A computable general equilibrium model for banking sector risk assessment in South Africa

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Abstract

In this article a banking sector Computable general equilibrium (CGE) model for South Africa is developed. The model is used to estimate the potential effect of regulatory policy on the economy and as a risk assessment tool to assess how changes in regulation affect the economy. The model provides a methodology for regulators of the banking sector and policy makers in South Africa to deal with risk assessment and future regulatory planning. The CGE model allows interactions amongst various entities of the economy so that policy makers could detect the risks in the banking sector. The CGE model used in this paper performed well as a risk assessment tool for the South African banking sector. The results of the various shocks from the model are consistent with the results obtained from similar shocks done in the UK. We establish that default penalty has a higher effect on the banks' profits and the interest rates than capital requirement infringement penalty. Our results also suggest that interest rate targeting has more controlled effects than monetary base targeting since pecuniary externalities are reduced.

Keywords: Computable general equilibrium; Banking regulation; Systemic risk

1 Introduction

Many models for assessing financial risk in a country, fail to allow for a holistic view of the economy and often consider institutions or economic sectors in isolation. Thus a negative shock from an institution may not be captured adequately by the other institutions when such models are used. This is particularly severe in times of financial crises. In South Africa, economic models also typically exclude a detailed financial sector. In this study, we consider a Computable General Equilibrium (CGE)[1] model that includes a detailed model for the banking sector. This model enables risk assessments such as stress testing, scenario analysis and sensitivity testing that includes individual banks as well as their exposure to other banks and links to the financial sector and private sector agents. This article will analyze the impact of banking regulations on banks and their consumers and apply it as a risk assessment tool.

In South Africa, CGE modelling have been used in several applications (Thurlow 2004) including the effect of providing anti-retroviral treatment for HIV/AIDS patients on the economy, the effect of the implementation of the basic income grant on the economy (Thurlow 2002), and how different labour policies could affect employment in future (Davies and Thurlow 2010). The banking sector model allows further uses such as modelling and analyzing financial fragility (Goodhart et al. 2006a; Lee et al. 2013; Lewis 2010; Saade et al. 2007), determining the effect of monetary and fiscal expansion on an economy (Rumler 1999) and for forecasting real-time inputs for policymakers (Altig et al. 1995).

However, in South Africa, not much research is done in the financial sector with CGE models. Financial regulation in South Africa is changing. It is currently implementing the Twin Peaks model where the Reserve Bank is responsible for prudential regulation and the Financial Service Board (FSB) the conduct of business (Financial Regulatory Reform Steering Committee and others 2013). As part of the Twin Peaks framework, an advisory committee called the Financial Stability Oversight Committee (FSOC) has been established. This committee, which comprises of the Reserve Bank, the FSB and the National Treasury is responsible for financial stability and mitigation of financial risks (Gordhan 2011). The FSOC makes use of many models for stress testing and uncertainties in general and do economic modelling. The development of a CGE model may provide a useful tool for them.

We did not concentrate on the real estate sector, as South African banks were not significantly affected following the 2008 financial crisis. As a result of the restrictions on foreign exchange (Saayman 2010) and associated capital controls, South African banks did not invest significantly in sub-prime securities, which was one of the main causes of the crisis. Owing to the fact that CGE models take into account interactions from other banks and the private sector agents, it could potentially provide early warning for systemic risk.

Systemic risk is a major factor in financial stability and very little is known about how models assess such risk (Allen et al. 2014). It occurs if many banks fail together or if one bank's failure brings about the failure of other banks (Acharya 2009). The 2008 financial crisis highlighted that systemic risk takes many forms (Georg 2013). One example is interbank contagion which occurs as a result of the linkages between banks from interbank lending, e.g. a default from one bank causing losses and further defaults from other banks. Another example is a common shock to the banking sector in general as a result of banks having similar asset holdings. Prior to the 2008 financial crisis, macroprudential regulation concentrated on single institutions (Allen and Carletti 2012) and failed to deal with systemic risk. In recent times systemic risk is taken into consideration when looking at regulation. Properly implemented capital regulation may lower systemic risk. Evidence indicates that banks are transferring credit risk to insurance companies. On one hand, this transfer is desirable as it allows for diversification amongst various sectors of the financial industry. However, it is argued that shifting the risks to insurance companies may impact the banking sector in the form of counter-party credit risk (Hellwig 1994, 1995, 1998). It was demonstrated that the transfer of risk indeed leads to optimal allocation of capital as a result of diversification, but if not properly designed could increase systemic risk (Allen and Gale 2007).

Central Bank intervention can reduce systemic risk (Georg 2013). However, regulators are sometimes accused of contributing to it unintentionally (Kaufman and Scott 2003), rather than alleviating it. Government liquidators may also not have the necessary expertise and may have no incentives to maximize profit (Kaufman and Scott 2003). Regulators are responsible for providing appropriate intervention no matter the source of a financial crisis (Freixas et al. 2000). Regulators should therefore be careful as to what methods they use in order not to contribute but rather curb this problem. Central Banks and regulators need to concentrate on monetary and regulatory policy that avoid crises. Some measures which can be taken to avoid and/or moderate systemic risk include the proper implementation of capital adequacy requirements through the use of CGE models.

We use the CGE model to conduct comparative analyses for the South African banking sector. The approach used is similar to Catarineu-Rabell et al. (2005) and Goodhart et al. (2006a) where a finite time horizon is used to calibrate the model. The contagion effect of one institution on the rest of the institutions as well as the actions of the banking customers is addressed and so should therefore give an early warning signal for the systemic risk, when used for regulation and risk assessment.

The CGE model used in this paper performed well as a risk assessment tool for the South African banking sector. The results of the various shocks which were also done in the UK (Goodhart et al. 2005) were in accordance with those obtained from our model. We observe that the effect of a rise in the default penalty was higher than that of the capital requirements infringement penalty on almost all the key variables. This could be attributed to the fact that banks view the possibility of being penalized for defaulting more seriously than infringing their capital requirements and thus act accordingly. Moreover, we also observe that banks react differently depending on whether the Reserve Bank sets its base money or the interbank rate as its monetary policy instrument. When the Reserve Bank sets the interbank rate as its policy instrument, the banks do not benefit much in the interbank market and focus on the loan and deposit markets. This suggests that interest rate targeting has more controlled effects than monetary base targeting akin to the findings of Goodhart et al. (2011).

The rest of the paper is organized as follows. Sect. 2 gives a detailed description of the CGE model for the banking sector and Sect. 3 characterizes the equilibrium conditions. In Sect. 4, we calibrate the model for the South African context and construct the initial equilibrium position. Subsequently, the model is used as a risk assessment tool for the South African banking sector in Sect. 5 and finally, in Sect. 6, we offer concluding remarks.

2 The model

The model used in this paper is an extension of the Goodhart, Sunirand and Tsomocos model. The model as illustrated (Aspachs et al. 2007; Goodhart et al. 2005, 2006a, b; Lewis 2010; Tabak et al. 2013) consists of three heterogeneous banks, four private sector agents, a Central Bank and a regulator. The banks are denoted by γ, δ, and τ and the agents by α, β, θ, and ϕ.

The three banks can represent many groupings of banks. In Goodhart et al. (2005, 2006a, b), the chosen banks are the seven largest banks in the UK. Two of the banks were taken as γ and δ and the rest were combined as τ. In Jamaica (Lewis 2010), the banks were categorized into three main groupings—commercial banks, merchant banks and building societies. They were grouped as public, private and foreign banks in Brazil (Tabak et al. 2013). Hence in principle, the banks can refer to any banking system of any country or region. In the case of South

Africa, all the major banks are represented in the model. In a case where a particular bank needs to be analysed, that bank should be taken as one of the three heterogeneous banks. In Colombia (Saade et al. 2007), banks were grouped into mortgage banks, domestic banks and foreign banks. Such grouping is essential if one is interested in analyzing the crisis in the real estate sector. However, in South Africa, the effect of the 2008 financial crisis was muted due to the aforementioned reasons and so it is not deemed necessary to have mortgage banks as a separate group. Nonetheless, almost all the banks in South Africa have mortgage loans in their balance sheet and there are no banks that exclusively specialize in mortgage lending. In this paper, we considered the largest six banks by assets which is in line with the analysis done in the UK. Two of the banks are taken as heterogeneous banks and the rest of the banks (four in total) are combined as the last of the three heterogeneous banks.

The private sector agents are individuals/households or firms who deposit funds or borrow from the banks. For simplicity, each of the first three agents are constrained to deal with a particular bank[2] and the fourth agent deals with any of the banks. This means agent α can only borrow from bank γ, agent β from bank δ, and agent θ from banks τ. The remaining agent, ϕ supplies funds to any of the banks.

There is also the interbank market where the Central Bank conducts open market operations (OMOs). Individual banks can borrow from each other, where a bank in deficit can borrow from a bank with a surplus or from the Central Bank. The model is presented in Fig. 1

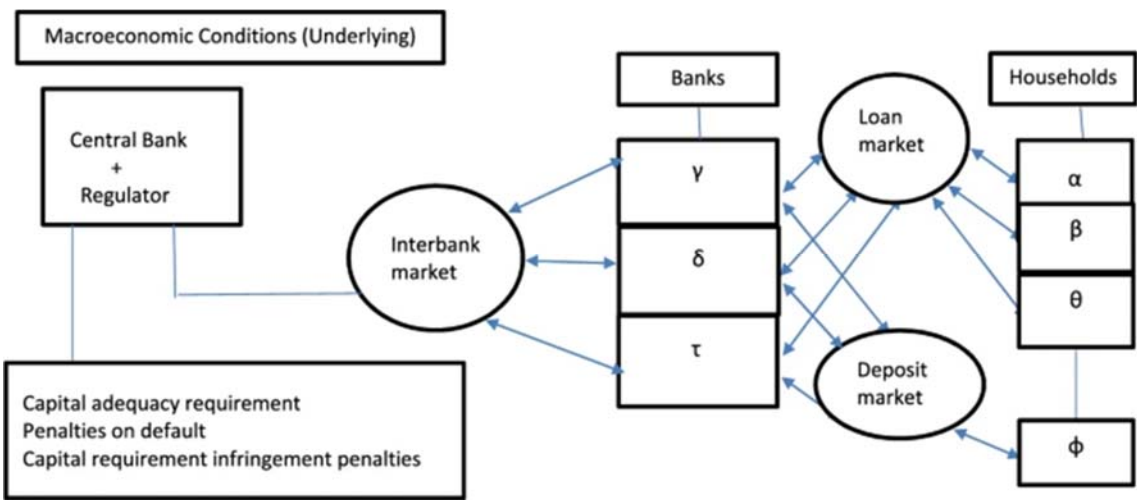

Fig. 1. The structure of the model (See Lewis 2010)

This representation of the structure of the model (Lewis 2010) indicates that the actions of the Central Bank and/or the Regulator affect the bank indirectly through the interbank markets. It needs to be noted that the actions of the Central Bank affect the banks directly as well, for example, through the imposition of the penalties. In addition ϕ represents the aggregate of all the depositors. Hence, the deposits from the private sector agents to their nature-selected banks are included in ϕ.

The time horizon can be infinite, with $t \in T = \{1,\ldots,\infty\}$ as in Goodhart et al. (2006b) or finite, e.g. $t = \{1,2\}$ as in Goodhart et al. (2005). In the case of two time periods, it may only be used to calibrate features of the country's banking sector at a particular point in time and offer policy insight via sensitivity analysis with respect to exogenous parameters. However, an infinite horizon model may be used to calibrate time series of certain variables and consequently be employed by forecasters. We hasten to add that the computational complexity of the period increases considerably. Hence the modeler needs to simplify the banking sector and, therefore, may potentially miss important contagious effects among heterogeneous banks. We adopt the finite horizon approach as in Goodhart et al. (2005) whereby there exist two possible future states. One state is the good/normal state and the other is the crisis state of nature. The good state is denoted by *i* and its corresponding probability $p = 0.95$ and the bad state by *ii* and its probability $1-p= 0.05$. These probabilities are assumed to be time invariant and common knowledge by the economic agents. They possess Von Neumann-Morgenstern preferences and the time structure of the model is presented in Fig. 2.

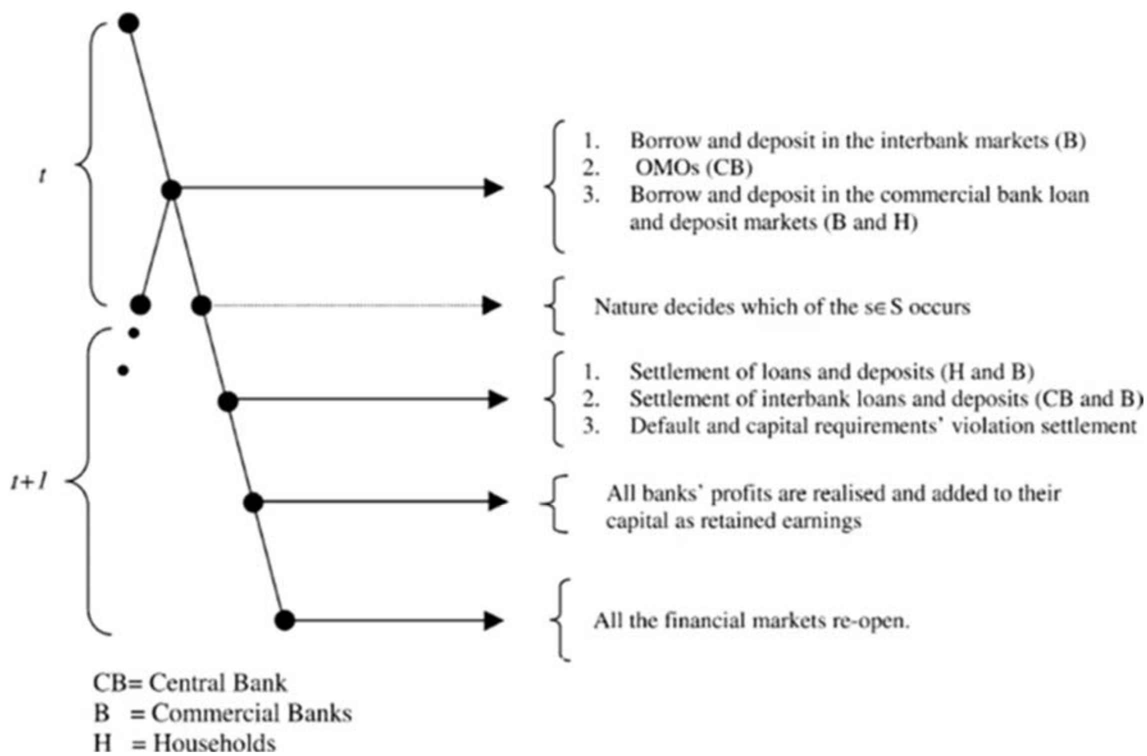

Fig. 2. Time structure of the model

Once the markets open at the end of period *t* or beginning of period *t* + 1, each bank decides how much to borrow or lend taking into account the fact that each of the two states could occur during period *t* + 1. The Central Banks also conducts OMOs in the interbank market during this period. All contracts are settled allowing for penalties for any defaults or capital infringements.

The balance sheet structure for a bank is given in Table 1. Capital is carried over, i.e. for each period, capital is equal to the capital at the start of the period plus the retained earnings, except for the initial period where the bank is given some initial capital to start operations. This process is repeated indefinitely for the case where the period is infinite. Capital is thus one of the variables that is both exogenous and endogenous in the model. The initial capital is exogenous as banks are given initial capital to start their operations. However, subsequent capital becomes endogenous as its value is determined by the model.

Table 1. Balance sheet structure of the bank

Assets	Liabilities
Loans to agent	Deposit from ϕ
Interbank deposits	Interbank borrowing
Market book	Equity
	Others

2.1 The banking sector

Each bank is unique in terms of the size of their capital and business portfolio. The level of risk taken by each bank is also different and as such they expect different returns. The business environment is assumed to be highly competitive and so each bank chooses its interest rate when making portfolio decisions in order to maximize its profits. As mentioned earlier, the six largest South African banks by assets are used for the analysis. Two of the banks are taken individually and the rest are combined as the third homogenous bank in the model.

Banks are allowed to default on their deposit and interbank borrowings but with the provision that they will be subjected to the default penalties set by the regulator. Default is defined as the inability of the institution to honour its financial contractual obligations. However, it could be strategic or due to ill fortune and lenders are assumed to be unable to distinguish between the two. Strategic default occurs when institutions choose not to honour their obligations even though they have the means to do so, while ill fortune default occurs when a bank is genuinely unable to honour its obligations as a result of not having adequate funds.

The default rate is akin to the probability of the bank shutting down[3]. If banks are not able to repay their loans fully when due, they are forced to shut down. The default rate for deposits and that for the interbank market for each bank are assumed to be the same. [4] In other words, banks pay their creditors *pro rata*. They cannot choose to pay their depositors and decide not to pay their fellow banks and/or the Central Bank. There is the freedom for each bank to infringe on their capital adequacy requirements. However each infringement is punished by the regulator imposing a capital requirements infringement penalty. In reality, most banks capital is above the minimum regulatory capital requirements. This is the case because banks maintain excess capital in accordance to their risk management models, and for signalling purposes in the capital markets. Therefore, we subject the banks, to reputation costs (i.e. capital requirements penalties) whenever they fall below the "market determined capital requirements threshold". The size of the penalty is proportional to the deviations from the "market determined capital requirements threshold".

The time horizon over which banks maximize their expected profit is taken as one year.[5] There are only two states (the good state and the bad state) and so the expectation is taken over only these two states. The privater sector agents optimization of their utility is not explicitly modeled as it is extremely difficult to obtain data such as amounts borrowed by individual households. As a result, reduced form equations are used.

2.1.1 Banks optimization problem

Each bank maximizes its expected payoff at the end of period t or beginning of period $t+1$. The expected payoff of the bank is a quadratic function of its expected profitability in the next period less the unbudgeted penalties it may suffer for defaulting on the deposit and interbank markets. Then there is also the capital infringement penalty which is a linear function of the capital requirements infringement. The expectation is taken over the two possible states in $t+1$. The optimization problem of bank b in period t is

$$\underset{\bar{m}_t^b, d_t^b, \mu_t^b, \mu_{d,t}^b, v_{t+1,s}}{Max} E_t(\Pi_{t+1}^b) = Max \left[\sum_{s \in S} p_s \left[\pi_{t+1,s}^b - c_s^b (\pi_{t+1,s}^b)^2 \right] - \sum_{s \in S} p_s \left[\lambda_{ks}^b max \left(0, \bar{k}_{t+1,s}^b - k_{t+1,s}^b \right) + \lambda_s^b \left(\mu_t^b - v_{t+1,s}^b \mu_t^b \right) + \lambda_s^b \left(\mu_{d,t}^b - v_{t+1,s}^b \mu_{d,t}^b \right) \right] \right] \tag{1}$$

(i.e. maximum expected payoff = expected profitability—capital infringement penalty—penalty on default of interbank obligations—penalty on default on deposits). Equation (1) is subject to the following two conditions:

$$\bar{m}_t^b + d_t^b + A_t^b = \frac{\mu_t^b}{(1+\rho_t)} + \frac{\mu_{d,t}^b}{(1+r_{d,t}^b)} + e_t^b + O_t^b \tag{2}$$

(i.e. Assets of the bank (loans to agents, interbank lending, and investments) should be the same as the liabilities of the bank (interbank borrowing, deposit, equity and residual). This is the usual balance sheet constraint for the bank),

$$(1+\rho_t)v_{t+1,s}^b \mu_t^b + (1+r_{d,t}^b)v_{t+1,s}^b \mu_{d,t}^b + e_t^b + O_t^b \leq v_{t+1,s}^{h^b}(1+r_t^b)\bar{m}_t^b + (1+r_t^A)A_t^b + \check{R}_{t+1,s} d_t^b (1+\rho_t),\ s \in S \tag{3}$$

(i.e money paid on liabilities must be less or equal to money received from assets. Banks will only continue to do business if they expect to make profit in the future or in the next time period).

Profit is defined as

$$\pi_{t+1,s}^b = v_{t+1,s}^{h^b}(1+r_t^b)\bar{m}_t^b + (1+r_t^A)A_t^b + \check{R}_{t+1,s} d_t^b (1+\rho_t) - ((1+\rho_t)v_{t+1,s}^b \mu_t^b + (1+r_{d,t}^b)v_{t+1,s}^b \mu_{d,t}^b + e_t^b + O_t^b) \tag{4}$$

(i.e. profit = money received from assets-money paid on liabilities). The capital at period $t+1$ is given by

$$e_{t+1,s}^b = e_t^b + \pi_{t+1,s}^b \tag{5}$$

(i.e. capital at period $t+1$= capital at period t + profit earned). The capital adequacy ratio is

$$k^b_{t+1,s} = \frac{e^b_{t+1,s}}{\hat{\omega} v^{h^b}_{t+1,s}(1+r^b_t)\bar{m}^b_t + \omega \check{R}_{t+1,s} d^b_t (1+\rho_t) + \check{\omega}(1+r^A_t)A^b_t} \tag{6}$$

(i.e. capital adequacy ratio equals the ratio of capital to the risk-weighted assets), and

p_s = probability that state $s \in S$ will occur,
c^b_s = coefficient of risk aversion in the utility function of bank $b \in B$,
λ^b_{ks} = capital requirements violation penalty imposed on bank $b \in B$ in state $s \in S$,
$\bar{k}^b_{t+1,s}$ = capital adequacy requirements for bank $b \in B$ in state $s \in S$,
λ^b_s = default penalties on bank $b \in B$ in state $s \in S$,
μ^b_t = amount of money that bank b owes in the interbank market at time t,
$\mu^b_{d,t}$ = amount of money that bank b owes in the deposit market at time t,
$v^b_{t+1,s}$ = repayment rate of bank b to all its creditors in state s in the period $t+1$,
$\bar{m}^b_t$ = amount of credit that bank b offers in the loan market at time t,
d^b_t = bank b's interbank lending at time t,
A^b_t = the value of market book held by bank $b \in B$ at time t,
e^b_t = capital held by bank b in state s at time t,
O^b_t = the other items in the balance sheet of bank $b \in B$ at time t,
r^b_t = lending rate offered by bank $b \in B$ at time t,
$r^b_{d,t}$ = deposit rate offered by bank $b \in B$ at time t,
ρ_t = interbank rate at time t,
r^A_t = rate of return on market book, A, at time t,
$v^{h^b}_{t+1,s}$ = repayment rate of agent h to his nature-selected bank b in the consumer loan market at time $t+1$,
$\check{R}_{t+1,s}$ = repayment rate by banks from their interbank lending,
$\hat{\omega}$ = risk weight on consumer loans,
$\check{\omega}$ = risk weight on market book, and
ω = risk weight on the interbank lending.

2.2 Private agent sector

In each period, each of the three households that are assigned to a specific bank, demands loans from that particular bank. Each household chooses their default rates on their loans. The other agent, ϕ, who is allowed to deal with all the banks, supplies deposits to the various banks. The actual individual information for the agents such as the size of the loans and deposits for each household are not readily available. As a result, the optimization problem of households is not explicitly modelled. The maximization problems are expressed in reduced form equations.

2.2.1 Household borrowers demand for loans

As the agents are restricted to particular banks in which they could borrow from, each agent's demand for credit/loans will be negatively correlated to the lending rate being offered by its nature-selected bank. In addition, as GDP improves the demand for credit/loans increases.

Therefore the demand for credit/loans will also depend on the GDP of the next time period. A linear trend is included to take into account of the fact that each household's demand for loan also depends on the time period. So in this case the trend value is 0 in the initial period (2016), 1 in 2017, 2 in 2018 and so on. Thus the reduced form equation is of the form

$$\ln(\mu_t^{h^b}) = a_{h^b,1} + a_{h^b,2} trend + a_{h^b,3} \ln[p(GDP)_{t+1,i} + (1-p)(GDP)_{t+1,ii}] + a_{h^b,4} r_t^b, \tag{7}$$

where $\mu_t^{h^b}$ = amount of money that agent $hb \in Hb$ chooses to owe in the loan market of bank $b \in B$ in period t, $GDP_{t+1,s}$ = Gross Domestic Product in period $t+1$ of state $s \in S$, r_t^b=lending rate offered by bank b, $a_{h^b,1}$, $a_{h^b,2}$, $a_{h^b,3}$, and $a_{h^b,4}$ are the coefficients or the elasticities of the model.

2.2.2 Supply of deposits

The fourth agent θ is not restricted on which bank to supply the deposits. Therefore the supply of deposit for bank b depends on the deposit rate that the bank is offering as well as the deposit rate of the other banks. Banks are allowed to default on their obligations in the model. Therefore the expected rate of return on the deposit needs to be adjusted for the corresponding default rate of the banks. Again, as GDP improves it is expected that agent θ will supply more deposits. Thus the deposit supply is positively correlated with future GDP. Hence the reduced form equation for deposit supply is of the form

$$\begin{aligned}\ln(d_{b,t}^{\theta}) &= z_{b,1} + z_{b,2} \ln[p(GDP)_{t+1,i} + (1-p)(GDP)_{t+1,ii}] \\ &+ z_{b,3}\left[r_{d,t}^b(pv_{t+1,i}^b + (1-p)v_{t+1,ii}^b)\right] + z_{b,4}\sum_{\acute{b}\neq b\in B}\left[r_{d,t}^{\acute{b}}(pv_{t+1,i}^b + (1-p)v_{t+1,ii}^{\acute{b}})\right],\end{aligned} \tag{8}$$

where $d_{b,t}^{\theta}$ = amount of money that agent θ chooses to deposit with bank $b \in B$ in period t, $r_{d,t}^b$ = interest rate offered on deposit by bank b in the period t and $r_{d,t}^{\acute{b}}$ = competitor interest rate on deposits, $v_{t+1,i}^b$ = repayment rate of bank b in $t+1,s$ and $v_{t+1,ii}^{\acute{b}}$ is the repayment rate of bank b's competitors, $z_{b,1}$, $z_{b,2}$, $z_{b,3}$, and $z_{b,4}$ are the coefficients or elasticities of the model.

2.2.3 Households loans repayment rates

The repayment rates of each household to the nature-selected bank at period $t+1$ for each possible state is positively correlated to the corresponding GDP. The default rate for every household increases with a fall in the overall credit supply. Therefore the repayment rates of the households also depend on the combined credit supply in the previous period. Hence the reduced form equation of the rates of each household is of the form

$$\ln\left(v_{t+1,s}^{h^b}\right) = g_{h^b,s,1} + g_{h^b,s,2}\ln(GDP_{t+1,s}) + g_{h^b,s,3}[\ln(\bar{m}_t^{\gamma}) + \ln(\bar{m}_t^{\delta}) + \ln(\bar{m}_t^{\tau})], \tag{9}$$

where $v_{t+1,s}^{h^b}$ is the repayment rate of household h^b at $t+1$ to the bank b if state s occurs and $\bar{m}_t^b$ is the amount of credit that bank b develops in period t, and $g_{h^b,s,1}$, $g_{h^b,s,2}$, and $g_{h^b,s,3}$ are the coefficients or the elasticities of the model.

2.3 Central bank and/or regulator

The Central Bank and the regulator could be two different entities. However, in some cases the Central Bank is also the regulator (Lewis 2010). This is the case in South Africa where the Central Bank is the Reserve Bank and also the regulator for the banking sector. In such a case, the Central Bank is responsible for both regulatory and monetary policies. The Central Bank manages monetary policy by conducting OMOs in the interbank market. It sets the interbank rate as its monetary policy instrument in each period by supplying base money or issuing government bonds to clear the interbank market. It does not do both at the same time. The overall liquidity of the economy is also controlled by the Central Bank.

The regulator is responsible for setting the capital adequacy requirements for the banks. It determines and imposes penalties when they fail to meet their capital requirements and/or default on their deposits and interbank borrowings. Its other responsibility is to set the risk weights on consumer loan, interbank market and market book investment.

2.4 Gross domestic product

The future GDP at each possible state is positively correlated to the overall credit supply and so GDP at time $t+1$ is a positive function of the aggregate credit supply of the previous period. A linear trend is included to improve the empirical fit. Hence the reduced form equation is of the form

$$\ln(GDP_{t+1,s}) = \mu_{s,1} + \mu_{s,2} trend + \mu_{s,3}[\ln(\bar{m}_t^{\gamma}) + \ln(\bar{m}_t^{\delta}) + \ln(\bar{m}_t^{\tau})], \quad (10)$$

where μs,1, μs,2 and μs,3 are the coefficients or the elasticities of the model.

3 Equilibrium

3.1 Market clearing conditions

There are seven markets in the model, i.e. three consumer loans, three deposits, and one interbank. Interest rates are determined for the respective markets ensuring there is a balance in demand and supply. The interest rates are adjusted to take account of the permissible defaults allowed in each market. Each of the three different markets (consumer loans, deposits and interbank) determines interest rate that ensures equilibrium.

Loan market clears, i.e.

$$1 + r_t^b = \frac{\mu_t^{h^b}}{\bar{m}_t^b}, h^b \in H^b, \forall b \in B, \quad (11)$$

Deposits market clears, i.e.

$$1 + r_{d,t}^b = \frac{\mu_{d,t}^b}{d_{b,t}^{\Theta}}, \forall b \in B, \tag{12}$$

Interbank market clears, i.e.

$$1 + \rho_t = \frac{\bar{B}_t + \sum_{b \in B} \mu_t^b}{M_t + \sum_{b \in B} d_t^t}, \tag{13}$$

where $\bar{B}_t$ = government bonds, and M_t = money issued by the Central Bank.

3.2 Equilibrium conditions

The equilibrium in the economy in each period is described by a vector of all choice variables of active agents such that banks maximize their payoffs subject to the following conditions: all markets (loan, deposit, and interbank) clear, banks expectations about repayment rates in the interbank market are accurate, and for each household and state the reduced form equations are satisfied.

Formally, let $\sigma^b = \{\bar{m}_t^b, \mu_t^b, d_t^b, \mu_{d,t}^b, v_{t+1,s}^b, \pi_{t+1,s}^b, e_{t+1,s}^b, k_{t+1,s}^b\} \in R_+^4 \times R^4$ for $b \in B$; $\sigma^{h^b} = (\mu_t^{h^b}, v_{t+1,s}^{h^b}) \in R_+ \times R$ for $h^b \in H^b$ and; $\sigma^{\phi} = (d_b^{\phi}) \in R_+$ for $b \in B$; and $GDP_{t+1,s} \in R$.

Also, let $\eta = \{r_t^{\gamma}, r_t^{\tau}, r_t^{\delta}, r_{d,t}^{\tau}, r_{d,t}^{\delta}, M_t, \bar{B}_t\}$, $B^b(\eta) = \{\sigma^2 : (3.7) - (3.10)\text{ hold}\}$. We say that the vector $((\sigma^b)_{b \in B}, \eta, (\sigma^{h^b})_{h^b \in H^b}, \sigma^{\phi}, (GDP_{t+1,s})_{s \in S})$ is a *monetary equilibrium with banks and default* for the economy
$E = \{(e_t^b, O^b, A^b)_{b \in B}; p; (\bar{k}_{t+1,s}^b, \lambda_s^b, \lambda_{ks}^b, \hat{\omega}, \omega, \check{\omega})_{b \in B, s \in S}; r_t^A; \rho\}$
only if,

(i) $\sigma^b \in Argmax\, E_t(\Pi_{t+1}^b(\pi_{t+1}^b))$, $b \in B$ so all banks optimize their payoff function,
(ii) all markets clear according to equations (3.11)–(3.13),
(iii) $\check{R}_s = \frac{\sum_{b \in B} v_{t+1,s}^b \mu_t^b}{\sum_{b \in B} \mu_t^b}$, $s \in S$, (i.e. all banks are correct about their expectations of repayment rates in the interbank market), and
(iv) $\sigma^{h^b}, \sigma^{\phi}$, and $GDP_{t+1,s}$, for $h \in H$ and $s \in S$ satisfy the reduced form equations (3.7)–(3.10).

4 Calibration methodology

If one excludes Lagrange multipliers then from conditions (i)–(iv) of the "Equilibrium condition" section above, we have a system of 56 equations with 143 unknown variables. In order to obtain a unique solution for the model, 87 of the 143 parameters/variables which are exogenous need to be chosen. The parameters/variables of the model are obtained in one of three ways. These are calibrated against South African banking sector data, arbitrarily chosen inputs (compatible with the South African economy) or endogenously solved from the model.

4.1 Balance sheet items

The items for the initial period were calibrated against annual account data for the banking sector as at the end of December 2016. The data is publicly available as standardized monthly balance sheet data (BA900) that are provided by individual South African banks. The extraction of the data is described in Walters et al. (2018) which made use of the monthly data from April 2015 to March 2017. The assets were grouped into short term, medium term, long term and interbank lending. The long term assets include mortgage loans. The credit extension is extracted from total asset as the difference between the total amount of loans and the interbank lending. The market book (i.e. investments) is the difference between the total assets of the bank and the total amount of loans. On the liability side, the term 'other liability' is the difference between the total liabilities and the sum of the deposit, interbank borrowing and equity. The latest available full calendar year data was therefore 2016. The values are normalised by dividing by 10^9 and are given in Table 2.

Table 2. Normalized balance sheet data for the South African markets

b	γ	δ	τ
$\bar{m}_t^b$	9.6189	19.1436	7.5744
Λ_t^b	7.1411	3.4910	2.0913
d_t^b	2.3066	1.5006	0.4392
μ_t^b	1.4591	0.6713	0.4966
$d_{b,t}^{\phi}$	20.6960	9.2916	7.6206
e_t^b	1.9830	0.8118	0.5587
O_t^b	4.4531	3.8358	1.4328

4.2 Loan repayment rates

The loan repayment rates of the private sector agents to their nature-selected banks in the good state are calibrated using actual non-performing loans to total loans data for each banking sector at the end of December 2016 from the same source as the balance sheet data. Since the period did not experience any bad or crisis state, no data is available for calibrating the default rate for the bad state so they are arbitrarily chosen to be 0.1. This implies that the repayment rates for each of the private sector agents in the bad state is 0.9. The repayment rates for the banks in the good state are set to be higher than that of the corresponding private sector agents since banks hardly default on their obligations in that state. For that reason, we set the repayment rates for the banks in the bad state to be relatively higher than the corresponding rates for the private sector agents. Tables 3 and 4 show the repayments for households and banks respectively.

Table 3. Household repayment to nature-selected bank

b	α^{γ}	β^{δ}	θ^{τ}
$v_{t+1,i}^{h^b}$	0.9790	0.9862	0.9824
$v_{t+1,ii}^{h^b}$	0.9000	0.9000	0.9000

Table 4. Repayment rate of banks

b	γ	δ	τ
$v_{t+1,i}^{b}$	0.999	0.999	0.999
$v_{t+1,ii}^{b}$	0.950	0.950	0.950

4.3 Other exogenous variables/parameters

4.3.1 Probability of a state occurring

The probability that the bad state occurs, $1-p$, is taken to be 0.05 to reflect a one-in-twenty year event (Goodhart et al. 2005, 2006b). Thus, p_i=0.95 and p_{ii}=0.05.

4.3.2 Interbank rate

The interbank rate is set to match the actual repurchase rate of the Reserve Bank at the end of December 2016. The repurchase rate is the rate at which the South African banks borrow money from the South African Reserve Bank and the value was ρ_t=0.07 [6]

4.3.2 Risk weights

The values of the risk weights were set taking into account risks attached to various asset classes from Basel I requirements. These are 1 for for loans and 0.2 for interbank lending and market book. Hence they are $\hat{\omega} = 1$ and $\omega = \breve{\omega} = 0.2$ (Bank for International Settlements, Committee on Banking Regulations and Supervisory Practices 1988).

4.3.3Capital adequacy ratio and penalties

In reality, most banks capital is above the minimum regulatory capital requirements. As we have already mentioned in Sect 2.1, we subject the banks to reputation costs (i.e. capital requirements penalties), if they fall below the "market determined capital requirements threshold". The size of the penalty is proportional to the deviations from the market determined capital requirements threshold. Thus $\bar{k}^b > k_s^b$. The values of default and capital violation penalties ($(\lambda_s^b$ and λ_{ks}^b, b∈B, s∈S) reflect both the tightness of the regulators policy and the (subjective) risk aversion of banks managements to putting themselves at risk of default and/or regulatory violations, and can, in principle, be treated as inputs given by the users of the model. Their values are however, unobservable, and therefore, have to be chosen. We have chosen them to be consistent with the following economic conjunction. First, the resulting endogenously solved banks lending rates are such that all banks earn high profit in the good state and lower in the bad state. This in turn implies that banks capital at t=2 decreases, whenever the bad state occurs. Second, all banks coefficients of risk aversion (c^b's, b ∈ B, s ∈ S) are positive, reflecting prudent risk management or the limited liability clause of the bank and the associated option like payoff strike. The values together with the penalties are given in Table 5.

Table 5. Capital requirements data and penalties

b	γ	δ	τ
k_i^b	0.1164	0.1083	0.0884
k_{ii}^b	0.0958	0.0685	0.0605
$\bar{k}_{t+1,i}^b$	0.1300	0.1200	0.1000
$\bar{k}_{t+1,ii}^b$	0.1300	0.1200	0.1000
λ_i^b	0.9000	0.9000	0.9000
λ_{ii}^b	1.0200	1.0200	1.0200
λ_{ki}^b	0.1000	0.1000	0.1000
λ_{kii}^b	0.1000	0.1000	0.1000

4.3.5 Rate of return on market book and GDP

The rate of return on the market book is arbitrarily chosen to be 30 basis point above the repurchase rate as at the end of December 2016 as it is naturally expected that return on the banks investments will be higher than the repurchase rate. The value is set equal to 0.073.

The nominal GDP in the good state is set to equal the actual GDP as at the end of December 2017. As South Africa did not experience any crisis state in the period of investigation and we generally expect the GDP in the bad state to be lower than in the good state, it is set to be 4% lower than GDP in the good state. Thus $GDP_{(t+1,i)} = 4.700$[7] and $GDP_{(t+1,ii)} = 4.512$

4.4 Elasticities for the reduced form equations

The elasticities or the coefficients of the reduced form equation for future GDP Eq. 8 were estimated using multiple regression analysis. The trend component was found to be statistically insignificant. Hence, it was set to be zero. The other trend component of the household borrowers demand for loans was also set to be equal to zero. This reduced the multiperiod model to the two time period model.

The rest of the elasticities were arbitrarily chosen in such a way that the deviations from the predicted values and the realized values were minimized akin to the Brazilian case (Tabak et al. 2013).

4.5 Initial equilibrium position

The exogenous variables and the resulting initial equilibrium position are as shown in Table 6 below:

Table 6. Initial equilibrium position

	Initial equilibrium			Exogenous variables in the model	
E	$r^{\gamma} = 0.0943$	$k_i^{\delta} = 0.1083$	$e_{ii}^{\gamma} = 1.9689$	$O^{\gamma} = 4.4531$	$a\alpha_{,1}^{\gamma} = 1.0135$
	$r^{\delta} = 0.0872$	$k_{ii}^{\delta} = 0.0685$	$e_i^{\delta} = 1.12167$	$O^{\delta} = 3.8358$	$a\beta_{,1}^{\delta} = 0.3139$
	$r^{\tau} = 0.0956$	$k_i^{\tau} = 0.0884$	$e_{ii}^{\delta} = 0.7076$	$O^{\tau} = 1.4328$	$a\theta_{,1}^{\tau} = 0.0883$
	$r_d^{\gamma} = 0.0659$	$k_{ii}^{\tau} = 0.0605$	$e_i^{\tau} = 0.7602$	$g\alpha_{,i,1}^{\gamma} = -0.4405$	$z_{\gamma,1} = 2.7943$
	$r_d^{\delta} = 0.0658$	$\pi_i^{\gamma} = 0.0604$	$e_{ii}^{\tau} = 0.4788$	$g\alpha_{,ii,1}^{\gamma} = -0.6679$	$z_{\delta,1} = 1.9935$
	$r_d^{\tau} = 0.0700$	$\pi_{ii}^{\gamma} = -0.0141$	$\check{R}_i = 0.9990$	$g\beta_{,i,1}^{\delta} = -0.4332$	$z_{\tau,1} = 1.7927$
	$\mu_d^{\gamma} = 22.0590$	$\pi_i^{\delta} = 0.4049$	$\check{R}_{ii} = 0.9500$	$g\beta_{,ii,1}^{\delta} = -0.6679$	$c_i^{\gamma} = 0.0864$
	$\mu_d^{\delta} = 10.4572$	$\pi_{ii}^{\delta} = -0.1042$	$\mu^{\alpha\gamma} = 20.9492$	$g\theta_{,i,1}^{\tau} = -0.4370$	$c_{ii}^{\gamma} = 0.5377$
	$\mu_d^{\tau} = 8.1540$	$\pi_i^{\tau} = 0.2015$	$\mu^{\beta\delta} = 10.4572$	$g\theta_{,ii,1}^{\tau} = -0.6679$	$c_i^{\delta} = 0.1345$
	$k_i^{\gamma} = 0.1164$	$\pi_{ii}^{\tau} = -0.0799$	$\mu^{\theta\tau} = 8.2982$	$\mu_{i,1} = 0.4154$	$c_{ii}^{\delta} = 0.0495$
	$k_{ii}^{\gamma} = 0.0958$	$e_i^{\gamma} = 2.5874$		$\mu_{ii,1} = 0.3745$	$c_i^{\tau} = 0.2770$
				B = 1.7367	$c_{ii}^{\tau} = 0.0461$
				$r^{A} = 0.0730$	$e_0^{\tau} = 0.5587$
C	$\mu^{\tau} = 0.0574$	$d_{\gamma}^{\phi} = 20.6960$		$A^{\gamma} = 7.1411$	$\mu_{s,2} = 0, \forall s \in S$
	$\rho = 0.0700$	$d_{\delta}^{\phi} = 9.2916$	$v_i^{\alpha\gamma} = 0.9790$	$A^{\delta} = 3.4910$	$\mu_{s,3} = 0.15637, \forall s \in S$
	$\bar{m}_t^{\gamma} = 19.1436$	$d_{\tau}^{\phi} = 7.6206$	$v_i^{\beta\delta} = 0.9862$	$A^{\tau} = 2.0913$	$\omega = 0.2000$
	$\bar{m}_t^{\delta} = 9.6189$	$d^{\gamma} = 0.8474$	$v_i^{\theta\tau} = 0.9824$	$e_0^{\gamma} = 1.9830$	$\breve{\omega} = 0.2000$
	$\bar{m}_t^{\tau} = 7.5744$	$d^{\delta} = 0.8293$	$GDP_i = 4.7$	$e_0^{\delta} = 0.8118$	$\hat{\omega} = 1.0000$
				$g_{h,s,2} = 0.0370$, $\forall h \in H^b$, $\forall s \in S$	$\lambda_i^b = 0.9000$, $\forall b \in B$
				$g_{h,i,3} = 0.0500$, $\forall h \in H^b$	$z_b, 2 = 0.1400$, $\forall b \in B$
				$g_{h,ii,3} = 0.0700$, $\forall h \in H^b$	$z_b, 3 = 0.5000$, $\forall b \in B$
				$\lambda_{ii}^b = 1.0200\ \forall b \in B$	$z_b, 4 = -0.1000$, $\forall b \in B$
A	$v_{ii}^{\alpha\gamma} = 0.0900$	$v_i^{\gamma} = 0.9990$	$v_{ii}^{\delta} = 0.9500$	$k_s^{\delta} = 0.1200$, $\forall s \in S$	$a^{hb}, 2 = 0$, $\forall h \in H^b$
	$v_{ii}^{\beta\delta} = 0.9000$	$v_{ii}^{\gamma} = 0.9500$	$v_i^{\tau} = 0.9990$	$k_s^{\tau} = 0.1000$, $\forall s \in S$	$a^{hb}, 3 = 1.3540$, $\forall h \in H^b$
	$v_{ii}^{\theta\tau} = 0.9000$	$v_i^{\delta} = 0.9990$	$v_{ii}^{\tau} = 0.9500$	$k_s^{\gamma} = 0.1300$, $\forall s \in S$	$a^{hb}, 4 = -0.6800$, $\forall h \in H^b$
			$GDP_{ii} = 4.512$	$\lambda_{ks}^b = 0.1000$, $\forall b \in B$, $\forall s \in S$	p = 0.95

E = endogenously solved, C = calibrated against South African data and A = arbitrarily chosen

5 The model as a risk assessment tool

In this section, we use the model as a risk assessment tool for South African banks. Once equilibrium is established, a series of comparative statistics is conducted by changing the exogenous variables in turns and studying how the equilibrium is affected. The analysis can be done in two different ways. One is where the Reserve Bank sets the base money as its monetary instrument and the other is where it sets the interbank rate (repo rate) as its instrument. At the starting point (year 2016) of the analysis, the Reserve Bank was a net borrower in the interbank market. In other words instead of supplying base money in the interbank market it was rather issuing bonds, that is borrowing from the interbank market. In this case an expansionary monetary policy will mean either reducing the amount of bonds issued or reducing the repo rate. At the same time, banks δ and γ had surplus funds (net lenders) whilst bank τ was in deficit (net borrower) in the interbank market.

South Africa is pursuing a financial inclusion policy agenda (García and José 2016) of which financial stability is an integral part. As the South African financial service industry is integrated with the global economy, it is exposed to increased systemic risk. Therefore, there exists a need for financial regulation to be incorporated along with monetary and fiscal policies, and to take account of systemic risk (Gordhan 2011). Consequently, the regulatory framework has shifted its focus from microprudential to macroprudential regulation. In addition, the performance of the South Africa economy has been poor in recent times with four quarters seeing negative growths between January 2018 and December 2019[8] and continues to deteriorate. Both the Reserve Bank and the International Monetary Fund (IMF) downgraded their forecasts of GDP growth of the country for both 2020 and 2021. South Africa's sovereign long-term foreign currency credit rating was downgraded by both Standard and Poor's and Fitch to sub-investment grade in April 2017[9]. After the release of the 2019 Medium Term Budget Policy Statement (2019 MTBPS) in October 2019, the exchange value of the rand depreciated and this presented a marked worsening in South Africa's fiscal position. This intensified concerns of further credit-rating downgrades as two international rating agencies (Moody's and Standard and Poor's) subsequently revised South Africa's sovereign rating outlook from stable to negative[10]. There is therefore a possibility of further downgrades for the country. There are high levels of credit extension in South Africa to an extent that households are considered to be over-indebted and so deposit supply will extend the availability of credit, and we want to know its impact on the banks profits and the economy. Restrictive and expansionary monetary policy will also have an effect on the inflation targeting strategy of the Reserve Bank to maintain the headline consumer price inflation between 4% and 6%.[11]

As alluded to earlier on, South Africa did not suffer much from the 2008 financial crisis. However, the Reserve Bank is vigilant and is committed to ensuring a similar financial crisis does not occur in future. In this respect, in the G20 leaders summit of November 2010, the then South African president committed the country to a global financial regulatory reform agenda aimed at strengthening financial stability (Gordhan 2011). Moreover, the Reserve Bank adopted an expansionary monetary stance to stimulate economic activities in the aftermath of the Global Financial Crisis of 2008.

South Africa being a member of G20 complies and participates in the Basel Accord. In order for banks to adhere to the capital requirement, the regulator needs to impose a penalty to ensure that their capital does not fall below a required limit. South Africa is an emerging economy and international investors tend to disinvest in the economy any time there is a perceived risk and to reinvest in the country when the risk subsides. This leads frequently to capital injections and capital flights, and it is therefore important to know their effects on the economy.

Against this background, we followed the work done in the UK (Goodhart et al. 2005) and examined the impacts of the following shocks for risk assessment purposes of the South African economy: an expansionary monetary policy; a positive deposit supply shock to a bank; a positive bank capital shock to a bank; a restrictive regulatory policy; and a positive shock in Gross Domestic Product (GDP).

5.1 An expansionary monetary policy

As mentioned before, there are two ways that the analysis can be done. The first is to reduce the amount of bonds issued by the Central Bank (reduce borrowing in the interbank market). The other is to reduce the interbank rate. In reducing the amount of bonds issued, the interbank rate is solved endogenously in the model and in reducing the interbank rate, the amount of bonds issued is solved endogenously. Therefore, the two analyses produce the same results, provided the induced interbank rate is the same in both cases. We consider the case where the Reserve Bank sets its base money as its monetary instrument. Here the amount of open market operations by the Central Bank was decreased from 1.72 trillion to 1.67 trillion of South African Rand (approximately 3%). Recall, in equilibrium, the Reserve Bank was a net borrower so this produced a decrease in the interbank rate of 0.09%. The results for some key variables are shown in Table 7. The main effects are as follows:

Table 7. Positive shock to base money (reduction of B by 3%)-Central Bank sets its base money

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	−0.08	−0.37		−0.01	−0.10	$\frac{-3}{10^3}$	−0.02	−0.10	−0.12	$\frac{-1}{10^3}$	$\frac{3}{10^3}$		
γ	−0.08	−0.34	−0.09	$\frac{-4}{10^3}$	−0.03	$\frac{-1}{10^3}$	0	−0.10	−0.11	0	$\frac{4}{10^3}$	0.07	0.07
τ	−0.09	−0.35		−0.01	−0.23	$\frac{-4}{10^3}$	−0.04	−0.13	−0.18	$\frac{1}{10^3}$	0.01		

As the interbank market is less attractive for lending because of the reduction in the repo rate, both banks δ and γ, the net lenders in the interbank market, invest less in that market. Thus given credit availability increased, they decide to take fewer deposits and lend more to their customers. Hence, both their lending and deposit rates are reduced. Inversely, the other bank τ, the net borrower in the interbank market, lowers its deposits demand and increases borrowing from the interbank market. Moreover, it lends more to its customers. Therefore, both its lending and deposit rates decrease. Households liquidity as well as income improve, due to the greater credit supply, which in turn increases GDP in both states by 0.07%.

Finally, agent ϕ , because of increased GDP, deposits more funds in all three banks. This contributes to the decrease in deposit rates for all banks. Consequently, the banks expect that the credit extension in the economy would increase, and so the household probability of default decreases as a result of higher household liquidity and income. In the model, banks choose their optimal expected level of profitability by equating the marginal benefit with the corresponding marginal cost. Higher profitability increases banks utility as well as their capital to asset ratios which in general should make them suffer less capital infringement penalty. However, in pursuit of higher profitability, the banks take more risk and consequently suffer higher cost from higher expected default penalties. There is therefore a trade off between the marginal benefits and cost of default and the banks choose a slightly lower profitability in order to reduce the default cost. In our case, GDP dominates default cost. Thus, even with lower default penalties, the greater GDP results into lower households default probability and the repayment rate of agents to their nature-selected banks in the consumer loan market increase, resulting in higher value for the risk-weighted assets for banks. Therefore all banks capital adequacy ratios reduce causing all banks to suffer higher capital infringement penalties. Therefore there exist another trade off between penalties due to high expected default probabilities and reputation penalty due to lower capital. In our case, the effect of default penalty dominates the capital requirements penalty. The banks prefer to default less and suffer the capital requirements penalty rather than default more and suffer less of capital penalty.

5.2 A positive deposit supply shock to bank *δ* in the initial period

The deposit supply is increased by increasing $z_{b,1}$ of Eq. 7 by 0.8%. The increase in the deposit supply to bank *δ* has almost the same (directional) impact as that of an expansionary monetary policy if the base money is used by the Reserve Bank as its monetary policy instrument. This is because in both scenarios, the overall broad money supply available becomes higher except that in this scenario (deposit supply shock), the concentration is specifically in bank *δ*. So in effect the interbank rate decreases. As a result, the other two banks also benefits from the liquidity improvement in the interbank market from bank *δ's* supplies. The % changes in the key variables are shown in Table 8.

Table 8. A positive deposit supply shock to bank *δ* in the initial period-Central Bank sets its base money

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	−0.24	−1.13		−0.05	−0.58	−0.02	−0.09	−0.60	−0.70	0.01	0.01		
γ	−0.25	−1,04	−0.28	−0.01	−0.11	$\frac{-3}{10^3}$	$\frac{-1}{10^3}$	−0.31	−0.33	0	0.01	0.20	0.20
τ	−0.28	−1.07		−0.04	−0.72	−0.01	−0.12	−0.41	−0.54	$\frac{2}{10^3}$	0.02		

Major differences occur, however, where the interbank rate is used as the monetary instrument by the Central Bank to conduct monetary policy. In this case, there is no change to the interbank rate and so that channel is closed which means the banks cannot benefit from the increased liquidity through their interactions in the interbank market. As a result the changes only come through in the probability of default in the loan market. As bank *δ* supplies more credit, the overall credit supply increases and every household benefits from improved liquidity and higher income from improved GDP. Every households default probability reduces. This in turn causes the expected rate of return to increase for all three banks leading to their lending rates falling. Bearing in mind that the interbank rate is fixed, the cost of borrowing in the interbank market is fixed no matter the amount demanded in that market. So bank *τ*, the net borrower in the interbank market, finance its credit extension by borrowing more from that market instead of requiring more deposits. This contributes to the reduction in its lending rate by 0.01% and ensures no change in its deposit rate. Table 9 has the % changes in the key variables.

Comparing Tables 8 and 9, it is clear that the contagion effect is much weaker for the banks when the Reserve Bank sets its monetary policy instrument as the interbank rate than when the monetary policy instrument is the base money. This is because apart from the fact that the contagion effect in the interbank market is shut down , the contagion effect in the loan market is also weakened when the interbank rate is fixed. This suggests that interest rate targeting has more controlled effects than monetary base targeting.

Table 9. A positive deposit supply shock to bank δ in the initial period-Central Bank sets the interbank rate

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	$\frac{2}{10^3}$	-0.01		-0.02	-0.28	-0.01	-0.04	-0.29	-0.34	0.01	0		
γ	0	-0.01	0	0	$\frac{-1}{10^3}$	0	0	$\frac{-3}{10^3}$	$\frac{-3}{10^3}$	0	0	$\frac{2}{10^3}$	$\frac{2}{10^3}$
τ	0	-0.01		0	-0.01	0	$\frac{-1}{10^3}$	$\frac{-4}{10^3}$	-0.01	0	0		

A

5.3 A positive bank capital shock to bank δ in the initial period

The initial capital of bank δ is increased by 5.6%. Considering the case where the monetary instrument is the base money, the result for most of the variables are in the same direction as that of a positive deposit supply shock as in both cases more funds become available for the bank. The only difference is with respect to capital to asset ratio of the bank. The increase in capital reduces the banks capital requirements infringement penalty. As a result, bank δ 's capital and capital adequacy ratio improve in both states. Table 10 has the % changes in the key variables.

Where the Central Bank uses the interbank rate as its monetary policy instrument, the consumer loan default channel becomes the main contagion effect. Bank δ switches part of the vast investment away from the loan market because of the enormous size of the investment which results in a negative contagion effects on the other banks. There is therefore pressure on the overall credit supply which increases the default probability. This higher default probability causes the other banks risk-weighted assets to reduce, resulting in less infringement of capital adequacy requirements and hence less capital infringement penalty. Hence, in this case the capital adequacy ratio for the other two banks γ and τ also improves. Table 11 has the % changes in the key variables.

So far it is not clear from our results which of the two monetary policy instruments offers better financial stability. All we can say is that the contagion effect through the interbank market is shut down completely when the Reserve bank sets it monetary policy using the interbank rate and this may negatively or positively affect the contagion effect through the other channels.

Table 10. A positive bank capital shock to bank δ in the initial period-Central Bank sets its base money

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	-0.10	-0.32		-0.02	-0.18	3.73	6.40	3.55	6.20	0.04	0.02		
γ	-0.09	-0.33	-0.10	$\frac{-4}{10^3}$	-0.03	$\frac{-1}{10^3}$	0	-0.10	-0.10	0	$\frac{3}{10^3}$	0.06	0.06
τ	-0.10	-0.34		-0.01	-0.22	$\frac{-3}{10^3}$	-0.03	-0.12	-0.16	$\frac{1}{10^3}$	0.01		

Table 11. A positive bank capital shock to bank δ in the initial period-Central Bank sets the interbank rate

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	-0.02	0.09		-0.01	-0.07	3.73	6.42	3.66	6.34	0.04	0.01		
γ	$\frac{-2}{10^3}$	0.05	0	$\frac{1}{10^3}$	0.01	0	0	0.02	0.02	0	$\frac{-1}{10^3}$	-0.01	-0.01
τ	0	0.05		$\frac{2}{10^3}$	0.04	$\frac{1}{10^3}$	0.01	0.02	0.03	0	$\frac{-1}{10^3}$		

5.4 Restrictive regulatory policy

5.4.1 The capital infringement penalties in the bad state is increased

The capital adequacy requirements penalty is increased from 0.1 to 0.12 (by 20%) for all banks in the bad state. The infringement of capital requirements is now costly for the banks in the bad state so in order to increase their capital to asset ratio, they respond as follows: They adopt a more risky strategy in order to optimize their profitability. Their profits in the bad state increase. This then enhances their capital situation in that state and make them suffer less capital infringement penalties. To reduce the capital infringement penalty, banks δ and γ reduce the level of risk-weighted asset in the bad state. The deposit rates for them reduce as they demand fewer funds. They lend less in the interbank market and more in the consumer loan market making the interbank rate to increase and their lending rate to reduce. The lending rate and deposit rate for bank τ increase by 0.16% and 0.18% respectively. The reason is that it borrows less from the interbank market as the interbank market is now expensive, takes more deposit and lend less in the consumer loan market. The extent of the reduction in the credit extension of bank τ outweighs the increase in the credit supply of banks δ and γ. As a result the overall credit supply in the economy decreases causing the GDP in both states to decline by 0.003% and consequently the probability of default for every household increases. Table 12 has the % changes in the key variables.

Table 12 A rise in CAR penalty of 20% for all banks in the bad state-Central Bank sets its base money

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	-0.11	-0.06		0	18.77	0	2.77	$\frac{3}{10^3}$	2.78	$\frac{2}{10^3}$	-0.23		
γ	$-0,11$	$-0,06$	0.18	0	6.43	0	0.05	$\frac{3}{10^3}$	0.05	$\frac{1}{10^3}$	-0.02	$\frac{-3}{10^3}$	$\frac{-3}{10^3}$
τ	0.18	0.16		$\frac{1}{10^3}$	34.31	0	5.73	0.01	5.74	$\frac{1}{10^3}$	-0.35		

5.4.2 The default penalties in the bad state is increased

The default penalty in the bad state is increased from 1.02 to 1.023 (approximately 0.3%). In order to reduce the default penalty they face in the bad state, the banks adopt a conservative strategy of choosing lower profitability in this state. The interbank market is now slightly safer compared to the other markets and so bank δ and bank γ, being net lenders in the interbank market, increase their investment there. They do this by taking more deposits and reducing their lending in the consumer loan market. The resultant effect is that the interbank rate reduces and the lending and deposit rates for the two banks increase. The other bank τ, the net borrower in the interbank market, takes advantage of the reduced interbank rate and borrows more in that market. It also reduces the intake of deposit so its deposit rate reduces. As the good state is not affected by the increase in default penalty, it lends more in an attempt to improve its profit in that state so that its overall payoff is not affected so much. This reduces its lending rate 0.19%.

It is interesting to note that results show that the effect of a rise in the default penalty is higher than that of the capital requirements infringement penalty even in the case where the percentage increase in the default penalty (0.3%) was much lower than the percentage increase in the capital adequacy requirements penalty (20%). This may be due to the fact that banks view the possibility of being penalized for defaulting more serious than infringing their capital requirements and thus act accordingly. Table 13 has the % changes in the key variables.

Table 13. A rise in default penalty of 0.3% for all banks in the bad state-Central Bank sets its base money

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	0.10	0.08		0	−29.08	0	−4.29	$\frac{-2}{10^3}$	−4.29	0	0.36		
γ	0.10	0.08	−0.26	0	−19.82	0	−0.14	$\frac{-2}{10^3}$	−0.15	0	0.03	$\frac{3}{10^3}$	$\frac{3}{10^3}$
τ	−0.26	−0.19		$\frac{-2}{10^3}$	−40.74	0	−6.80	−0.02	−6.82	$\frac{1}{10^3}$	0.42		

5.5 A positive shock in GDP in the bad state

We increase $\mu_{ii,1}$ by 0.6%. This is equivalent to increasing autonomous GDP in the bad state by approximately 0.23%. The shock raises the expected aggregate output. It also increases the demand for loans as well as the probability of repaying the loans. The lending rates of the banks increase. A lower default probability increases the expected rates of return on the loans. Consequently, the banks invest heavily in the markets. The effect of the individual borrowers borrowing more from the banks is weaker than that of the banks' greater demand for deposit and so the interbank and deposit rates increase. The two net lenders in the interbank market, bank δ and bank γ take advantage of the higher interbank rate to invest more there. They do this by demanding more deposits. Their deposit rates end up being higher than the other bank. The banks risk-weighted assets rise as a result of higher probability of individuals paying their loans in full. This lowers capital infringement penalties for all banks. The rise in the banks risk-weighted assets makes the benefit of higher profitability from capital infringement penalty lower. The banks therefore revise their optimal profits downwards in order not to suffer much default penalty which in turn worsen their capital position. Table 14 has the % changes in the key variables.

Table 14. A positive shock in GDP in the bad state-Central Bank sets its base money

b	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	e_i^b	e_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	0.14	0.09		$\frac{-1}{10^3}$	−0.02	0	$\frac{-3}{10^3}$	−0.01	−0.02	$\frac{1}{10^3}$	0.01		
γ	0.14	0.09	0.13	$\frac{-1}{10^3}$	−0.01	0	0	−0.01	−0.02	$\frac{-1}{10^3}$	0.01	$\frac{2}{10^3}$	0.23
τ	0.13	0.08		$\frac{-1}{10^3}$	−0.04	0	−0.01	−0.01	−0.03	0	0.01		

As mentioned earlier, we followed the work done for the UK banking sector. The aim was to determine whether the CGE model will be appropriate in assessing risks for the South African banking sector and also determine if the banks in the two countries will behave in a similar manner if they were exposed to the same risks. It is interesting to note that the results obtained from the shocks are similar to that obtained for the same analyses of the UK banks (Goodhart et al. 2005) especially in terms of the directional changes. However, the magnitude of the changes are much lower for the South African case than for the UK for all the rates- deposit, lending and interbank rates. The reason for this is mainly that at the time of the various analyses, the corresponding rates were much lower for the UK than South Africa and hence the impact of the same shocks are lower for South Africa. This supports the assertion that the CGE model works well for the South African banking sector, although the impact depends on the features of the particular economy at the time the analysis is done.

These results are consistent with other studies using different methodologies such as Owusu-Sekyere (2017), which indicated that consumption and loans to households decreased during periods of monetary tightening but increased during periods of expansionary monetary policy in South Africa, and effective regulation is associated with economic growth in developing countries (Jalilian et al. 2007).

6 Concluding remarks

The CGE model worked well as a risk assessment tool for the South African banking sector. The results of the various shocks which were also done in the UK are in line with that obtained from the work done on the UK banking sector (Goodhart et al. 2005). This is particularly the case in terms of direction of the impacts of the shocks. However, the magnitude of the changes for the interest rates (the deposit rates, lending rates and interbank rate) are higher for the UK case than for South Africa mainly due to the fact that these rates were very low in the UK compared to the South Africa, at the times the various analyses were done.

We also observe that the effect of a rise in the default penalty is higher than that of the capital requirements infringement penalty on almost all the key variables. This could be attributed to the fact that banks view the possibility of being penalized for defaulting more seriously than infringing their capital requirements and thus act accordingly. Banks are exposed to different risks and react differently depending on whether the Reserve Bank sets its base money or the interbank rate as its monetary policy instrument. Our result suggests that interest rate targeting has more controlled effects than monetary base targeting due to the elimination of pecuniary second order effects.

The possibility of risk neutral banks merits further consideration. In such a case, instead of using a quadratic expected profitability function, we could use a linear one. This should pose no problem as the model punishes banks that take huge risk by deducting the penalties from the profit in the objective function. Thus in effect, risk is already taken into account in the model. Other appropriate utility risk functions (such as a log function) could be explored in future work. There is also an opportunity for future research on some of the exogenous variables which were arbitrarily chosen, in particular, the elasticities of the reduced form equations to be calibrated against South African data.

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Notes

[1.]A CGE model is defined as an economy-wide model that describes the behavior of all consumers and producers in an economy and the linkages among them (Burfisher 2011). A set of equations is used to describe the economy and the interactions of the various parts. The model comprises of two distinct sets of variables (exogenous and endogenous) as well as market clearing conditions. The user of the model provides or inputs the exogenous variables whilst the values of endogenous variables are determined as solutions to the equations of the model. The solutions of the equations at equilibrium are the set of prices which make the quantities of supply and demand equal in every market. The model is said to be computable because of its capability to quantify a shock to the economy. A change in an exogenous variable does not only give the directional changes in the endogenous variable but also the size of the change. It is “general” in the sense that all the economic activities (spending, investing, taxation, and employment) are covered contemporaneously. The CGE model is used to determine the effect on the endogenous variables when an exogenous variable varies. There are three components making up a CGE model (Hosoe 2004). These are consumers, producers and the markets. For the banking sector model, the consumers are households/individuals and firms. The producers are the banks and other financial institutions making up the financial sector, and the market comprises the deposit, loan and interbank markets.

[2.]Individuals/firms being attached to a particular bank may be unrealistic as individuals or firms can borrow from any bank. However, for justification of this limited participation assumption, see Bhattacharya et al. (2003).

[3.]See, Zicchino (2012) where the equivalence of repayment rates and probabilities of default is discussed.

[4].The assumption of the default rate for deposit and that for the interbank market for each bank being the same is chosen for the sake of simplicity. However, in reality banks do not default on their deposit. Evidently, if they do so then they become bankrupt and close down. However, our repayment rate are akin to the endogenized probability of default as has been argued in Zicchino (2012).

[5].In our model, banks maximize their expected profits over a period of one year. This may not be true as banks usually have longer horizon for their profit expectation. It is chosen for the sake of simplicity and for analytical tractability.

[6].https://www.global-rates.com/interest-rates/central-banks/central-bank-south-africa/sarb-interest-rate.aspx.

[7.]http://www.statssa.gov.za/publications/P0441/P04414thQuarter2017.pdf

[8].https://tradingeconomics.com/south-africa/gdp-growth.

[9.]South African Reserve Bank Quarterly Bulletin, June 2017, No. 284.

[10.]South African Reserve Bank Quarterly Bulletin, December 2019, No. 294.

11.https://www.resbank.co.za/MonetaryPolicy/DecisionMaking/Pages/InflationMeasures.aspx.

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