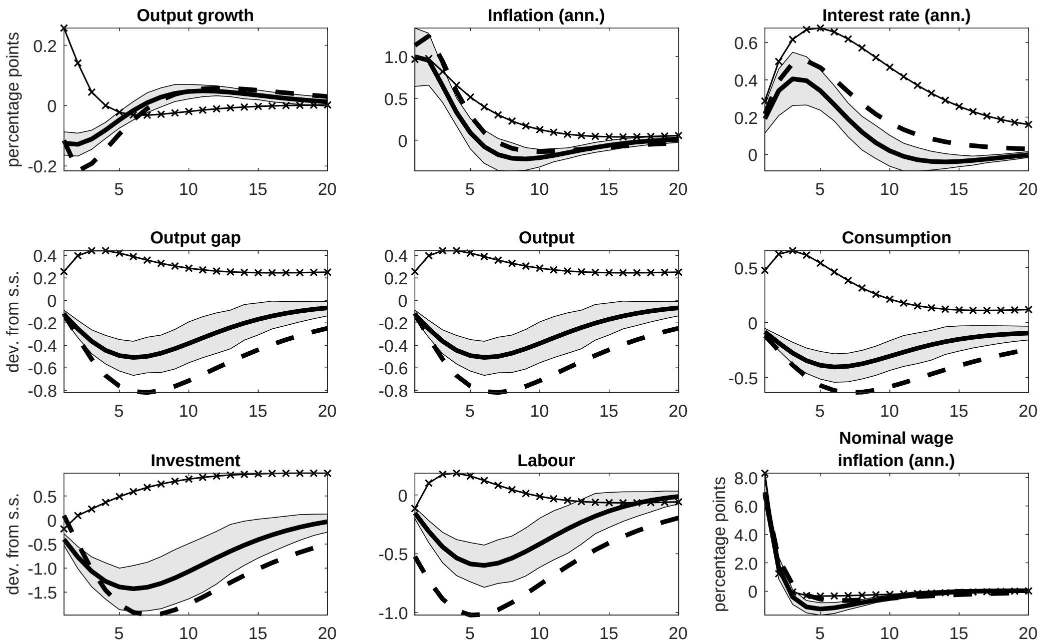

Figure 13: IRF to a wage mark-up shock. Solid line: Sticky prices and wages (SW) model. Dashed line: Small open economy. Cross-marker line: Financial frictions.

quickly, whereas the effect of the risk premium shock persists strongly into the medium- and long-run. Supply-side mark-up shocks to domestic prices and wages account for the bulk of the variance in total inflation. Monetary policy innovations contribute relatively little to output and inflation variance (1 to 6%), but make up almost a half (45.55%) of first quarter short-term nominal interest rate movements. The medium- to long-run interest rate contribution dampens significantly with the rising contribution of exogenous risk premium and price mark-up factors. Interestingly, the large and persistent role for cost-push shocks suggests a non-negligible inflation-output trade-off for monetary authorities (see also, *HGW18*). That is, cost-push shocks drive a wedge between the output gap and inflation stabilising objectives of the monetary authority (see, e.g., Hollander and Christensen, 2018, Section 6.3).

On the domestic front, this overall picture conforms strongly with the literature.[37] That is, demand-side shocks dominate output and output gap fluctuations in the short- to medium-run, whereas supply-side shocks dominate aggregate real economic activity in the medium- to long-run. Further, total (headline) inflation is driven mainly by cost-push shocks, and due to the endogenous response of the monetary policy reaction function, these cost-push shocks, together with monetary

[37] *SPS14*, in contrast, find that domestic labour supply shocks, not specified here, contribute a significant portion towards variation in all three variables along with domestic price mark-up shocks. For *SPS14*, it is not possible to decompose the short- versus long-run contributions of each shock as only the unconditional (infinite horizon) FEVD results are presented. The short- to medium-run likely exhibit results more directly comparable.

policy and risk premium innovations, contribute non-negligibly to nominal interest rate variability.

All the alternative models presented in Tables 3 and 4, with the exception of *PG16* (discussed below), show that accounting for the foreign economy with traditional New-Keynesian specifications has only a marginal effect on the contributions of the domestic shocks. Even in Ortiz and Sturzenegger's estimated small (5-equation) open economy NK-DSGE model of South Africa (following Gali and Monacelli (2005)), terms-of-trade shocks play a relatively smaller role than technology or monetary policy innovations, and account mostly for nominal exchange rate fluctuations (Ortiz and Sturzenegger, 2007, Fig. 4, p. 670). This should not be seen as a "failure" of the open economy structure, but rather the "success" of the New-Keynesian design to fit the data and provide plausible estimations of business cycle moments. For a large, relatively closed economy such as the U.S. or the Euro area, such a framework may provide a satisfactory structural decomposition of the business cycle (Smets and Wouters, 2003, 2007). For a small open economy, such as South Africa, the domestic business cycle may often be the global trend.

Notably, we see that simple extensions to the open economy specifications can substantially alter the estimated responses to domestic shocks. For example, in the open economy model of *SPS14*, mark-up shocks to imported consumption goods inflation (that has a New-Keynesian Phillips Curve specification) contribute approximately one-third of the unconditional FEVD of CPI inflation and the interest rate. Moreover, *HGW18* show that accounting for commodity shocks can significantly reduce the relevance of domestic price mark-up shocks in headline inflation figures. In the *HGW18* model, oil (energy) imports are used in the firm's production process as a factor input and enter directly into the household's consumption basket. These model extensions are question-specific, and it is unclear how a policy-maker should weight each of the implied dynamic responses to a particular shock (e.g., the degree and scope of sticky import prices) or the sources of estimated responses altogether (commodity trade shocks).

In other open economy models with New-Keynesian features, stricter underlying assumptions can drastically change how the estimated model allocates weight to foreign economy shocks to the domestic business cycle. Following the model in Funke et al. (2011), *PG16* show a large effect for "foreign demand" on output and inflation variance. This is due to the specification of the model where foreign demand/output ($\hat{y}^*$), domestic technology ($\hat{\xi}^a$) and a household preference shock ($\hat{\xi}^b$) drive natural output (i.e., the flexible-price equilibrium)—and therefore the natural real interest rate (*PG16*, p. 176, Eqs. A.37 and A.39). Specifically, international risk sharing under log utility implies that domestic output is a function of foreign output and terms-of-trade ($\hat{s}_t$): $\hat{y}_t = \hat{y}_t^* + \Phi^s \hat{s}_t$ (Funke et al. (2011), p. 322, Eq. 36), where $\hat{s}_t$ evolves according to the real interest rate differential between the domestic economy and the foreign economy (Funke et al. (2011), p.

320, Eq. 17). In addition, the production technology ($\hat{y}_t$) is assumed to be linear in labour (Funke et al. (2011), p. 321 and 323), and $\hat{y}^*$ follows a stochastic auto-regressive process. In contrast, the greater contribution of $\hat{\xi}^b$ to output and interest rate deviations mimics that of the *Naive-NK* model developed by Ireland (2011) for his decomposition of the 2007−09 Great Recession episode in the U.S. This does not, however, imply that household preference shocks are robust and domestic technology innovations are not.[38]

Introducing financial frictions into the model has a similar significant impact on the estimated responses of all the main macroeconomic variables to the identified structural shocks. Table 5 shows a very large and persistent role for equity price shocks on all the main macroeconomic variables: approximately one-third for output and one-half for the output gap across all horizons. For the nominal interest rate and total inflation, equity prices generate strong co-movement in the medium- to long-run. Interestingly, price mark-up shocks are still important, especially in the short- and medium-run, for total inflation and, to a much lesser degree, nominal interest rate. Similarly, shocks to the monetary policy rule are important in the short-run for nominal interest rate variance, but are negligible for the total inflation FEVD. This would, on the surface, suggest a relatively minor role for demand-side intervention by the monetary authorities. Here, it is important to consider the endogeneity of monetary policy as being the important business cycle stabilization factor, rather than identified moments based on estimated exogenous shocks to the short-term interest rate—which may be completely unrelated to the monetary authorities or simply due to the overly restrictive Taylor-rule specification of the monetary policy reaction function.

Another interesting observation from Table 5 is that demand-side shocks in the *SW-NK* model ($\epsilon_b, \epsilon_g, \epsilon_v$) become subservient to financial factors. Equity price shocks, as noted above, garner a significant portion of the variance decompositions. Aside, credit supply shocks are also an important driver of variance for all of the variables: between 8 and 12% at 1- and 2-year horizons. Credit demand shocks (the loan-to-value ratios in the household and firm borrowing constraints) contribute one-quarter and one-eighth to output gap and output, respectively. This exercise serves to highlight the narrative throughout this section that careful consideration should be taken when attempting to provide a structural decomposition of the business cycle. Counterfactual analyses, the identification ("effectiveness") of monetary policy and forecasting—all relevant for policy analysis—may deliver quite different results under different specifications. For example, the results from the *FF-NK*

[38] Unfortunately, it is not clear which data series are used to estimate the model, making inference difficult regarding the source or specification of the foreign economy. In addition, model misspecification is likely if the preference shock contributes significantly to the variance of output and interest rate but either has little explanatory power for other key macroeconomic variables (inflation, stock prices, consumption or investment) or the FEVD of key macro variables appear to be each individually driven by one particular shock; this appears to be the case (see *PG16*, Table 2, p. 172).

model suggests an influential role for macroprudential policy in credit demand and supply, not at all observable from the *SW-NK* model. The *SW-NK* model, in contrast, identifies financial distortions solely through an exogenous risk premium that monetary policy can directly offset. In the following section we give a brief discussion on the contribution of shocks to each observed point in the data.

6.3 Historical Decomposition

Figures 14 to 17 presents the historical variance decomposition of output growth, output gap, interest rate and headline inflation over the estimated sample period 1995Q1−2017Q3. The decomposition is based on the benchmark *SW-NK* model. We avoid attempting to make strong inferences regarding the individual shocks and instead group the seven shocks into their demand-side ($\epsilon_b, \epsilon_v, \epsilon_i$) and supply-side ($\epsilon_a, \epsilon_p, \epsilon_i$) origins.[39] Although Smets and Wouters (2007) refer to the exogenous spending shock (ϵ_g) as an exogenous *government* spending shock and therefore demand-side in nature, it actually includes demand- and supply-side (trade) factors as well as possible measurement errors in the aggregate resource constraint, not accounted for by consumption and investment data. There is also a non-negligible estimated cross-correlation component with the technology shock. We therefore keep this component separate.

First, in Figure 14, it is interesting to compare the main sources of the recessions or downward phases over this period (see, e.g., Bosch and Ruch, 2013, for comparison of alternative business cycle dating procedures). Output growth was negative and persistent from 1997Q1 until 1998Q4 with an unclear pattern of both supply and demand factors as contributing factors. The mild recession of 2001Q2−2001Q3 and great recession of 2008Q3−2009Q3 clearly identify demand-side factors; in fact, we find credit demand side factors to be the predominant source of the 2008-09 recession, but not the 2001 recession.[40] This narrative fits well with the influence of the 2008 global financial crisis, in that domestic financial factors have become increasingly pervasive since the mid-2000s. The most recent episodes of weak economic growth that began in 2014 are again both supply-side and demand-side in origin. The first and last downward phases both occurred outside the global economic boom period from 2002Q1 to 2007Q4. Persistent supply-side factors facilitated the early days of the boom. From 2006Q1, demand-side factors fuelled an over-heating economy (see output gap in Figure 15) which led to the deep recession in 2008-09. More recently, the persistence of output below its potential since 2014Q1 can be characterized unequivocally as

[39] Table 5 gives an indication of the relative importance of these demand- and supply-side components. Detailed historical decomposition figures are available upon request.

[40] Historical decomposition figures for the *FF-NK* model, as well as detailed shock breakdowns for the other models, are available upon request.

Table 5: Forecast error variance decomposition of output, total inflation and nominal interest rate

Forecast error variance decomposition of output

		SW-NK: Time Horizons				*FF-NK*: Time Horizons			
Description	Shocks	1-quarter	1-year	2-years	5-years	1-quarter	1-year	2-years	5-years
Technology	ϵ_a	4.95	10.58	19.6	30.53	24.27	23.84	23.17	22.79
Risk premium	ϵ_b	34.95	32.52	22.55	17.02	0.32	0.26	0.25	0.25
Exogenous spending	ϵ_g	37.22	13.46	7.95	5.98	9.63	10.4	10.08	9.91
Investment specific	ϵ_v	12.26	14.16	12.11	10.29	1.29	1.28	1.24	1.22
Monetary policy	ϵ_i	3.27	5.16	4.91	4.02	1.08	0.9	0.88	0.86
Price mark-up	ϵ_p	5.39	15.24	16.41	13.22	6.95	6.38	6.23	6.19
Wage mark-up	ϵ_w	1.95	8.89	16.47	18.95	3.24	3.41	3.41	3.41
Credit supply	ϵ_τ; $\epsilon_{h,e}$	-	-	-	-	6.58	7.7	8.03	8.64
Credit demand	ϵ_{ν_h,ν_e}	-	-	-	-	12.02	14.29	14.27	14.27
Equity	ϵ_ψ	-	-	-	-	34.61	31.53	32.43	32.47

Forecast error variance decomposition of total inflation

		SW-NK: Time Horizons				*FF-NK*: Time Horizons			
Description	Shocks	1-quarter	1-year	2-years	5-years	1-quarter	1-year	2-years	5-years
Technology	ϵ_a	4.33	6.87	6.45	6.56	0.32	0.2	0.21	0.19
Risk premium	ϵ_b	2.94	6.71	6.81	6.79	0.22	0.62	0.9	1.5
Exogenous spending	ϵ_g	0.39	0.8	0.8	0.79	0	0	0	0.01
Investment specific	ϵ_v	0.64	1.54	1.62	1.7	0.04	0.06	0.06	0.05
Monetary policy	ϵ_i	1.34	3.79	4.55	4.56	0.01	0.05	0.12	0.27
Price mark-up	ϵ_p	81.2	65.99	66.13	65.34	76.73	46.02	32.88	26.01
Wage mark-up	ϵ_w	9.16	14.31	13.64	14.27	8.83	13.78	11.15	8.82
Credit supply	ϵ_τ; $\epsilon_{h,e}$	-	-	-	-	6.3	12.02	11.07	9.28
Credit demand	ϵ_{ν_h,ν_e}	-	-	-	-	0.47	1.41	2.09	4.93
Equity	ϵ_ψ	-	-	-	-	7.07	25.85	41.53	48.93

Forecast error variance decomposition of nominal interest rate

		SW-NK: Time Horizons				*FF-NK*: Time Horizons			
Description	Shocks	1-quarter	1-year	2-years	5-years	1-quarter	1-year	2-years	5-years
Technology	ϵ_a	0.94	4.16	5.93	6.1	3.31	0.58	0.23	0.12
Risk premium	ϵ_b	7.84	16.92	21.84	22.3	0.28	0.6	0.93	1.79
Exogenous spending	ϵ_g	4.32	3.09	3.1	3.08	1.88	0.33	0.13	0.06
Investment specific	ϵ_v	2.23	4.98	6.75	7.08	0.37	0.13	0.08	0.05
Monetary policy	ϵ_i	45.55	19.69	15.71	15.22	46.24	18.54	8.3	3.57
Price mark-up	ϵ_p	35.65	40.11	33.44	33.14	19.1	14.59	5.95	3.38
Wage mark-up	ϵ_w	3.46	11.04	13.21	13.1	6.7	14.63	13.12	8.53
Credit supply	ϵ_τ; $\epsilon_{h,e}$	-	-	-	-	2.83	10.79	11.5	7.66
Credit demand	ϵ_{ν_h,ν_e}	-	-	-	-	2.24	4.08	4.55	5.07
Equity	ϵ_ψ	-	-	-	-	17.06	35.73	55.21	69.78

Forecast error variance decomposition of output gap

		SW-NK: Time Horizons				*FF-NK*: Time Horizons			
Description	Shocks	1-quarter	1-year	2-years	5-years	1-quarter	1-year	2-years	5-years
Technology	ϵ_a	21	13.74	9.69	8.7	2.95	1.27	0.52	0.21
Risk premium	ϵ_b	53.64	40.66	30.72	26.99	0.48	0.29	0.25	0.27
Exogenous spending	ϵ_g	6.35	4.35	3.26	2.9	0.16	0.09	0.06	0.04
Investment specific	ϵ_v	2.7	4.46	4.59	4.28	0.34	0.15	0.18	0.22
Monetary policy	ϵ_i	5.02	6.45	6.66	6.29	1.63	1.16	1.02	0.94
Price mark-up	ϵ_p	8.3	19.14	22.45	21.02	10.42	9.72	8.89	7.4
Wage mark-up	ϵ_w	3	11.2	22.64	29.82	4.8	5.37	3.75	2.29
Credit supply	ϵ_τ; $\epsilon_{h,e}$	-	-	-	-	9.86	10.52	8.07	5.99
Credit demand	ϵ_{ν_h,ν_e}	-	-	-	-	17.89	25.06	26.33	24.26
Equity	ϵ_ψ	-	-	-	-	51.46	46.38	50.93	58.37

one of weak domestic demand. Monetary policy was strongly accommodative from 2008 through to 2015 in attempting to close the output gap (not shown here), but was offset by large and persistent shocks to the risk premium and inflation.

The historical decomposition of headline inflation reveals that this variable is primarily driven by cost-push shocks (Figure 16). The risk premium shock dominates the cyclical component of demand-side inflationary pressures in recent times, with monetary policy shocks playing a some role during and after the financial crisis. Similarly, interest rates movements also receive input from both demand and supply side innovations, with demand side components (the risk premium in particular) playing a much greater role in recent years (Figure 16).

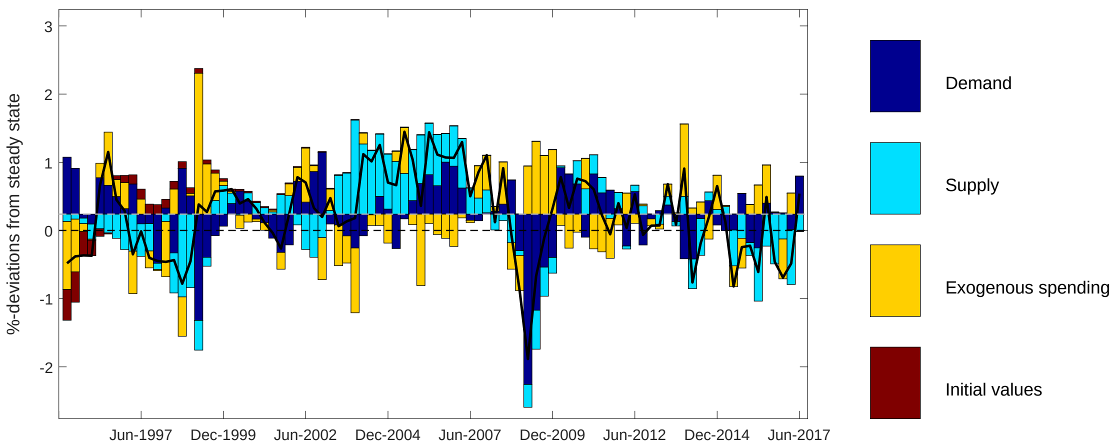

Figure 14: Historical decomposition of output growth. Period: 1995Q1−2017Q3

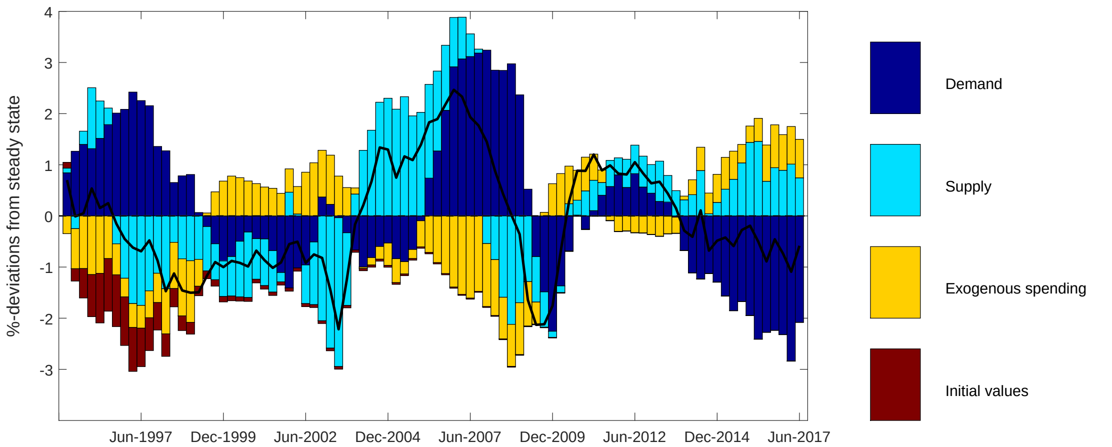

Figure 15: Historical decomposition of output gap. Period: 1995Q1−2017Q3

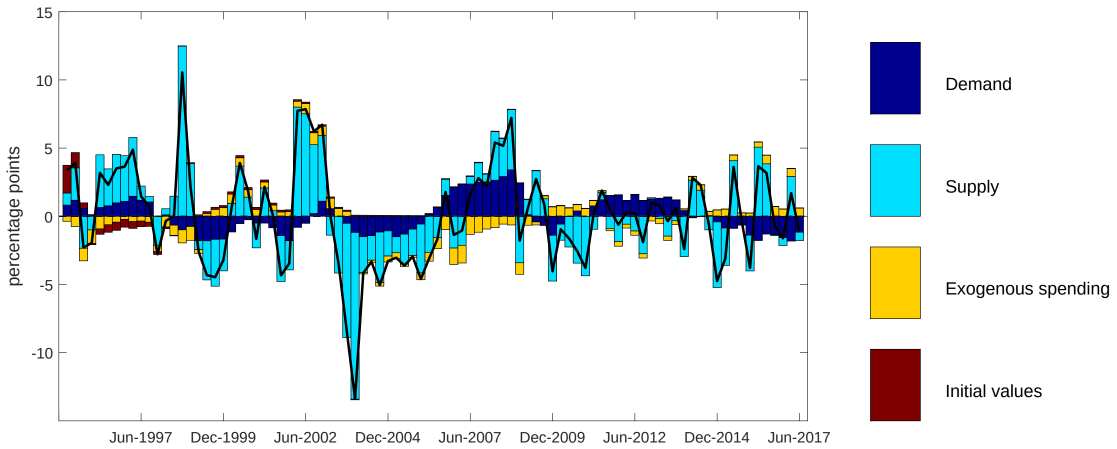

Figure 16: Historical decomposition of headline inflation (annualized). Period: 1995Q1−2017Q3

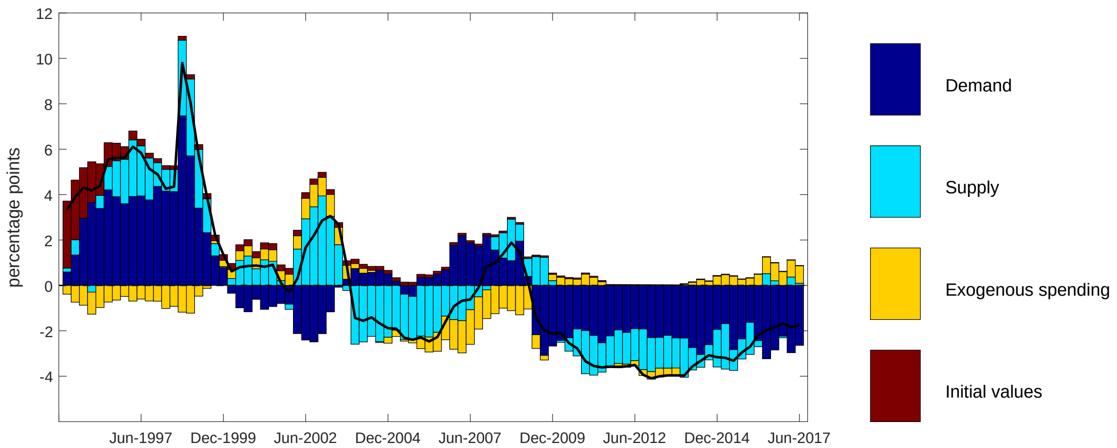

Figure 17: Historical decomposition of the interest rate (annualized). Period: 1995Q1−2017Q3

7 Concluding Remarks

The primary purpose of this paper is to contribute to the understanding of business cycle dynamics in the South African economy through the comparison of several dynamic general equilibrium models. We believe that the theoretical restrictions imposed, through the development of these micro-founded models, creates a useful link between observed- and model variables. In other words, these models help to bring theory to the data in a coherent fashion. We introduce nested models that cater to the needs of the South African macroeconomy, but also speak to the direction that the economics discipline is taking after the financial crisis. We acknowledge that models will, on occasion, fail to predict possibly catastrophic market failures. However, this is a result of the complexities and opacity of real world interaction that models will never be able to fully accommodate.

We interpret our main results from the benchmark New-Keynesian framework as described by Smets and Wouters (2003, 2007). Model dynamics reveal that inflation is sensitive to interest rate movements, which is observed across the different models used in this paper and in the face of different shocks imposed. Although interpreting the influence or effectiveness of the implied monetary policy transmission mechanism warrants caution. Output, consumption, investment and labour showcase some persistence with respect to most shocks. The surprising result is the rigidity in the labour market that appears to be robust in the face of different innovations, especially once incorporating financial sector features.

When considering the variance decomposition one observes that output variability, in the long run, is driven primarily by technology shocks. However, in the short- to medium-run the risk premium and exogenous spending play a greater part, with the risk premium having a more persistent impact. Inflation variance in the long run is explained mostly by cost-push shocks, with price mark-up shocks contributing a significant amount. Monetary policy innovations contribute relatively little to output and inflation variance, but make up almost a half of the first quarter short-term nominal interest rate movements. Interestingly, the large and persistent role for cost-push shocks on the output gap suggests a non-negligible inflation-output trade-off for monetary authorities. The relevant contribution of these traditional shocks change substantially once financial factors are included. Equity price shocks account for the largest share output, inflation and nominal short-term interest rate variance at medium- to long-term horizons (2 to 5 years). Credit supply factors are more important for inflation and interest rate variance, and credit demand factors are more important for output.

Going forward, it is clear that a significant amount of thought should go into the specification of model dynamics and the identification and selection of exogenous shocks. Pertinent research questions usually require specific model assumptions and augmented features, such as the open economy and financial sectors developed here. There is, therefore, an apparent trade-off to incorporating new and/or alternative features of the real world with a consistent and coherent interpretation of non-trivial theoretical interpretations. This trade-off, together with the atheoretical-theoretical trade-off at large in macroeconometric modelling, cannot be over-looked by policy-makers, academics and private sector practitioners alike.

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Appendix

A Ireland's 3-Equation New-Keynesian Model

IS curve:

$$\lambda_t = i_t + \lambda_{t+1} - \pi_{t+1} \tag{A.1}$$

New Keynesian Phillips Curve:

$$\pi = \frac{\gamma_p}{(1+\gamma_p\beta)}\pi_{t-1} + \frac{\beta}{(1+\gamma_p\beta)}E_t[\pi_{t+1}] - \kappa_h(\lambda_t + \xi_t^b) + \xi_t^p \ . \tag{A.2}$$

where $\kappa_h = \frac{(1-\theta_p)(1-\theta_p\beta)}{\theta_p(1+\beta\gamma_p)}$.
Monetary policy rule

$$i_t = \rho_i i_{t-1} + \kappa_\pi \pi_t + \kappa_y \Delta y_t + \epsilon_t^i \ , \tag{A.3}$$

where the growth rate of output is $\Delta y_t = y_t - y_{t-1} + \xi_t^a$. The marginal utility of consumption with *internal* habit formation and log preferences (i.e., $\sigma_c = 1$):

$$(1-\beta\phi)(1-\phi)\lambda_t = \phi y_{t-1} - (1+\beta\phi^2)y_t + \beta\phi y_{t+1} + (1-\beta\phi\rho_b)(1-\phi)\xi_t^b - \phi\xi_t^a \ , \tag{A.4}$$

where ξ_t^b is the preference shock. We do not include this shock in the other models. Instead, the dynamics and relative contribution are compared to two similar shocks in the *SW2007* framework, namely: the risk premium shock and the exogenous spending shock. All three of these shocks are variant aggregate demand shocks.[41] A quick comparison with the 3-equation model of the foreign economy in *HGW18* shows how similar these two linearized frameworks are (see Section B and Section 4). Another key difference is that ξ_t^a is a shock to the growth rate of output. A number of variables therefore need to be renormalized to remove the inherited unit root. Setting $\beta = 0$ in Equation A.4 gives the marginal utility of consumption with external habit:

$$\lambda_t = \frac{\phi}{(1-\phi)}y_{t-1} - \frac{1}{(1-\phi)}y_t + \xi_t^b - \phi\xi_t^a \ , \tag{A.5}$$

The efficient level of output is:

$$0 = \phi q_{t-1} - (1+\beta\phi^2)q_t + \beta\phi q_{t+1} + \beta\phi(1-\phi)(1-\rho^b)\xi_t^b - \phi\xi_t^a \ ,$$

[41]Ireland's preference shock explains a significant portion of the models fluctuations over the estimated great recession period.

where the output gap is: $y_t^{gap} = y_t - q_t$. The laws of motion for the preference shock, the (renormalized) cost-push shock, and the technology shock are: $\xi_t^b = \rho^b \xi_{t-1}^b + \epsilon_t^b$; $\xi_t^p = \rho^p \xi_{t-1}^p + \epsilon_t^p$; $\xi_t^a = \epsilon_t^a$.

B The Open Economy

The open economy system of equilibrium conditions shown here is a direct extension of the "benchmark" closed economy New-Keynesian model presented in Section 3. The corresponding *SW2007* model has some slight differences particularly related to the investment specific efficiency shock. Specifically, the shock in *SW2007* directly affects the accumulation of investment and its efficiency (via an adjustment cost) in physical capital accumulation, whereas *HGW* affects the adjustment cost only—as in Iacoviello (2005) (i.e., the relative price of capital, or, as described in *SW2007*, the arbitrage equation for the value of capital). Also, we shut off the capital utilization channel in *SW2007*.

Aggregate demand

$$\hat{c}_t^h = \gamma_c \eta_c (r\hat{e}r_t - \hat{\psi}_t^f) - (\gamma_c \eta_c) p\hat{r}_t^h + \hat{c}_t \tag{A.6}$$

$$\hat{c}_t^f = (1-\gamma_c)(\eta_c) p\hat{r}_t^h + (\gamma_c - \eta_c)(r\hat{e}r_t - \hat{\psi}_t^f) + \hat{c}_t \tag{A.7}$$

$$\hat{c}_t = \frac{1}{(1+\phi)}\hat{c}_{t+1} + \frac{\phi}{(1+\phi)}\hat{c}_{t-1} - \frac{(1-\phi)}{\sigma_c(1+\phi)}(\hat{i}_t^b - \hat{\pi}_{t+1} + \hat{\mu}_t^b) \tag{A.8}$$

$$r\hat{e}r_t = \frac{\sigma_c}{1-\phi}(\hat{c}_t - \phi\hat{c}_{t-1}) - \frac{\sigma_c^*}{1-\phi^*}(\hat{c}_t^* - \phi^*\hat{c}_{t-1}^*) \ . \tag{A.9}$$

Eq.A.6 domestic consumption of home goods; Eq.A.7 domestic consumption of foreign goods; Eq.A.8 Euler eqn; Eq.A.9 is the international risk sharing condition (where $\hat{c}_t^* = \hat{y}_t^*$).[42]

Investment schedule

$$\hat{v}_t - \hat{k}_t = \beta E_t(\hat{v}_{t+1} - \hat{k}_{t+1}) + \frac{\beta R^k}{\kappa_v} E_t(\hat{r}_{t+1}^k) + \frac{\sigma_c}{\kappa_v}(\hat{c}_t - \hat{c}_{t+1}) + \frac{1}{\kappa_v}(\hat{\xi}_t^v - \beta E_t \hat{\xi}_{t+1}^v) \ , \tag{A.10}$$

where $R^k = 1/\beta - (1-\delta)$ and $\hat{\xi}_t^v$ is the investment-specific shock, and $q_t^k = \kappa_v(v_t - k_t) - \tilde{\xi}_t^v$.

[42]The UIP condition holds from the Euler equations of the domestic and foreign sectors: $\hat{i}_t^b = \hat{i}_t^{b*} + E_t[\Delta\hat{\varepsilon}_{t+1}] + \hat{\Phi}_t$, which implies that the real exchange rate equates the marginal utilities of consumption between the domestic and foreign households.

Aggregate supply & inflation

(real) wage setting equation:

$$\begin{aligned}\hat{w}_t &= \Omega\beta E_t\hat{w}_{t+1} + \Omega\hat{w}_{t-1} + \Omega\Omega^*(\hat{mrs}_t - \hat{w}_t)\\ &\quad + \Omega\beta E_t\hat{\pi}_{t+1} - \Omega\hat{\pi}_t - \Omega\theta_w\beta\gamma_w\hat{\pi}_t + \Omega\gamma_w\hat{\pi}_{t-1} \ .\end{aligned}$$

The real wage ($\hat{w}_t = w_t - p_t$) setting equation can be re-written in nominal wage inflation form as:

$$\hat{\pi}^w_t - \gamma_w\hat{\pi}_{t-1} = \beta E_t\hat{\pi}^w_{t+1} - \theta_w\beta\gamma_w\hat{\pi}_t + \Omega^*(\hat{mrs}_t - \hat{w}_t), \tag{A.11}$$

where $\Omega^* = \frac{(1-\theta_w)(1-\theta_w\beta)}{\theta_w(1+\xi^w\sigma_n)}$, $\Omega = \frac{1}{(1+\beta)}$, and $\hat{mrs}_t = \frac{\sigma_c}{1-\phi}(\hat{c}_t - \phi\hat{c}_{t-1}) + \sigma_n\hat{n}_t$.

Domestic production and inflation (for consumption goods)

$$\hat{\pi}^h_t = \frac{\gamma_p}{(1+\gamma_p\beta)}\hat{\pi}^h_{t-1} + \frac{\beta}{(1+\gamma_p\beta)}E_t\hat{\pi}^h_{t+1} + \kappa_h(\hat{mc}^h_t + \hat{\xi}^p_t), \tag{A.12}$$

where $\hat{mc}^h_t = \hat{\lambda}_t$ is the real marginal cost of production, and $\kappa_h = \frac{(1-\theta_p)(1-\theta_p\beta)}{\theta_p(1+\gamma_p\beta)}$.

$$\hat{\lambda}_t = (\hat{w}_t - \hat{pr}^h_t) - (\hat{y}^h_t - \hat{n}_t) \tag{A.13}$$

$$\hat{\lambda}_t = \hat{r}^k_t - (\hat{y}^h_t - \hat{k}_t) \tag{A.14}$$

$$\hat{y}^h_t = \hat{\xi}^a_t + \alpha\hat{k}_t + (1-\alpha)\hat{n}_t \ , \tag{A.15}$$

Imported inflation (for foreign consumption goods)

$$\hat{\pi}^f_t = \beta E_t[\hat{\pi}^f_{t+1}] + \kappa_f\hat{\psi}^f_t, \tag{A.16}$$

where $\kappa_f = \frac{(1-\theta_f)(1-\theta_f\beta)}{\theta_f}$, and $\hat{\psi}^f_t$ measures the l.o.p gap:[43]

$$\begin{aligned}\hat{\psi}^f_t &= \hat{\varepsilon}_t + \hat{p}^{f*}_t - \hat{p}^f_t,\\ &= \hat{rer}_t - \hat{pr}^f_t \ .\end{aligned} \tag{A.17}$$

Inflation aggregation equations

From the inflation aggregation equations we have:

$$\hat{\pi}_t = (1-\gamma_c)\hat{\pi}^h_t + \gamma_c\hat{\pi}^f_t \ .$$

[43] $\hat{rer}_t = \hat{\varepsilon}_t + \hat{p}^{f*}_t - \hat{p}_t$ and $\hat{pr}^f_t = \hat{p}^f_t - \hat{p}_t$.

Eq. A.18 can be re-written as

$$0 = (1-\gamma_c)\hat{pr}_t^h + \gamma_c(\hat{pr}_t^f) \; . \tag{A.18}$$

Evolution of relative prices

$$\hat{pr}_t^h = \hat{pr}_{t-1}^h + \hat{\pi}_t^h - \hat{\pi}_t \tag{A.19}$$

$$\hat{pr}_t^f = \hat{pr}_{t-1}^f + \hat{\pi}_t^f - \hat{\pi}_t \tag{A.20}$$

$$r\hat{e}r_t = r\hat{e}r_{t-1} + \Delta\hat{\varepsilon}_t + \hat{\pi}_t^{f*} - \hat{\pi}_t \tag{A.21}$$

$$\hat{s}_t = \hat{pr}^f - \hat{pr}^h \tag{A.22}$$

$$\hat{w}_t = \hat{w}_{t-1} + \hat{\pi}_t^w - \hat{\pi}_t \; , \tag{A.23}$$

where Eq.A.21 is the equation of motion for the relative purchasing power parity condition[44] Here, we can think of nominal exchange rate changes ($\Delta\hat{\varepsilon}_t$) as the price adjustment mechanism that maintains equilibrium between foreign and domestic goods markets.

Evolution of capital

$$\hat{k}_{t+1} = (1-\delta)\hat{k}_t + \delta\hat{v}_t + \delta\hat{\xi}_t^v \tag{A.24}$$

Policy rule

The central bank conducts monetary policy according to a Taylor (1993) rule:

$$\hat{i}_t^b = \rho_i \hat{i}_{t-1}^b + (1-\rho_i)\kappa_\pi \hat{\pi}_t + (1-\rho_i)\kappa_y(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^i \; . \tag{A.25}$$

The short-term nominal interest rate rises (falls) whenever inflation and output growth rise above (fall below) their average, or steady-state.

Foreign economy

We assume a large open economy for the foreign market. This allows us to specify the foreign rate, $\hat{i}_t^{b*}$, foreign inflation $\hat{\pi}_{t+1}^* = \hat{\pi}_{t+1}^{f*}$, and foreign consumption $\hat{y}_t^* = \hat{c}_t^*$ according to the standard 3-equation New-Keynesian model, namely: an IS curve, a Phillips curve, and a Taylor-type policy rate rule.

[44] Derived from $r\hat{e}r_{t+1} = r\hat{e}r_t + (\hat{i}_t^b - \hat{\pi}_{t+1}) - (\hat{i}_t^{b*} - \hat{\pi}_{t+1}^{f*} + \hat{\Phi}_t)$, where $(\hat{i}_t^b - \hat{\pi}_{t+1})$ and $(\hat{i}_t^{b*} - \hat{\pi}_{t+1}^{f*})$ are the domestic and foreign real interest rates on bonds, i.e., the Fisher equations; $\hat{\Phi}_t = \hat{\mu}_t^{b*} - \hat{\mu}_t^b$

$$\hat{y}_t^* = \frac{1}{(1+\phi^*)}\hat{y}_{t+1}^* + \frac{\phi^*}{(1+\phi^*)}\hat{y}_{t-1}^* - \frac{(1-\phi^*)}{\sigma_c^*(1+\phi^*)}(\hat{i}_t^{b*} - E_t[\hat{\pi}_{t+1}^*] + \hat{\mu}_t^{b*}) \tag{A.26}$$

$$\hat{\pi}_t^* = \frac{\gamma^*}{(1+\gamma^*\beta)}\hat{\pi}_{t-1}^* + \frac{\beta}{(1+\gamma^*\beta)}E_t[\hat{\pi}_{t+1}^*] + \kappa_*\hat{mc}_t^*, \tag{A.27}$$

where $\hat{mc}_t^*$ is the real marginal cost of production, and $\kappa_* = \frac{(1-\theta_*)(1-\theta_*\beta)}{\theta_*(1+\gamma^*\beta)}$.

$$\hat{mc}_t^* = \left(\frac{\sigma_c^*}{1-\phi^*} + \sigma_n^*\right)\hat{y}_t^* - \left(\frac{\sigma_c^*\phi^*}{1-\phi^*}\right)\hat{y}_{t-1}^* - (1+\sigma_n^*)\hat{a}_t^*, \tag{A.28}$$

$$\hat{i}_t^{b*} = \rho_{i*}\hat{i}_{t-1}^{b*} + (1-\rho_{i*})\kappa_\pi^*\hat{\pi}_t^* + (1-\rho_{i*})\kappa_y^*(\hat{y}_t^* - \hat{y}_{t-1}^*) + \epsilon_t^{i*}, \tag{A.29}$$

Aggregate equilibrium

$$\begin{aligned}\hat{y}_t^h &= \frac{C^h}{Y^h}\hat{c}_t^h + \frac{C^{h*}}{Y^h}\hat{c}_t^{h*} \\ &= \frac{C^h}{Y^h}\hat{c}_t^h + \frac{(1-C^h)}{Y^h}(\hat{y}_t^* - \xi^{f*}(\hat{pr}_t^h - \hat{rer}_t)) \ ,\end{aligned} \tag{A.30}$$

where ξ^{f*} is the foreign price elasticity of demand for domestic goods (i.e., the change in foreign demand for domestic goods given the foreign price of domestic goods relative to the foreign price of foreign goods).

$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{V}{Y}\hat{v}_t + \frac{X}{Y}\hat{x}_t - \frac{M}{Y}\hat{m}_t \tag{A.31}$$

$$\hat{x}_t = \hat{c}_t^{h*} = \hat{y}_t^* - \xi^{f*}(\hat{pr}_t^h - \hat{rer}_t) \tag{A.32}$$

$$\hat{m}_t = \frac{C^f}{M}\hat{c}_t^f \tag{A.33}$$

Exogenous shocks

We include 10 shocks in the model. For the domestic economy, the monetary policy shock (ϵ_t^i), as given in Eq. A.25, is i.i.d, whereas the domestic technology shock, the domestic price markup shock, the wage markup shock and the investment-specific shock follow AR(1) processes: $\hat{a}_t = \rho_a\hat{a}_{t-1} + \epsilon_t^a$; $\hat{\xi}_t^p = \rho_p\hat{\xi}_{t-1}^p + \epsilon_t^p$: $\hat{\xi}_t^w = \rho_w\hat{\xi}_{t-1}^w + \epsilon_t^w$; $\hat{\xi}_t^v = \rho_v\hat{\xi}_{t-1}^v + \epsilon_t^v$. Following Smets and Wouters (2007), we include the exogenous spending shock in the aggregate resource constraint: $\hat{\xi}_t^g = \rho_g\hat{\xi}_{t-1}^g + \epsilon_t^g + \rho_{g,y}\epsilon_t^a$.[45]

[45] Primarily, this is to avoid stochastic singularity in the closed economy model. In this context, we can think of this exogenous component as being exogenous government spending shocks plus shocks to the trade balance not implied

Notably, $\rho_{g,y}$ captures spillover effects from domestic technology shocks.[46] The foreign economy follows with an i.i.d monetary policy shock (ϵ_t^{i*}) and the following supply shock: $\hat{a}_t^* = \rho_{a*}\hat{a}_{t-1}^* + \epsilon_t^{a*}$. In addition, the risk premium shocks on domestic-currency assets relative to the policy rate and for foreign-currency borrowing abroad (equivalent to negative demand shocks) are described as follows: $\hat{\mu}_t^{b*} = \rho_b\hat{\mu}_{t-1}^{b*} + \epsilon_t^{b*}$ and $\hat{\mu}_t^b = \rho_b\hat{\mu}_{t-1}^b + \epsilon_t^b$.

C The Financial Frictions Model

Households

Labour supply

$$\hat{w}_t = aa\frac{\gamma}{1-\phi}(\hat{c}_t - \phi\hat{c}_{t-1}) + \eta\hat{h}_t - aa(\frac{1}{R^h} - \beta_h)\nu_h\phi_w(\hat{\lambda}_t^h + \hat{\nu}_{h,t}), \tag{A.34}$$

where aa is $1/(1 + (\frac{1}{R^h} - \beta_h)\nu_h\phi_w)$, and $\hat{w}_t$ is the real wage.

Households' Euler equation

$$(\frac{1}{R^h} - \beta_h)\hat{\lambda}_t^h = \beta_h(\frac{\gamma}{1-\phi}(\hat{c}_{t+1} - \phi\hat{c}_t) + \hat{\pi}_{t+1}) - \frac{1}{R^h}(\frac{\gamma}{1-\phi}(\hat{c}_t - \phi\hat{c}_{t-1}) + \hat{i}_t^h). \tag{A.35}$$

Safe-assets demand

$$\hat{b}_t = \frac{\gamma}{(1-\phi)(1-\beta_h R)}(\hat{c}_t - \phi\hat{c}_{t-1}) + \frac{\beta_h R}{1-\beta_h R}(\hat{i}_t - \hat{\pi}_{t+1} - \frac{\gamma}{1-\phi}(\hat{c}_{t+1} - \phi\hat{c}_t)) - \hat{\xi}_{b,t}, \tag{A.36}$$

where $1/(1-\beta_h R)$ is the asset-consumption ratio of households and is calibrated from the data as 0.856.

Equity price

$$\begin{aligned} \hat{q}_t^\psi &= E_t[\hat{q}_{t+1}^\psi - \frac{\gamma}{1-\phi}(\hat{c}_{t+1} - \phi\hat{c}_t)] + \frac{\gamma}{(1-\Gamma_\psi)(1-\phi)}(\hat{c}_t - \phi\hat{c}_{t-1}) \\ &+ \frac{\Gamma_\psi}{1-\Gamma_\psi}(\hat{\lambda}_t + \hat{\nu}_{h,t}) - \hat{\xi}_{\psi,t}, \end{aligned} \tag{A.37}$$

where $\Gamma_\psi = ((1/R^h) - \beta_h)\nu_h(1-\phi_w)$.

Borrowing constraint

$$\hat{l}_t^h = \frac{\phi_w}{R^h}(\hat{w}_t + \hat{h}_t) + \frac{(1-\phi_w)}{R^h}\hat{q}_t^\psi - \hat{i}_t^h + \frac{1}{R^h}\hat{\nu}_{h,t}. \tag{A.38}$$

by the structural model.

[46] Following (Steinbach et al., 2014, p. 24), we fix ρ_g but estimate the cross-correlation coefficient.

Entrepreneurs in firm production

Labour demand

$$\hat{h}_t = \hat{y}_t - \hat{x}_t - \hat{w}_t, \tag{A.39}$$

Entrepreneurs' Euler equation

$$(\frac{1}{R^e} - \beta_e)\hat{\lambda}_t^e = \beta_e(\gamma^e(\hat{c}_{t+1}^e) + \hat{\pi}_{t+1}) - \frac{1}{R^e}(\gamma^e(\hat{c}_t^e) + \hat{i}_t^e), \tag{A.40}$$

Investment schedule

$$\begin{aligned} \hat{v}_t - \hat{k}_t &= \frac{\beta_e}{(1-\Upsilon_k)}E_t[\hat{v}_{t+1} - \hat{k}_{t+1}] + \frac{(1-\beta_e(1-\delta_e)-\Upsilon_k)}{(1-\Upsilon_k)\kappa_v}(\hat{y}_{t+1} - \hat{x}_{t+1} - \hat{k}_{t+1}) \\ &+ \frac{\Upsilon_k}{(1-\Upsilon_k)\kappa_v}(\hat{\lambda}_t^e + \hat{\nu}_{e,t}) + \frac{\beta_e(1-\delta_e)\gamma^e}{(1-\Upsilon_k)\kappa_v}(\hat{c}_t^e - \hat{c}_{t+1}^e)\ , \end{aligned} \tag{A.41}$$

where $\Upsilon_k = ((1/R^e) - \beta_e)\nu_e\phi_k$ and the shadow price of capital is:

$$\hat{q}_t^k = \kappa_v(\hat{v}_t - \hat{k}_t) - \gamma^e\hat{c}_t^e, \tag{A.42}$$

where $\Upsilon_k = 0$ is the same as Iacoviello (2005, p. 760 (A3)).

Production function

$$\hat{y}_t = \alpha\hat{k}_t + (1-\alpha)\hat{h}_t + \hat{\xi}_t^a\ . \tag{A.43}$$

Borrowing constraint

$$\hat{l}_t^e = \frac{\phi_k}{R^e}(\hat{q}_t^k + \hat{k}_t) + \frac{(1-\phi_k)}{R^e}\hat{q}_t^\psi - \hat{i}_t^e + \frac{1}{R^e}\hat{\nu}_{e,t} \tag{A.44}$$

Capital accumulation

$$\hat{k}_{t+1} = (1-\delta_e)\hat{k}_t + \delta_e\hat{v}_t \tag{A.45}$$

The entrepreneur flow of funds constraint

$$\frac{C^e}{Y}\hat{c}_t^e = \frac{(1-\alpha)}{X}(\hat{y}_t - \hat{x}_t) + \frac{L^e}{Y}(\hat{l}_t^e - R^e\hat{i}_{t-1}^e - R^e\hat{l}_{t-1}^e + R^e\hat{\pi}_t) - \frac{\delta_e K}{Y}\hat{v}_t - \frac{Q^\psi\Psi^e}{Y}\zeta_\psi\hat{q}_t^\psi \tag{A.46}$$

Retailers and labour unions

The forward-looking Phillips curve with price indexation

$$\pi_t = \frac{\beta_R}{(1+\beta_R\gamma_p)}E_t\pi_{t+1} + \frac{\gamma_p}{(1+\beta_R\gamma_p)}\pi_{t-1} - \frac{(1-\theta_p)(1-\theta_p\beta_R)}{(1+\beta_R\gamma_p)\theta_p}\ x_t + \varepsilon_t^p. \tag{A.47}$$

The forward-looking sticky (real) wage equation with price indexation (where $\hat{w}_t = w_t - p_t$)

$$\begin{aligned} \hat{w}_t &= \Phi\beta E_t\hat{w}_{t+1} + \Phi\hat{w}_{t-1} + \Phi\Phi^*(mrs_t - \hat{w}_t) \\ &\quad + \Phi\beta E_t\pi_{t+1} - \Phi\pi_t - \Phi\theta_w\beta\gamma_w\pi_t + \Phi\gamma_w\pi_{t-1} \ , \end{aligned} \tag{A.48}$$

where $\Phi^* = \frac{(1-\theta_w)(1-\theta_w\beta)}{\theta_w(1+\xi^w\sigma_n)}$, $\Phi = \frac{1}{(1+\beta)}$, and $mrs_t = \frac{\gamma}{1-\phi}(c_t - \phi c_{t-1}) + \eta h_t$.

The real wage ($\hat{w}_t = w_t - p_t$) setting equation can be re-written in nominal wage inflation form as:

$$\hat{\pi}_t^w - \gamma_w\hat{\pi}_{t-1} = \beta E_t\hat{\pi}_{t+1}^w - \theta_w\beta\gamma_w\hat{\pi}_t + \Phi^*(m\hat{r}s_t - \hat{w}_t) \ . \tag{A.49}$$

Banking sector

Interbank rate

$$i_t^c = i_t - \frac{\kappa_k}{r}\tau^3(k_t^B - l_t - \xi_{\tau,t}) \tag{A.50}$$

Bank capital accumulation

$$k_t^B = (1-\delta_B)k_{t-1}^B + \delta_B\omega_{B,t-1} + \phi_\psi(q_t^\psi - q_{t-1}^\psi) - (1-\phi_\psi)\pi_t \tag{A.51}$$

Profit function

$$\frac{\omega_B}{L}\omega_{B,t} = r^h\frac{L^h}{L}(i_t^h + l_t^h) + r^e\frac{L^e}{L}(i_t^e + l_t^e) - r\frac{B}{L}(i_t + b_t) - \frac{Q^\psi\Psi_B}{L}\zeta_\psi(q_t^\psi) \tag{A.52}$$

Retail loan rate setting to households

$$\begin{aligned} \hat{i}_t^h = &\frac{\kappa_h}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}\hat{i}_{t-1}^h + \frac{\beta_B\kappa_h}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}E_t\hat{i}_{t+1}^h \\ &+\frac{2(\varepsilon^h-1)}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}\hat{i}_t^c + \frac{(1-\nu_B)(\varepsilon^h-1)}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}\mu_{h,t}, \end{aligned} \tag{A.53}$$

where $\mu_{h,t} = \varepsilon_t^h/(\varepsilon_t^h - 1)$ is the stochastic markup shock.

Retail loan rate setting to entrepreneurs

$$\begin{aligned} \hat{i}_t^e = &\frac{\kappa_e}{(1-\nu_B)(\varepsilon^e-1)+(1+\beta_B)\kappa_e}\hat{i}_{t-1}^e + \frac{\beta_B\kappa_e}{(1-\nu_B)(\varepsilon^e-1)+(1+\beta_B)\kappa_e}E_t\hat{i}_{t+1}^e \\ &+\frac{2(\varepsilon^e-1)}{(1-\nu_B)(\varepsilon^e-1)+(1+\beta_B)\kappa_e}\hat{i}_t^c + \frac{(1-\nu_B)(\varepsilon^e-1)}{(1-\nu_B)(\varepsilon^e-1)+(1+\beta_B)\kappa_e}\mu_{e,t}, \end{aligned} \tag{A.54}$$

where $\mu_{e,t} = \varepsilon_t^e/(\varepsilon_t^e - 1)$ is the stochastic markup shock.

Interbank spread and retail spread definitions (indexed by $z = h, e$)

$$s_t = i_t^c - i_t, \tag{A.55}$$

$$s_t^z = i_t^z - i_t^c. \tag{A.56}$$

Monetary policy and market clearing conditions

$$i_t = \kappa_i i_{t-1} + \kappa_\pi (1 - \kappa_i)\pi_t + \kappa_y (1 - \kappa_i)(y_t - y_{t-1}) + \xi_{i,t}, \tag{A.57}$$

$$y_t = \frac{C}{Y} c_t + \frac{C^e}{Y} c_t^e + \delta_e \frac{K}{Y} v_t + \frac{K^B}{Y} \delta_B k_{t-1}^B, \tag{A.58}$$

$$l_t = \frac{L^h}{L} l_t^h + \frac{L^e}{L} l_t^e. \tag{A.59}$$

D Tables and Figures

Table D.1: Calibrated parameters

Parameter	Description	Value
Households & Firms		
β_h	Discount factor	0.99
δ	Rate of depreciation	0.03
α	Share of capital in firm production	0.30
Price setting		
ξ^p	Price elasticity of demand for goods	11
ξ^w	Wage elasticity of demand for labour	5
Shocks		
ρ_g	Exogenous spending persistence	0.82

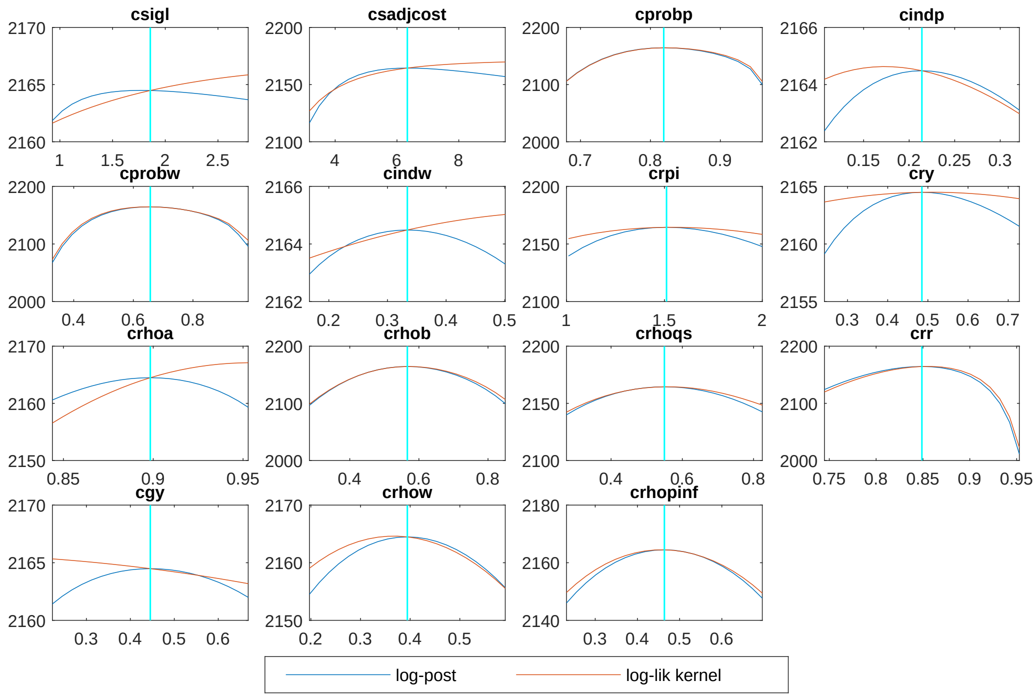

Figure D.1: Log-posterior likelihood functions and log-likelihood kernels.

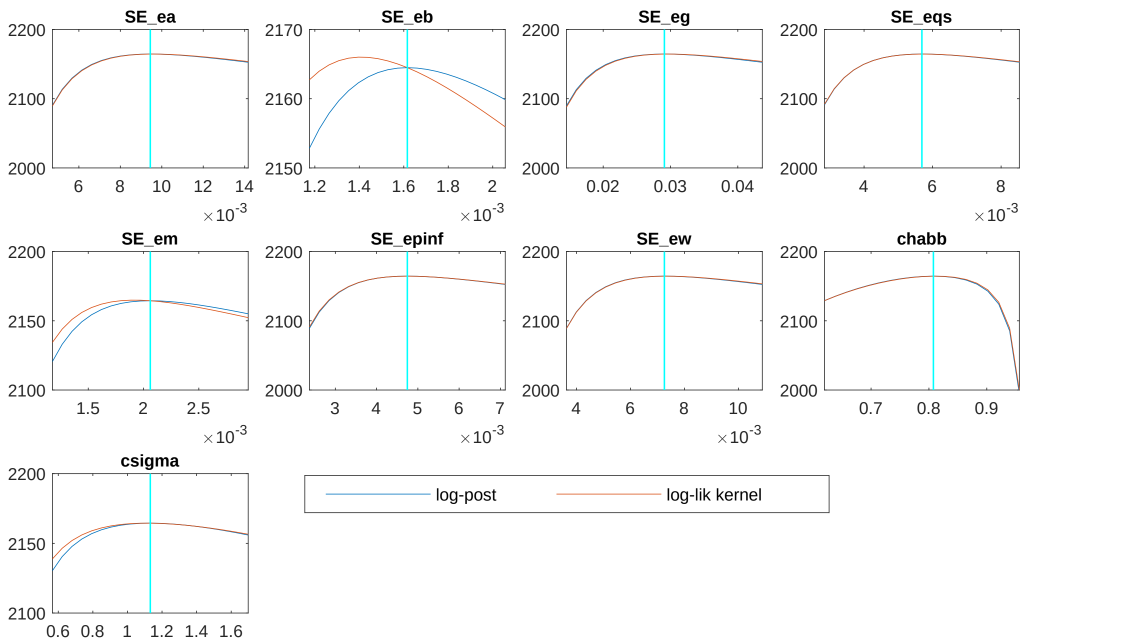

Figure D.2: Log-posterior likelihood functions and log-likelihood kernels. If the estimated mode is the local mode, it should be at the maximum of the posterior likelihood.

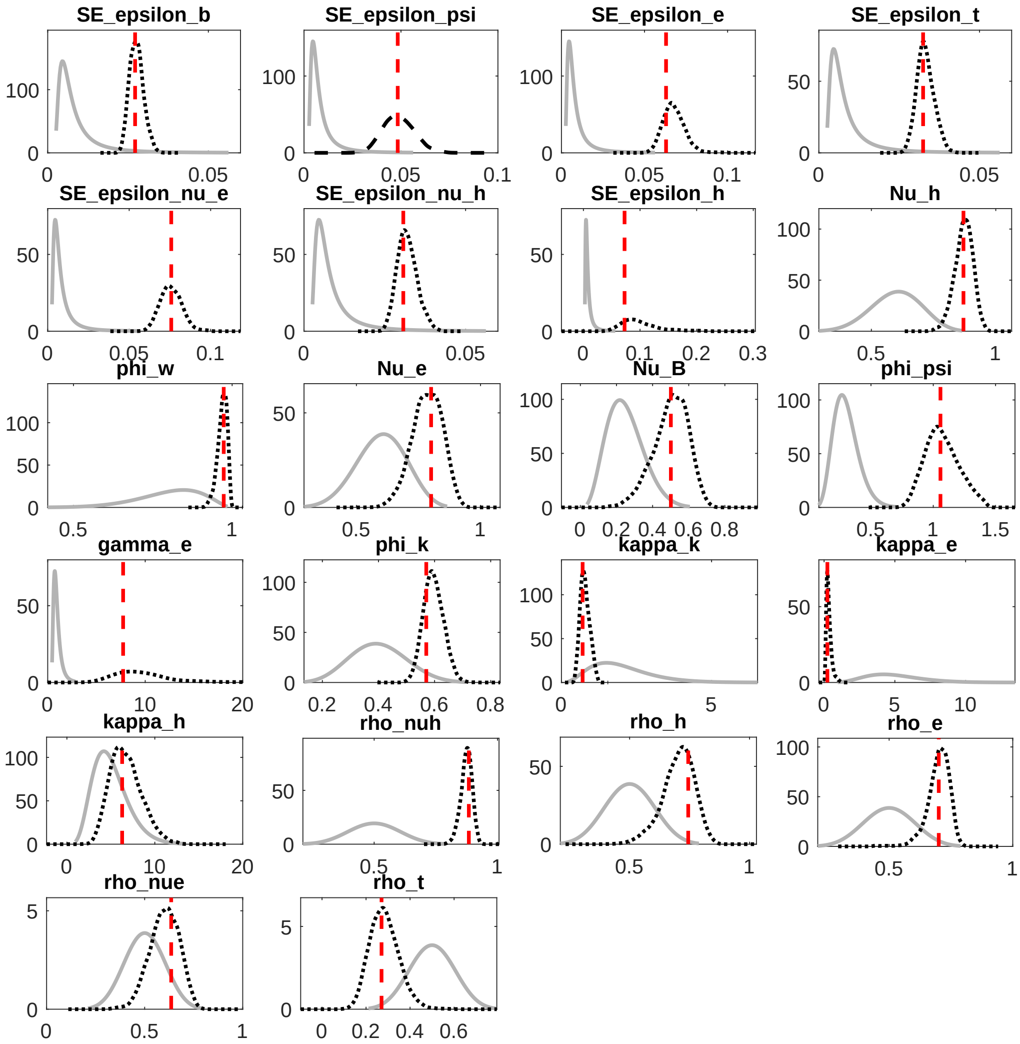

Figure D.3: Additional posterior distribution statistics for *FF-NK*.

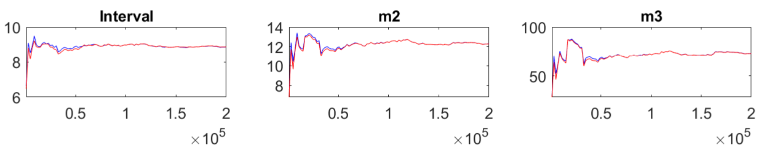

Figure D.4: Multivariate convergence diagnostic for *SW-NK*.

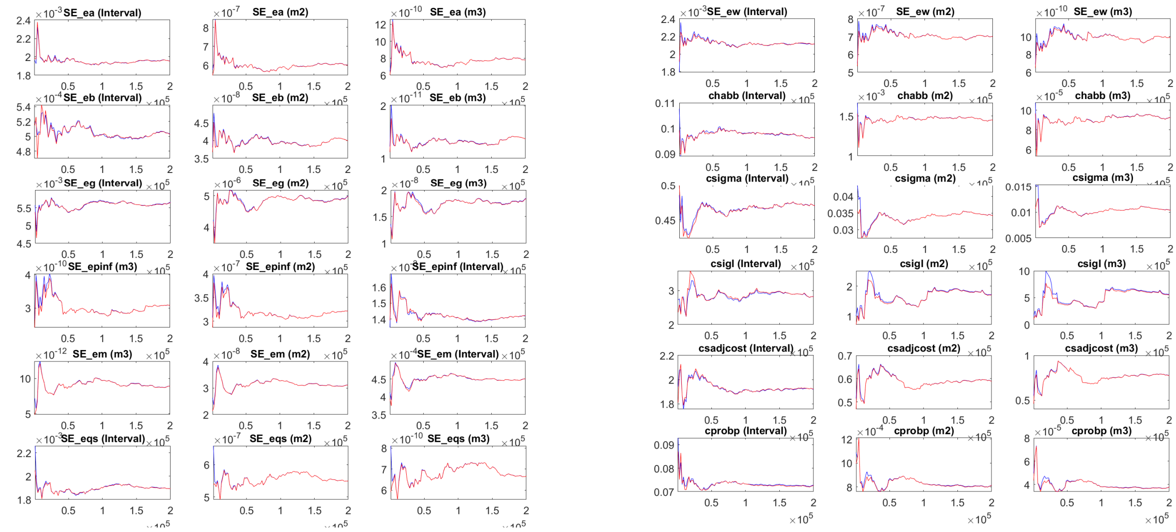

Figure D.5: Univariate convergence diagnostics for *SW-NK*.

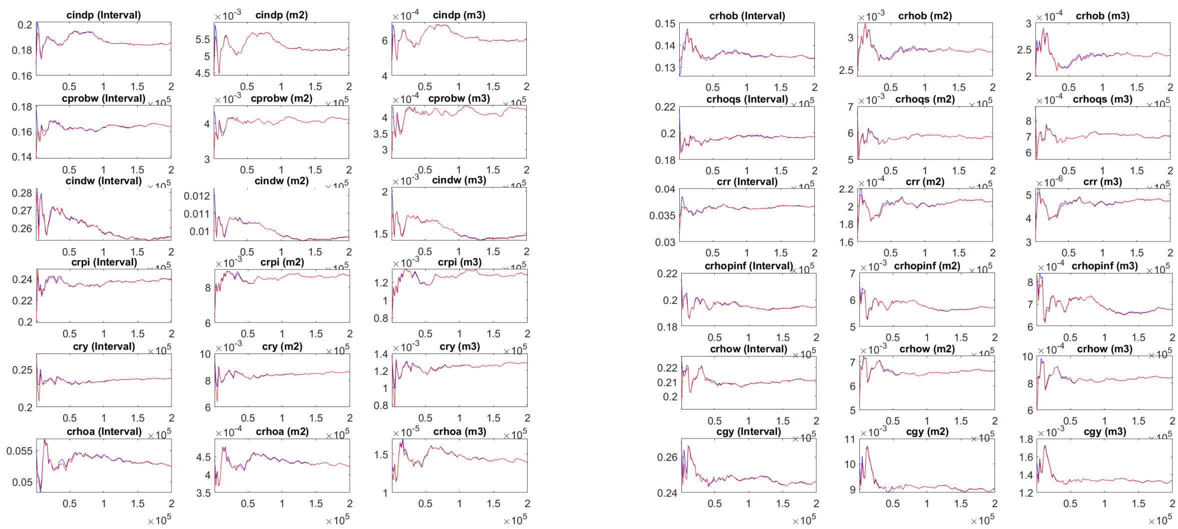

Figure D.6: Univariate convergence diagnostics for *SW-NK*.

E Data and Sources

Data sources retrieved from the Federal Reserve Bank of St. Louis (FRED), the South African Reserve Bank (SARB), Eurostat and OECD.stat:

1. Consumer Price Index of All Items in the United States [CPIAUCSL], United Kingdom [GBRCPIALL], Euro area [EZCCM086NEST], Japan [JPNCPIALL] and in South Africa [ZAFCPIALL] retrieved from FRED (Copyright, 2018, OECD)

2. Real Gross Domestic Product by Expenditure for the United States [GDPC1], United Kingdom [GBQ661S], Euro area [EURSCAB1GQEA19], Japan [JPQ661S] and South Africa [ZAQ661S], retrieved from FRED (Copyright, 2018, OECD)

3. Interest Rates, Government Securities, 3-Month Treasury Bills for United States [Gs3M], United Kingdom [GBM193N], Euro Area [EZQ193N], Japan [JPM193N], and South Africa [ZAM193N] retrieved from FRED (Copyright, 2018, IMF and Eurostat)

4. Population: United States (Civilian Noninstitutional Population) [CNP16OV], Japan (15 and over) [JPQ647S], United Kingdom (Total) [POPNC; GBQ647S], and Euro area (Total) [POPNC; EZQ647S] (Copyright, 2018, OECD)

5. SARB, Balance of payments statistics [KBP5000L - KBP5010L]

6. SARB, Final consumption expenditure by households: Total (PCE) [KBP6007L]

7. SARB, Gross fixed capital formation (Investment) [KBP6009L]

8. SARB, Banking statistics