DOI: 10.1111/saje.12383

ORIGINAL ARTICLE

A computable general equilibrium model of the monetary policy implications for financial stability in South Africa

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Funding information
ABSA Chair in Actuarial Science; University of Pretoria; Czech Science Foundation

Abstract
The South African Reserve Bank (SARB) uses interest rates to control inflation. The Computable General Equilibrium (CGE) model can contribute to inflation targeting objective and also determine the effects on banks and the economy. We improved the accuracy of the results from previous work on the banking sector CGE model by estimating the elasticities of the reduced form equations of the model instead of arbitrarily choosing them.
Our results conform with the established view that lower policy rates lead to an increase in inflation and a reduction in banks' profits. However, because of the adverse supply shocks arising from the effects of the COVID-19 pandemic, the increase in the GDP is crowded out. The CGE model is a useful tool for the SARB for monetary policy implications on financial stability, informing and providing analysis on its repo rate decision, and determining the consequent effects on the economy.

KEYWORDS
banks' profit, gross domestic product, inflation, monetary policy, repo rate

1 | INTRODUCTION

Almost all countries across the globe have prioritised financial stability through the regulation of their financial systems after the global financial crisis. Stress testing banks may be of interest, but it is the assessment of the sector as a whole that matters for the economy. Thus systemic interactions of banks must be accounted for in any financial stability research. The computable general equilibrium (CGE) models allow interactions with banks and consider the entire banking sector. This is the distinguishing characteristic of our work from most of the other work performed on financial stability. Also, the relationship between inflation and default, and its consequences on financial stability needs to be investigated. This interaction of inflation and financial stability is *limited* in most of the research work on financial stability. The South African Reserve Bank (SARB) uses interest rates to control inflation. One of the Central Bank's main objectives is inflation targeting. It serves to discipline monetary policy and increases bank's accountability (Van der Merwe, 2004). Inflation targeting aims to keep inflation, within a predetermined range, in the case of South Africa as the consumer price inflation (CPI), in a fixed range. The SARB's inflation target range is between 3% and 6%. This specification does not imply that monetary policy ought to change immediately if the inflation rate moves outside the target. In case when the CPI is expected to return into the target range within a short period, no action is required. Monetary policy is implemented by setting the short-term policy rate. This affects the borrowing costs of the financial sector, which, in turn, affects the real economy. The policy rate is the rate at which individual banks borrow money from the Central Bank. Inflation targeting has several advantages as a medium-term strategy for monetary policy (Mishkin, 2001). Inflation targeting allows monetary policy to focus on domestic considerations and to respond to exogenous shocks to the domestic economy. With inflation targeting, a stable relationship between money and inflation is not critical to its success because the strategy does not depend on such a relationship. It is also easily understood by the public because of its transparency. However, inflation targeting requires exchange rate flexibility, and this could lead to financial instability, especially for emerging countries such as South Africa. Comert and Epstein (2011) argue that a strict inflation-targeting regime is inappropriate for a country facing significant problems with unemployment, major inequality and financial instability emanating from home and abroad. The SARB seems to have recognised this and has moved to a more flexible approach following the global financial crisis of 2008 (Comert & Epstein, 2011).

The financial system is stable when the banking sector is profitable and financially sound. The sector is able to withstand adverse shocks in such circumstances. We define financial stability as higher default for both the banks and the private sector agents and lower profitability for the banking sector. As explained in Peiris et al. (2018), neither of the two conditions is sufficient enough to constitute a financially fragile regime. Higher default alone could indicate increased volatility and risk taking, and lower bank profitability alone may be a sign of recession in the real economy and not financial vulnerability. Because profitability is a major determinant of bank capital in the short run Alessandri and Nelson (2015), financial stability and monetary policy are closely linked. This is because of the fact that changes in interest rates affect bank profitability and financial system resilience. Even though the possible impacts of monetary policy can be observed through various monetary transmission channels (interest rates, exchange rates, inflation, expectations and asset prices), the most influential monetary transmission channel is undoubtedly the interest rate. Interest rates affect the whole economy by determining the level of many economic variables such as investments, capital flows, credit demand, bank profitability and exchange rates. Whilst the central bank directly controls the short-term rate through its policy rate, it indirectly affects the shape of the yield curve through its impact on market participants' expectations about the future path of the policy rate Borio et al. (2017). Compared with advanced countries, banks in emerging economies enjoy higher profit margins. This is mainly because of the apparent higher inflationary environment (Aydemir & Ovenc, 2016). de Jager et al. (2022) used an econometric model with rich South African financial sector data to study how different macro policies affect the business and financial cycles. They concluded that countercyclical monetary and fiscal policies can stabilise both real and financial cycles without recourse to financial stability policy measures.

The SARB has been using the Quarterly Projection Model (QPM) since 2007. It is a general equilibrium model and also a so-called gap model (Botha et al., 2017). The gaps are the output gap, the exchange rate gap, the inflation gap and the real interest rate gap. It has played an integral part in decisions taken by the SARB as part of its monetary policy stance. However, the QPM focusses on gross domestic product (GDP) as a whole and not the underlying components of aggregate demand. Therefore, it needs to be complemented with other models and so the SARB makes use of a suite of models. The banking sector CGE model could be added to the suite as it incorporates banking sector heterogeneity, endogenous default and incomplete markets. The Bureau for Economic Research (BER) also publishes annually and forecasts of over 140 macro-economic variables (Van der Wath, 2013) which include inflation. Our results are consistent with both the QPM and the BER forecast as both suggest that future inflation or inflation expectation, GDP and banks' profits could be affected by altering short-term interest rates.

Related literature—The dynamic stochastic general equilibrium (DSGE) models have been used in recent times to address issues on financial stability and financial frictions. They aim to capture business cycle fluctuations and thus have a stronger focus on the shorter-term impacts. They are less disaggregated and allow for random variation to account for uncertainty. These models have played an important part in reasonable explanation for development during and after the 2008 global financial crisis. There are also a number of CGE models with financial dynamics in South Africa although there is a gap in applications in the banking sector. For example, Makrelov et al. (2019) developed a small general equilibrium model that has several financial instruments and institutions to study the impacts of capital flow reversal shocks in the South African economy. This model is different from the DSGE models and is more microfounded, and consistent with stock and flow models. Erero (2023) used a CGE model to determine the impact of the load shedding on the South African economy and concluded that it negatively affected the GDP and welfare of citizens.

A General Equilibrium model that included heterogeneous banks and capital requirements with incomplete markets, money and default was introduced by Tsomocos (2003). This was followed by Goodhart et al. (2006a) that included possible capital requirements infringement and its associated penalties. A simplified solution was proposed in Goodhart et al. (2004), where a minimal market structure was introduced. This minimal system initially had three households, two banks, a central bank and a regulator. They concluded that the framework had the capacity to characterise the UK's financial stability. They extended the model to cover three banks where the third bank comprises of the five remaining largest banks in the UK. It is important to note that even though the model makes use of three banks, it can cover the entire banking sector. All that needs to be performed is to group the banks into three homogeneous classes. Two time periods were initially used and later modified to cover several periods even though the model could not work with infinite time periods. This model is now fully developed and been used successfully to analyse financial fragility in the UK (Goodhart et al., 2006b). It has also been applied in a few emerging countries such as Jamaica, Lewis (2010), Colombia (Saade et al., 2007) and Brazil (Tabak et al., 2013). Therefore the model could be applied successfully in both developed and developing nations. This is the model we are using for our work. It is indeed a CGE model and not a linearised GE model which is the DSGE model. This allows us to also access and analyse second-order effects and price effects that are usually overlooked in the DSGE model. It is important to mention that in our model, there is a default channel with interaction with liquidity which is an endogenous choice rather than a stochastic choice as in the cases of financial accelerator models.

A CGE model is an economy-wide model that describes the behaviour of all consumers and producers in an economy and the linkages among them (Burfisher, 2011). Three components make up the model. They are consumers, producers and the markets. For our model, the producers are the banks. The consumers are the private sector agents (households/individuals and the firms), and the markets comprise the deposit, loan and the interbank markets. It is assumed there exist two possible future states. One state is the good/normal state and the other is the bad/crisis state of nature. The good state is denoted by i and the bad state by ii with corresponding probability of ocurring, p and $1-p$, respectively. These probabilities are assumed to be time invariant and common knowledge by the economic agents. The banks aim to maximise their profits whilst the private sector agents aim to maximise their utility. We maximise the expected payoff of each bank which is defined as the expected profitability less capital infringement penalty less penalty on default of interbank obligations less penalty on default on deposits. Subject to the following two conditions: 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), and money paid on liabilities must be less or equal to money received from assets. Where profit is defined as money received from assets less money paid on liabilities, the capital at the end of the period is the initial capital plus profit earned during the period, and the capital adequacy ratio is equal to the ratio of capital to the risk-weighted assets.

A CGE model may potentially assist in informing and providing analysis on the policy rate including assessing the impact of actions taken by the Central Bank, for example, the effects of changes in the policy rate on the financial sector. This is crucial, especially during periods of global uncertainty and systemic risk, such as the COVID-19 pandemic. Our two papers, Beyers et al. (2020, 2021), covered banking risk assessment and regulation in the South African banking sector, respectively. The intention now is to cover not only financial stability of the banking sector of South Africa but also monetary policy and their mutual interdependence.

The data used for the previous papers were based on the 2016 year end. This was before the COVID-19 pandemic. During the pandemic, the Government introduced specific financial policies to assist lower income classes and the SARB also took actions to address financial problems caused by the pandemic. It is important therefore for us to assess the impact of these actions on the banks and the macro economy.

Both low inflation leading to deflation and high inflation leading to slow economic growth should be examined. Both scenarios have detrimental effects to the economy. In our model, many variables can be used as proxies for inflation. Some of these variables are the interest rates for both deposits and lending, the probability of default and hence the repayment rates of customers to their nature-selected banks, profits of the banks and the GDP. Many studies have shown the link between inflation and these variables. For instance, Bittencourt et al. (2014) showed that inflation has a detrimental effect on economic growth for the member countries of the Southern African Development Community. Mitchell-Innes (2006) established a long-run relationship between interest rates and expected inflation, and Mpofu (2011) showed that interest rate has a significant negative relationship with inflation and should be an integral part of a macroeconomic policy framework in South Africa.

In summary, there are four contributions of this study as compared with Beyers et al. (2020, 2021). First, the current work incorporates the data during the COVID-19 pandemic. Second, we have used econometric/statistical methods to determine the elasticities for the reduced form equations for the private sector agents and future GDP which were arbitrarily chosen in our previous work. Third, we focus primarily on monetary policy and its effects on the economy whilst our previous work considered bank risk assessment and banking regulation. Finally, we analysed the impact of the actions taken by both the government and the SARB to curb the effects of the COVID-19 pandemic. We hasten to add though that the imperfect substitutability constraint is not satisfied in our model and that there are alternatives to bank funding. These limitations were highlighted and argued in our previous paper Beyers et al. (2021). Nevertheless, we regard that the model is appropriate for South Africa; however, we are only focussing on the 'bank-based' aspect of the economy.

The results indicate that reducing the policy rate leads to an increase in inflation, a reduction in banks' profits, and a rise in GDP. However, because of supply shocks arising from the COVID-19 pandemic, the rise in GDP is marginal. The results also suggest that if a bank is in a weak capital position, then expansionary monetary policy rather worsens the capital adequacy condition of that particular bank as the marginal benefit effect dominates the capital requirement violation cost. In addition, the higher liquidity resulting from the expansionary monetary policy may induce banks to expand rather than improve their capital requirement position.

The rest of the paper is organised as follows. In Section 2, we discuss financial regulation in general equilibrium. Section 3 is devoted to the estimation of the elasticities of the reduced form equations for the private sector agents and future GDP. Calibration of the model using the latest available (up to December 2021) information about the banking sector and the economy of South Africa is described in Section 4. The analysis which involves the monetary policy and its effect together with the capital adequacy requirement is discussed in Section 5. Finally, in Section 6, we offer concluding remarks.

2 | FINANCIAL REGULATION IN GENERAL EQUILIBRIUM

One of the reasons why the 2008 global financial crisis was not foreseen is that most of the mainstream economic models assume away financial frictions such as defaults (Goodhart et al., 2019). It is difficult to properly model default, partially because it is a discrete variable. The probability of default has always been an important item in finance even though very little effort has been made to include it in formal macroeconomic models, Goodhart and Tsomocos (2011). There are now models where endogenous default and regulation are assessed in general equilibrium. One such model which is presented in Goodhart et al. (2012) delves into how different types of financial regulation in general equilibrium deal with many of the problems encountered in the 2008 global financial crisis. The framework includes a bank and a 'shadow bank' (sometimes referred to as an 'investor') that each lends to households. Households have the option to default on their borrowing but that prompts forced selling by the shadow bank. Forced selling usually leads to sales below the property value (a fire sale). Five different policy options that could be used to deal with default, credit crunches and fire sales were considered in Goodhart et al. (2012). These are limits on loan-to-value ratios, margin requirements on repurchase agreements used by shadow banks, capital requirements for banks, liquidity ratios for banks and dynamic loan loss provisioning for banks. We consider two of these options which are relevant for monetary policy.

2.1 | Capital requirements

If the capital ratio (CR) is set high enough and becomes binding, banks would be forced to respond by limiting risky mortgage offers. According to the Basel rules, risk weights are attached to assets. If the risk weights on mortgages and mortgage-backed securities are different, then banks would decide to securitise more mortgages and benefit from diversification and, in doing so, shift the risk to the less risk-averse investors. So this option has the benefit of ensuring that instead of just reducing intermediation, it does not become part of the banking system altogether. Whether the households benefit or not will depend on the decision taken by the bank. Choosing more securitisation will result in amplified mortgage credit contraction for households than simply reducing the amount of mortgage credit. If the bank reduces its mortgage lending, purchasers will be unable to have as many properties as they would prefer and sellers will have to keep more of their properties than they would otherwise want to, and this impacts their consumption. There are competing effects for the banks when the capital requirement is increased. It acts as a cushion against losses and also alters their motivations for securitisation.

2.2 | Dynamic provisioning

The first four options (including CR) are all intended to make the fire sale less severe. Thus, they are very effective during times of economic downturn. It is, therefore, important to have a regulatory tool that changes behaviour in boom times. One such tool is dynamic loan loss provisioning. It forces banks to keep cash on their balance sheets throughout the boom period when the increase in real estate-related credit surpasses a particular limit. The importance of dynamic provisioning has been alluded to when it was mentioned in De Lis et al. (2001) that it could strengthen financial stability in many ways. It encourages banks to price their products taking into account their risk exposure. It also lowers the procyclicality of bank lending and strengthens the banking systems ahead of an economic downturn. Hence, its execution is needed to surmount established accounting and taxation codes. The banking sector is one of the losers from such regulation as their profits decrease during boom periods. Existing homeowners lose as the value of their properties is reduced and their welfare also drops during the same period. Thus, one may conclude that the dynamic provisioning regulation benefits from distributing the cost of the regulation quite differently when compared with the other policies.

Three observations were made from the analysis of the five regulatory tools (Goodhart et al., 2012). The first is that entities will respond differently to different regulatory policies. The second is that capital requirements provide motivations for regulatory arbitrage, by allowing intermediation to be shifted from the banks to the shadow bank. Finally, whether regulations act as complements or substitutes depends on the particular tools used.

Some of the conclusions made are first, there is a considerable benefit from having a formal general equilibrium model that allows the financial system to also depend on the shadow banks for funding. Second, combining market incompleteness with higher default costs distorts the housing market. Wealthy agents take decisions on their savings taking into account the possibility that there could be a default on deposits. With low default penalties for banks, the households assume that risk, and so put fewer funds into the banking system and rather maintain more funds in the housing market. Thus, more houses are supplied in times of boom and so house prices fall, which raises welfare for first-time home purchasers. Finally, considering the complicated interrelationship among the different agents of the model, none of the regulatory tools will be sufficient alone to overcome the distortions that arise from defaults. The actual combination of tools that does the work well depends on the precise context of the economic conjuncture, but the proposition that different sources of inefficiency require numerous tools holds in all situations (Kashyap et al., 2011).

3 | ELASTICITIES FOR THE REDUCED FORM EQUATIONS

In our previous papers Beyers et al. (2020, 2021), only a few of the elasticities were estimated. The rest were arbitrarily chosen. The results from these papers could be improved by either calibrating these elasticities against a given database (setting specified parameters to replicate benchmark data set as a model solution) or using econometric methods to determine them. The ideal methodology would have been the calibration but as attested to by Zhang and Verikios (2006), not all elasticities can be calibrated endogenously to a given database. Therefore, we have used econometric/statistical methods to estimate all the coefficients of elasticities other than those of deposit supply and the intercepts for the reduced form equations of the private sector agents and future GDP. We followed the work of Saade et al. (2007) and Lewis (2010).

3.1 | Household borrowers demand for loans

The reduced form equation for household borrowers' demand for loans as established in Beyers et al. (2020) is

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

where $\mu_t^{h^b}$ = amount of money that agent $h^b \in H^b$ 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, and $a_{h^b,1}$, $a_{h^b,2}$, $a_{h^b,3}$ and $a_{h^b,4}$ are the coefficients or the elasticities of the model.

We needed to estimate the long-run relationship between the variables: private consumption, real GDP, unsecured lending, unemployment rate, inflation rate, broad money supply, credit spread and deposit spread. Quarterly data for the variables other than the credit spread and the deposit spread were collected from 2010 to 2021. The earliest available data for the credit and deposit spread was in 2013. The private consumption, real GDP, unemployment rate and inflation rate were obtained from Statistics South Africa[1] whereas the broad money supply and unsecured lending were obtained from

[1] https://www.statssa.gov.za/publications/P0441/P04411stQuarter2022.pdf

SARB.[2] The credit spread is the difference between the average lending rate for all the South African banks and the interbank rate. The deposit spread is the difference between the interbank rate and the average deposit rate for all the South African banks. These rates are all available from the SARB.

The quarterly data for these variables are shown as graphs in Figure B1. The results from the Augmented Dick Fuller (ADF) test indicated that all but inflation were not stationary. The results for a few of these variables from the ADF test are in Table B1. The next step is to determine the number and magnitude of the cointegrating vector. Cointegration is a statistical method used to test the correlation between two or more non-stationary time series in the long run or for a specified time period. This method helps identify given long-run parameters or equilibrium for two or more variables. So, the cointegrating vector is the linear relationship between the time series variables. We used Johansen (1995) procedure, and the results are in Table B2 which allows us to reject the null hypothesis of no cointegration and conclude that there is a long-run relationship among the variables.

The most important step is to impose justifiable restrictions on the estimation of the vector. Because we aim to obtain long-run elasticities for the reduced form Equation (1) of household's demand for loans, we needed to impose some restrictions to ensure that only the required variables are included. The restrictions are the coefficient on unsecured consumer lending must be one, and the coefficients on broad money, private consumption and deposit spread must be zero. The restriction on deposit spread means that it is not long-run related to loans.

Even though the individual variables are non-stationary in levels (that is I[1]), they converge in the long run (cointegrated). Thus, a meaningful conclusion can be derived from the coefficients of the long-run relationship from the ordinary least square (OLS) regression. As we are interested in the long-run elasticity coefficients and not the short-run relationship, we applied the OLS. The resulting relationship for household demand for loans (from Table B3) is

$$L_t = 1.1458 \ln (GDP)_{t+1} - 0.0571 (CS_t) - 0.0680 (I_t) + 0.0240 (\Delta U), \tag{2}$$

where L_t is unsecured lending at time t, CS_t is credit spread at time t, I_t is inflation at time t and ΔU_t is the change in unemployment rate at time t.

The coefficients on ln (GDP) and on credit spread are used for the model as the elasticities for the reduced form Equation (1) for each nature selected agent. Where $\mu_t^{h^b}$ = amount of money that agent $h^b \in H^b$ chooses to owe in the loan market of bank $b \in B$ in period t, $GDP_{t+1,s}$ = GDP in period $t+1$ of state $s \in S$, r_t^b = lending rate offered by bank b, and $a_{h^b,1}$, $a_{h^b,2}$, $a_{h^b,3}$ and $a_{h^b,4}$ are the coefficients or the elasticities of the model. Hence, comparing the coefficients of the required variables in Equations (1) and (2), the values are $a_{h^b,3} = 1.1458$ and $a_{h^b,4} = -0.0571$.

3.2 | Households loans repayment rates

The reduced form equation of the household repayment rate as established in Beyers et al. (2020) is

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

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 $\overline{m}_t^b$ 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. In determining the elasticities for this reduced form equation, we used a panel data set. The parameters were set common for the private sector agents α, β and θ.

[2]https://www.resbank.co.za/en/home/publications/publication-detail-pages/quarterly-bulletins/quarterly-bulletin-publications/2022/FullQuarterlyBulletinNo303March2022

This panel data set involves bank-specific information about the percentage of non-performing loans, amount of credit and real GDP (as independent variables). These are also quarterly data for the period 2010 to 2021 but are specific to the banks used in the model and not the aggregated data used for the estimation of the elasticities of the demand for household loans' reduced form equation. Because we are interested in the repayment rate and not default, we set the dependent variable to be 1% non-performing loans. Hence, the model used for the household's repayment rate (Equation 3) is

$$\ln(1-NPL_{i,t+1})=a_i+b_{1i}\ln\left(y_{t+1}\right)+b_{2i}\ln(TL_{i,t+1})+e_{i,t}, \tag{4}$$

where $NPL_{i,t+1}$ is the ratio of non-performing loans to total loans of bank i at time $t+1$, y_{t+1} is real GDP at time $t+1$, $TL_{i,t+1}$ is total loans of bank i at time $t+1$ and $e_{i,t}$ is the error term.

We performed the Hausman's test with the null hypothesis which states that the 'Random effects model is appropriate'. The alternative hypothesis states that the 'fixed effects model is appropriate'. We accept the null hypothesis if the *p*-value of the Hausman test is >0.05 (*i.e.* random effect is consistent and efficient). The result is as in Table B4. According to the result, the fixed effects model is appropriate. The results under the fixed effects model are shown in Table B5. The coefficients on real GDP and total loans are used for the running of the CGE model as the elasticities for the reduced form Equation (3) for each nature selected agent. Thus $g_{h^b,s,2}=0.0643$ and $g_{h^b,s,3}=-0.0250$.

3.3 | GDP

The elasticities or the coefficients of the reduced form equation for future GDP equation:

$$\ln(GDP_{t+1,s})=\mu_{s,1}+\mu_{s,2}trend+\mu_{s,3}\left[\ln\left(\overline{m}_t^{\gamma}\right)+\ln\left(\overline{m}_t^{\delta}\right)+\ln\left(\overline{m}_t^{\tau}\right)\right], \tag{5}$$

where $\mu_{s,1}$, $\mu_{s,2}$ and $\mu_{s,3}$ are the elasticities of the model estimated in the same manner as that of the household demand for loans. We needed to test for the non-stationarity of the variables (GDP and total loans). The result from the ADF unit root test is as in Table B6.

Once the non-stationarity is confirmed, the next step was to perform the Johansen (1995) procedure. The results are in Table B7 which allows us to reject the null hypothesis of no cointegration and conclude that there is a long-run relationship among the variables.

In order to conform with the reduced form Equation (5), we needed to restrict the coefficient associated with GDP to one. Following the same procedure as that of the households demand for loan, the resultant relationship of future GDP (from Table B8) is

$$\ln(GDP_{t+1,s})=11.2380+0.1672\ln(L_t), \tag{6}$$

where L_t is the total loans at time t. As the intercept is solved endogenously from the model, it was ignored and $\mu_{s,3}$ set to be 0.1672.

3.4 | Supply of deposits

We were unable to obtain the quarterly average rates for individual banks and, as a result, could not use econometric methods to estimate the elasticities for the deposit suply reduced form equation. They were therefore arbitrarily chosen from our earlier paper Beyers et al. (2020).

It is important to mention that as the endogenous variables of the model are not necessarily the endogenous variables of the system of equations, one can impose exogenously (from real data) the value of the endogenous variables of the model in the initial period of the simulation. These estimated variables are then used as exogenous variables in the model. This strategy was used for the intercepts of the reduced form equations as well as the risk aversion coefficients (similar to the approach used in (Tabak et al., 2013).

4 | CALIBRATION FOR THE SOUTH AFRICAN BANKING SECTOR

4.1 | Introduction

The CGE model used for the study is based on an extension of the Goodhart, Sunirand, and Tsomocos model (Goodhart et al., 2006a). The model consists of three heterogeneous banks, four private sector agents, a central bank and/or a regulator. In the case of South Africa, the six largest banks by assets and/or deposits are covered. This ensured that almost the entire banking sector is covered as the South African Banking Sector is highly concentrated (Simbanegavi et al., 2015). Two of the banks are taken as heterogeneous banks and the rest of the banks (four in total) are combined as the last heterogeneous bank. There are two periods with certainty in the first and uncertainty in the second. The private sector agents borrow and deposit within the banking system whilst banks conduct financial trade among themselves to obtain an optimal portfolio. The SARB participates in the interbank market by injecting money and affecting the interbank rate. Each bank is subject to the CAR set by a regulator, and penalties are imposed upon violations of the CAR. Banks are liquidated at the end of the second period with profits and assets distributed to shareholders. The private sector agents and the banks incur private (non-pecuniary) costs of defaulting on their financial obligations. They are also penalised proportionately to the size of the default. In the first period, the private sector agents and the banks observe current prices and form correct (rational) expectations of prices in the (uncertain) second period. The private sector agents are heterogeneous with respect to their endowment/income stream and risk attitudes and hence in their propensities for default. Each bank is unique in terms of the size of its capital and business portfolio. The level of risk taken by each bank is also different, and as such they expect different returns because each bank has heterogeneous attitude towards risk. The business environment is assumed to be highly competitive, and so each bank chooses its interest rate when making portfolio decisions in order to maximise its profits. Limited access to consumer credit markets is introduced, with each of the first three private sector agents assigned to a particular bank. The fourth private sector agent is the depositor and deals with all the banks.

The detailed description of the model is given in Essel-Mensah (2021) and for completeness is given in Appendix A. It details the optimisation problem for the banking sector and uses reduced-form equations for the private sector agents as a consequence of limited data availability. The optimisation problem of the banks is specified together with its constraints (Equations A.1 to A.5). This is followed by a discussion on how the reduced form equations are obtained for each of the private sector agents (Equations A.6 to A.8) and the future GDP (Equation A.9). Then there is a discussion on the involvement of the Central Bank and/or the Regulator in the model. Finally, the equilibrium position is considered by discussing the market clearing constraints (Equations A.10 to A.12) and the equilibrium conditions. The calibration of the model follows.

4.2 | 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 2021. These data are influenced by the effects of the COVID-19 pandemic as compared with the data used for our earlier papers Beyers et al. (2020, 2021) which were at the end of

TABLE 1 Normalised balance sheet data for the South African markets.

b	γ	δ	τ
$\overline{m}_t^b$	21.7313	11.3853	10.2075
A_t^b	8.0434	3.1679	2.0605
d_t^b	2.6290	1.6741	1.2613
μ_t^b	0.7221	0.5673	1.3749
$d_{b,t}^{\phi}$	24.6139	11.0514	10.2536
e_t^b	2.5151	1.0649	0.9965
O_t^b	4.5506	3.5437	0.9043

December 2016. The data are publicly available as standardised monthly balance sheet data (BA900)[3] provided by individual South African banks. The credit extension is the total loan excluding interbank lending. The market book (*i.e.* investments) is the difference between the total assets of the bank and the sum of credit extension and interbank lending. 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 values are normalised by dividing by 10^8 for computational tractability and are given in Table 1.

4.3 | 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 2021 from the same source as the balance sheet data obtained in Section 4.2. The default rates for the bad state are arbitrarily chosen to be 0.1 because it is expected that they would be worse than the default rates in the good states. This implies that the repayment rate 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 because banks hardly default on their obligations in that state. For that reason, the repayment rates for the banks in the bad state are set to be relatively higher than the corresponding rates for the private sector agents. Tables 2 and 3 show the repayment rates for households and banks, respectively.

4.4 | Other exogenous variables/parameters

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 $p_{ii} = 0.05$. The interbank rate is set to match the actual interbank rate as at the end of December 2021, and the value was $\rho_t = 0.0225$. The values of the risk weights were set taking into account risks attached to various asset classes from Basel I requirements.[4] These are 1 for loans and 0.2 for interbank lending and market book. Hence, they are $\widehat{\omega} = 1$

[3]https://www.resbank.co.za/en/home/what-we-do/statistics/releases/banking-sector-information/banks-ba900-economic-returns. The data include monthly institutional and maturity breakdown of assets and liabilities. This return is a detailed balance sheet and the main source of information for compiling the monetary and credit aggregates. The BA900 must be reconcilable with the balance sheet which banks and mutual banks submit for bank supervision purposes.

[4]Bank for International Settlements Committee on Banking Regulations and Supervisory Practices (1988) International convergence of capital measurement and capital standards. Bank for International Settlements

TABLE 2 Household repayment to nature-selected bank.

b	α^{γ}	β^{δ}	θ^{τ}
$v^{h^b}_{t+1,i}$	0.9630	0.9648	0.9692
$v^{h^b}_{t+1,ii}$	0.9000	0.9000	0.9000

TABLE 3 Repayment rate of banks.

b	γ	δ	τ
$v^{b}_{t+1,i}$	0.999	0.999	0.999
$v^{b}_{t+1,ii}$	0.955	0.955	0.955

and $\omega = \breve{\omega} = 0.2$. The higher value attached to the risk weight of the loans compared to the other assets is an indication that loans are defaultable and therefore riskier than the other two types of assets.

In reality, the capital of most banks is above the minimum regulatory capital requirements. However, one subjects 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 $\overline{k}^b > k^b_s$. The values of default and capital violation penalties (λ^b_s and λ^b_{ks}, b $\in$ B, s $\in$ S) reflect both the tightness of the Regulator's 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. They have been chosen to be consistent with the following economic conjunction. First, the resulting endogenously solved banks' lending rates are such that all banks earn high profits in the good state and lower in the bad state. This in turn implies that the bank's capital at $t = 2$ decreases, whenever the bad state occurs. Second, all banks coefficients of risk aversion 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 4.

The rate of return on the market book is arbitrarily chosen to be 30 basis points above the repurchase rate at the end of December 2021 as it is naturally expected that the return on the bank's investments will be higher than the repurchase rate. In addition, the repurchase rate is assumed to be default free and so does not include a default premium whilst the return on the asset must include some margin. The repurchase rate as of 31 December 2021 is 0.0375[5], and hence, the rate of return on the market book is set equal to 0.0405. The nominal GDP in the good state is set to equal the actual GDP at the end of December 2021. As one generally expects the GDP in the bad state to be lower than in the good state, it is set to be 4% lower than the GDP in the good state. Thus, $GDP_{(t+1,i)} = 4.504$[6] and $GDP_{(t+1,ii)} = 4.324$.

4.5 | Initial equilibrium position

From the model in Appendix A, if one excludes Lagrange multipliers, then 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 variables which are exogenous need to be chosen. From the estimation of the elasticities (Section 3) and the calibration in this section, these 87 variables have been chosen. We are now left with a system of

[5]https://www.resbank.co.za/en/home/what-we-do/statistics/key-statistics/selected-historical-rates
[6]https://www.statssa.gov.za/publications/P0441/P04411stQuarter2022.pdf

TABLE 4 Capital requirements data and penalties.

b	γ	δ	τ
k_i^b	0.1212	0.1028	0.1042
k_{ii}^b	0.1099	0.0810	0.0840
$\overline{k}_{t+1,i}^b$	0.1300	0.1100	0.1100
$\overline{k}_{t+1,ii}^b$	0.1300	0.1100	0.1100
λ_i^b	0.9000	0.9000	0.9000
λ_{ii}^b	1.0100	1.0100	1.0100
λ_{ki}^b	0.1000	0.1000	0.1000
λ_{kii}^b	0.1000	0.1000	0.1000

56 simultaneous equations in 56 unknown variables. By solving such a system, the values of all the remaining variables are specified and a numerical solution to the model is obtained. The exogenous variables and the resulting initial equilibrium position are shown in Table 5.

5 | POLICY ANALYSIS

5.1 | Introduction

The SARB began using inflation targeting in February 2000 (Comert & Epstein, 2011). Before then, the SARB used many different frameworks. Some of them are exchange rate targeting and money supply targeting. Inflation targeting has developed into a key framework for the SARB for its mandate on price stability. The SARB uses the repo rate to ensure that inflation in the future remains in its target range of 3% and 6%. This shielded South Africa from being significantly impacted by the 2008 global financial crisis (Gordhan, 2011). Before the crisis, there was a massive demand for credit and as a result, between 2005 and mid-2008, the SARB gradually increased the policy rate from 7% to 12% to ensure that the consumer price inflation stayed in its target range (Gordhan, 2011). This assisted in halting the excessive credit extension and mitigated the risks from financial activities. Then in the period of the global financial crisis, to ensure that inflation does not breach the lower target, the SARB reduced rates rapidly and that lowered the impact on the domestic economy.

The financial situation in the country has been deteriorating since the advent of the COVID-19 pandemic. Both the Government and the SARB took some actions to assist in mitigating the effects of the pandemic. Actions taken by the Government included providing bailout packages for the poor and the introduction of lockdown measures to curb the impact of the COVID-19 pandemic. These led to industries collapsing and unemployment rising which resulted into borrowers defaulting on their loans. The SARB's priority was on the stability of the banking sector and, therefore, started loosening capital adequacy requirement during the COVID-19 pandemic to facilitate banks to extend more credits. The SARB also reduced interest rates by 400 basis points since the beginning of the pandemic to stimulate the economy and ensure that inflation target range is not breached. This led to inflation increasing and breaching the upper limit of the SARB's inflation target. The SARB then had to increase its policy rate gradually for 11 consecutive meetings to fight inflation. As of November 2023, the policy rate was 8.25% and inflation was back in the SARB's range.

The Russian–Ukraine war also had some effects on the country. It created a multifaceted risk to the South African economic outlook and thus the making of monetary policy. Disruption of trade and sanctions has not helped the South African economy. Even though South Africa does not trade substantially

TABLE 5 Initial equilibrium position.

		Initial equilibrium		**Exogenous variables in the model**	
	$r^{\gamma}=0.0625$	$k_i^{\delta}=0.1028$	$e_{ii}^{\gamma}=2.5089$	$O^{\gamma}=4.526$	$a\alpha_{,1}^{\gamma}=1.4208$
	$r^{\delta}=0.0609$	$k_{ii}^{\delta}=0.0810$	$e_i^{\delta}=1.2886$	$O^{\delta}=3.5437$	$a\beta_{,1}^{\delta}=0.7728$
	$r^{\tau}=0.0603$	$k_i^{\tau}=0.1042$	$e_{ii}^{\delta}=0.9515$	$O^{\tau}=0.9068$	$a\theta_{,1}^{\tau}=0.6630$
	$r_d^{\gamma}=0.0189$	$k_{ii}^{\tau}=0.0840$	$e_i^{\tau}=1.1372$	$g\alpha_{,i,1}^{\gamma}=0.0614$	$z_{\gamma,1}=2.9876$
	$r_d^{\delta}=0.0188$	$\pi_i^{\gamma}=0.4308$	$e_{ii}^{\tau}=0.8546$	$g\alpha_{,ii,1}^{\gamma}=-0.0037$	$z_{\delta,1}=2.1869$
E	$r_d^{\tau}=0.0225$	$\pi_{ii}^{\gamma}=-0.0062$	$\breve{R}_i=0.9990$	$g\beta_{,i,1}^{\delta}=0.0633$	$z_{\tau,1}=2.1098$
	$\mu_d^{\gamma}=25.0780$	$\pi_i^{\delta}=0.2237$	$\breve{R}_{ii}=0.9550$	$g\beta_{,ii,1}^{\delta}=-0.0037$	$c_i^{\gamma}=0.1209$
	$\mu_d^{\delta}=11.2590$	$\pi_{ii}^{\delta}=-0.1134$	$\mu^{\alpha\gamma}=23.0887$	$g\theta_{,i,1}^{\tau}=0.0678$	$c_{ii}^{\gamma}=0.4536$
	$\mu_d^{\tau}=10.4843$	$\pi_i^{\tau}=0.1407$	$\mu^{\beta\delta}=12.0784$	$g\theta_{,ii,1}^{\tau}=-0.0037$	$c_i^{\delta}=0.2414$
	$k_i^{\gamma}=0.1099$	$\pi_{ii}^{\tau}=-0.0062$	$\mu^{\theta\tau}=10.8233$	$\mu_{i,1}=0.1544$	$c_{ii}^{\delta}=0.0066$
	$k_{ii}^{\gamma}=0.1099$	$e_i^{\gamma}=2.9459$		$\mu_{ii,1}=0.1952$	$c_i^{\tau}=0.3810$
				$B=2.9679$	$c_{ii}^{\tau}=0.0006$
				$r^{A}=0.0405$	$e_0^{\tau}=0.9965$
	$\mu^{\tau}=0.1136$	$d_{\gamma}^{\phi}=24.6139$		$A^{\gamma}=8.0434$	$\mu_{s,2}=0, \forall$ s $\in$ S
	$\rho=0.0225$	$d_{\delta}^{\phi}=11.0514$	$\upsilon_i^{\alpha\gamma}=0.9630$	$A^{\delta}=3.1679$	$\mu_{s,3}=0.1672, \forall$ s $\in$ S
	$\overline{m}_t^{\gamma}=21.7313$	$d_{\tau}^{\phi}=10.2536$	$\upsilon_i^{\beta\delta}=0.9648$	$A^{\tau}=2.0605$	$\omega=0.2000$
C	$\overline{m}_t^{\delta}=11.3853$	$d^{\gamma}=1.9069$	$\upsilon_i^{\theta\tau}=0.9692$	$e_0^{\gamma}=2.5171$	$\breve{\omega}=0.2000$
	$\overline{m}_t^{\tau}=10.2075$	$d^{\delta}=1.1068$	$GDP_i=4.504$	$e_0^{\delta}=1.0649$	$\widehat{\omega}=1.0000$
				$g_{h,s,2}=0.0643, \forall$ h $\in H^b$, $\forall$ s $\in S$	$g_{h,i,3}=-0.0250, \forall$ h $\in H^b$
				$g_{h,ii,3}=-0.0659, \forall$ h $\in H^b$	$a^{hb},2=0, \forall$ h $\in H^b$
				$a^{hb},3=1.1458, \forall$ h $\in H^b$	$a^{hb},4=-0.0571, \forall$ h $\in H^b$
				$\lambda_i^b=0.9000, \forall$ b $\in B$	$z_b,2=0.1400, \forall$ b $\in B$
	$GDP_{ii}=4.324$			$\lambda_{ii}^b=1.0100 \forall$ b $\in$ B	$z_b,4=-0.1000, \forall$ b $\in$ B
	$\upsilon_{ii}^{\alpha\gamma}=0.0900$	$\upsilon_i^{\gamma}=0.9990$	$\upsilon_{ii}^{\delta}=0.9500$	$k_s^{\delta}=0.1100, \forall$ s $\in$ S	$z_b,3=0.5000, \forall$ b $\in B$
A	$\upsilon_{ii}^{\beta\delta}=0.9000$	$\upsilon_{ii}^{\gamma}=0.9500$	$\upsilon_i^{\tau}=0.9990$	$k_s^{\tau}=0.1100, \forall$ s $\in$ S	$\lambda_{ks}^b=0.1100, \forall$ b $\in$ B
	$\upsilon_{ii}^{\theta\tau}=0.9000$	$\upsilon_i^{\delta}=0.9990$	$\upsilon_{ii}^{\tau}=0.9500$	$k_s^{\gamma}=0.1300, \forall$ s $\in$ S	$p=0.95$

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

with any of the two countries, the shock to the global trade has impacted on the country's exports and imports. This created inflationary pressures through higher energy and food prices and led to a more tightening of the monetary policy. Then there is also the problem of load shedding. Load shedding began about a decade ago and continues to get worse with time. It has negatively affected firms through waisted worthful working hours rather than producing goods and services as a result of lack of electricity. Families have had their electrical appliances damaged because of the load shedding. The economy has been the hardest hit as the unemployment increased and the government revenue declined substantially. The SARB reduced its GDP growth forecast for 2023 to 0.3% from an earlier forecast of 2.3% as a result of the load shedding.[7]

[7]SARB. 2023. Quarterly bulletin

The SARB has a model that assists them in determining monetary policy to fulfil their inflation target (Smal et al., 2007; Botha et al., 2017). The CGE model could be considered as one such model. Even though the intention is to ensure that inflation remains within its target range, one may also be interested in the macroeconomic effects on banks and the economy more generally.

5.2 | Expansionary monetary policy

The repo rate is reduced by a percentage point. The impact on the key variables is as follows: a reduction in both the deposit and lending rates for all banks, a reduction of profits in both states for all banks, a reduction in the repayment rate for bank δ in the good state, a rise in the repayment rate for the rest and an increase in GDP in both states. The percentage changes in key variables are shown in Table 6, where:

r_t^b = lending rate offered by bank b in the period t,
$r_{d,t}^b$ = deposit rate offered by bank b in the period t,
ρ_t = interbank rate in the period t,
$\pi_{t,s}^b$ = profit of bank b in state s in the period t,
$k_{t,s}^b$ = capital adequacy ratio of bank b in state s in the period t,
$GDP_{t,s}$ = GDP in state s in the period t and
$v_{t,s}^b$ = repayment rate of bank b to all its creditors in state s in the period t.

With a reduction in the interbank rate, the interbank market is more attractive to the net borrower and less attractive to the net lenders. Therefore, bank τ, the net borrower in the interbank market, readjusts its portfolio by borrowing more from the interbank market and lending more to its customer θ in the customer loan market. It also demands fewer deposits from agent ϕ. Its actions put downward pressure on its lending as well as deposit rates ensuring that both of them reduce. The net lenders, banks γ and δ, on the other hand, reduce their lending in the interbank market and rather lend more to their private sector agents in the loan market. With increased credit availability, they can take fewer deposits. Such portfolio readjustments of the banks ensure that both their deposit and lending rates also reduce. Lower interest rates result in lower defaults for households from increased liquidity. So the three banks expect the overall supply of credit to rise because of their greater credit extension. This causes the probability of household default to decline as a result of greater aggregate credit supply that contributes to increasing household liquidity as well as income. All these, therefore, lead to greater economic activities from not only the private sector agents but also the banks that ensure GDP increases in both states. However, the increase in GDP was not substantial as a result of credit supply issues encountered in the South African economy because of actions taken by the government to curb the effects of the COVID-19 pandemic. This is a reflection of the fact that the South African economy entered into technical recession even with all the reduction in the repo rates by the SARB.

On reducing the repo rate, it is expected that the repayment rates for both the customers and the banks will improve. Even though, this happened, apart from bank δ whose repayment rate worsens in the good state, the improvement was not substantial as a result of lower effective demand following the restrictions imposed during the COVID-19 pandemic. This reduced supply shock was reflected in

TABLE 6 Repo rate reduced by 1%.

Bank	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	−1.056	−0.470		−0.002	−0.186	−0.033	−0.055	−0.003	0.002		
γ	−1.052	−0.458	−1.000	−0.001	−0.025	−0.032	−0.032	0.001	0.002	0.035	0.035
τ	−1.000	−0.520		−0.107	−2.822	−0.060	−0.515	0.001	0.037		

the GDP increasing only marginally. However, it is not surprising that in reality, the economy ended up in recession during the pandemic because of the severity of the adverse supply shock.

For a given capital level, the banks infringe on their capital requirements as a result of the risk-weighted assets increasing because of the effects of higher credit extension and lower repayment rates off-setting the effects of the reduction in interest rates. This is exacerbated by the fact that banks consider the benefit from increased profits more rewarding than the higher cost of violating the capital requirements. Therefore, in a situation where capital is initially compromised, the profit effect from expansionary monetary policy overshadows the capital requirement violation cost, thus worsening the capital adequacy condition of the banks. The marginal costs from default and capital requirements' violation differ. Therefore, as was stated in Goodhart et al. (2004), to achieve the optimal banks' asset composition, interactions between the capital adequacy ratio and credit extension should be analysed contemporaneously. Moreover, as banks want to maximise their profit all the time, they respond to lower defaults on consumer borrowing by increasing their lending. In addition, there exists a trade-off between the marginal benefits and cost of default, and the banks choose slightly lower profitability to reduce the default cost.

As far as welfare is concerned, the three private agents, who are allowed to borrow from their nature selected banks, improve their utility or payoffs as a result of lower borrowing costs and lower default penalties since they increase their repayment. The expected income of the other private sector agent who is allowed to deposit funds in any of the banks falls because of reduced deposit rates. Its consumption is therefore reduced. Similarly, the payoffs of all the banks reduce. This is because the benefit resulting from higher repayment rates from their customers is dwarfed by the negative effects of lower lending rates. More money chases the same amount of goods, so by the quantity theory of money proposition, prices in both states increase. Put differently, inflation increases. As income improves from economic activities as a result of higher prices, this contributes to higher repayment rates.

5.3 | Tightening of the capital adequacy requirement

As the CAR for each bank is enhanced so that each bank violates its CAR, to tighten the capital requirement, one can reduce the capital adequacy ratio for each bank. This is performed by increasing the risk weights on loans akin to what was carried out in Goodhart et al. (2004). Thus, the risk weights on loans are increased by 10%. As expected, the profits for all three banks decrease in both states. The deposit rates and the lending rates for all three banks as well as the interbank rate increase. By the CAR violation trade-off, the banks' capital adequacy ratios reduce in each of the two states. Repayment rates for all the banks in the bad state increase. The repayment rates for banks γ and τ decrease in the good state. GDP decreases slightly. The percentage changes in key variables as a result of the change are shown in Table 7.

As far as the effects on the banks are concerned, tightening the capital requirement regulatory policy is similar to a contractionary monetary policy. Therefore, it is expected that the interbank rate will increase. All the banks adjust their portfolios to take advantage of the increase in the interbank rate. The two net lenders, bank γ and bank δ, increase their lending in the interbank market whilst the net borrower, bank τ, reduces its borrowing as it is now more attractive to do so. The net lenders instead reduce their credit extension in the consumer loan market and increase their deposit intake. These adjustments

TABLE 7 Risk weights on loans increased by 10%.

Bank	r_d^b	r^b	ρ	π_i^b	π_{ii}^b	k_i^b	k_{ii}^b	v_i^b	v_{ii}^b	GDP_i	GDP_{ii}
δ	0.910	0.342		−0.038	−3.147	−0.515	−0.922	0.000	0.066		
γ	0.904	0.336	0.582	−0.026	−0.561	−0.674	−0.720	−0.002	0.023	−0.018	−0.018
τ	0.000	0.050		−0.002	−22.966	−0.369	−4.194	−0.001	0.322		

ensure that both their deposit and lending rates increase in both states. Bank τ, the net borrower, on the other hand, increases its deposit demand and rather borrows less in the interbank market. Moreover, it lends more to its customer. These lead to increases in both the deposit and lending rates.

As the shock is equivalent to tightening monetary policy, it is expected that less credit becomes available and by the liquidity structure of interest rates, the interest rates should increase. The bank which was not constrained by funds could transfer the negative shock to the two banks and the private sector agents. This suggests that banks with many investment opportunities and sufficient capital can turn things around in terms of adverse shocks and which in the end negatively affect private sector agents and banks with limited opportunities and funds.

Fewer funds become available as even though agent ϕ gains from the increased deposit rates, the other agents lose out from the increase in the lending rate of their nature selected banks. This reduction in funds outweighs the increase in funds from the other agent who benefited as a result of the deposit rate increase. Therefore, by the quantity theory of money proposition, economic activities (prices of goods) worsen from the much-reduced income and liquidity which leads to a slight decrease in GDP. Finally, the profits of the banks reduce as a result of higher payments on CAR violation penalties and the higher interest payments on deposits to agent ϕ outweighing the increased interest receipt of the banks from their nature selected customers. As the banks violate their CAR in the initial condition, it may be regarded as an adverse economic condition. Therefore, one may conclude that as CAR is tightened during periods of economic downturn, banks' profits further reduce.

We need to mention though that the SARB actually loosened the capital adequacy requirement during the COVID-19 pandemic to facilitate banks to extend more credits, but because the effect is similar to that of expansionary monetary policy, we decided to consider tightening the CAR. The result of loosening CAR is just the reverse of tightening CAR.

6 | CONCLUDING REMARKS

The SARB uses the policy rate to ensure that inflation remains within its targeted range. When the repo rate is reduced, the macroeconmic effects in the economy are as follows: a reduction in both the deposit and lending rates for all banks, a reduction in profit in each state for each bank, an increase in the repayment rate for bank γ and a reduction in the repayment rate for the rest. These changes lead to an increase in inflation. Thus, if the policymakers are interested in reducing inflation, they could increase the repo rate. It is also expected that a reduction in the repo rate would lead to an increase in GDP in both states, but only marginally because of the adverse supply-side effects as a result of the COVID-19 pandemic. It is therefore not surprising that even though the SARB reduced the repo rate substantially, South Africa ended up in recession from supply-side pressures during the pandemic. Thus, we conclude that the CGE model performed well in the South African context.

The result also suggests that if a bank is in a tight capital position, then expansionary monetary policy rather worsens the capital adequacy position of that particular bank as the marginal benefit effect dominates the capital requirement violation cost. In addition, the higher liquidity resulting from the expansionary monetary policy may induce banks to expand their credit extension rather than improve their capital requirement position.

In summary, expansionary monetary policy indeed leads to higher expected inflation, so the SARB to ensure that inflation does not breach the lower bound of its target could reduce the repo rate. However, restrictive monetary policy (increasing the repo rate) has the opposite effect. So the SARB could increase the repo rate if it is concerned that expected inflation may breach the upper bound of its target range. Finally, even though the actions of the SARB aggressively reducing the repo rate may not lead to substantial positive GDP growth, it will help ameliorating the effects of the COVID-19 pandemic. Given an initial tight capital position, expansionary monetary policy worsens the capital adequacy condition of banks as the banks' attempt to make additional profit overshadows the cost incurred from violating capital requirements. There is a trade-off between earning a greater excess return through interest payments and the cost of capital requirement violation. Expansionary monetary policy, even though it reduces aggregate consumer default rates, it does not increase banks' profit because of lower interest rate payments. Hence, it may worsen the capital requirement position.

ACKNOWLEDGMENTS

The financial assistance of the University of Pretoria (UP) and the ABSA Chair in Actuarial Science towards this research is hereby acknowledged. Dimitrios P. Tsomocos acknowledges the support from the Czech Science Foundation grant no. 20-17044S. Opinions expressed, and conclusions arrived at, are those of the authors and are not necessarily attributed to the UP or ABSA or the Czech Science Foundation.

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How to cite this article: Beyers, C., Essel-Mensah, K.A. & Tsomocos, D.P. (2024) A computable general equilibrium model of the monetary policy implications for financial stability in South Africa. *South African Journal of Economics*, 1–29. Available from: https://doi.org/10.1111/saje.12383

APPENDIX A: THE BANKING SECTOR CGE MODEL

A.1 | Introduction

The model used in this paper is an extension of the Goodhart, Sunirand and Tsomocos model (Goodhart et al., 2004). The model, as illustrated in Aspachs et al. (2007), Goodhart et al. (2005, 2006a, 2006b), Lewis (2010) and 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, 2006b), 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 categorised 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. Banks can be strategically grouped to assist in focussing the analysis. For example, 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 analysing the crisis in the real estate sector. However, in South Africa, the effect of the 2008 financial crisis was muted because of 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 specialise in mortgage lending. In this study, consideration is given to the largest six banks by assets which is in line with the analysis carried out 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 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. Individuals/firms being attached to a particular bank may be unrealistic as individuals or firms can borrow from any bank. However, a provision of microfoundations to this limited participation assumption is achieved by showing that whenever banks incorporate a relative performance criterion in their maximisation problem, limited participation emerges naturally as an equilibrium phenomenon within the model (Bhattacharya et al., 2003). Limited participation is the specialisation of banks' lending to specific consumer classes. 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 Figure A1. 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 Aspachs et al. (2007), Goodhart et al. (2006b), Lewis (2010) or finite, *e.g.* two time periods, $t \in T = \{1, 2\}$ as in Catarineu-Rabell et al. (2005) and 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. One hastens to add that the computational complexity of the period increases considerably. Hence, the modeller needs to simplify the banking sector and, therefore, may potentially miss important contagious effects among heterogeneous banks. It is assumed there exist two possible future states. One state is the good/normal state and the other is the bad/crisis state of nature. The good state is denoted by i and its corresponding probability p and the bad state by ii and its probability $1-p$. 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 Figure A2.

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 Bank 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 A1. Capital is carried over, *i.e.* for each period, capital is calculated as capital from the previous period plus 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

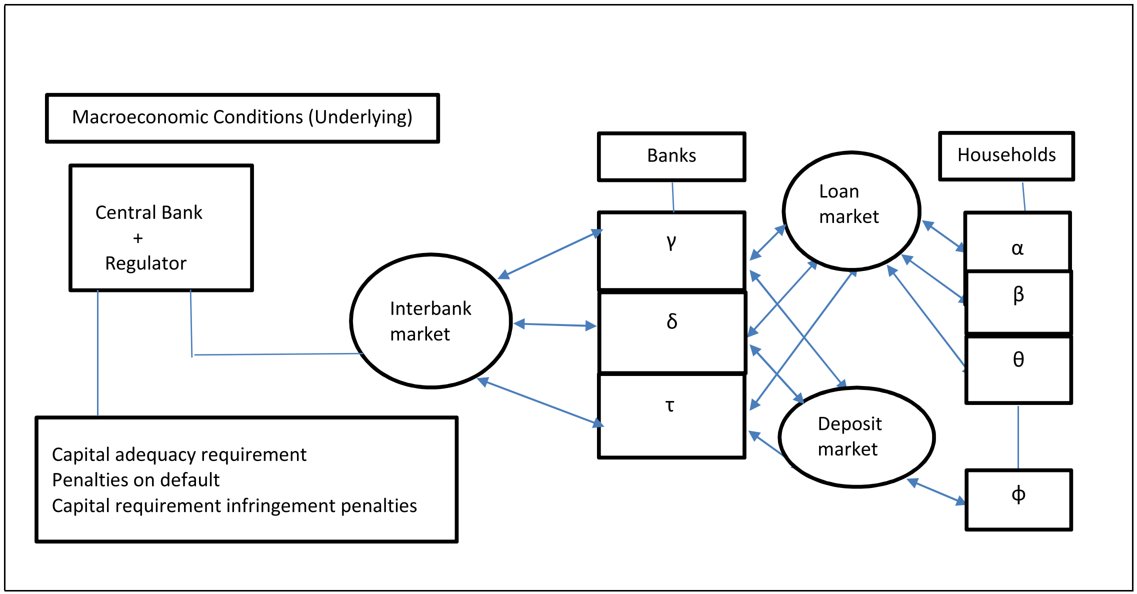

FIGURE A1 The structure of the model (see Lewis, 2010).

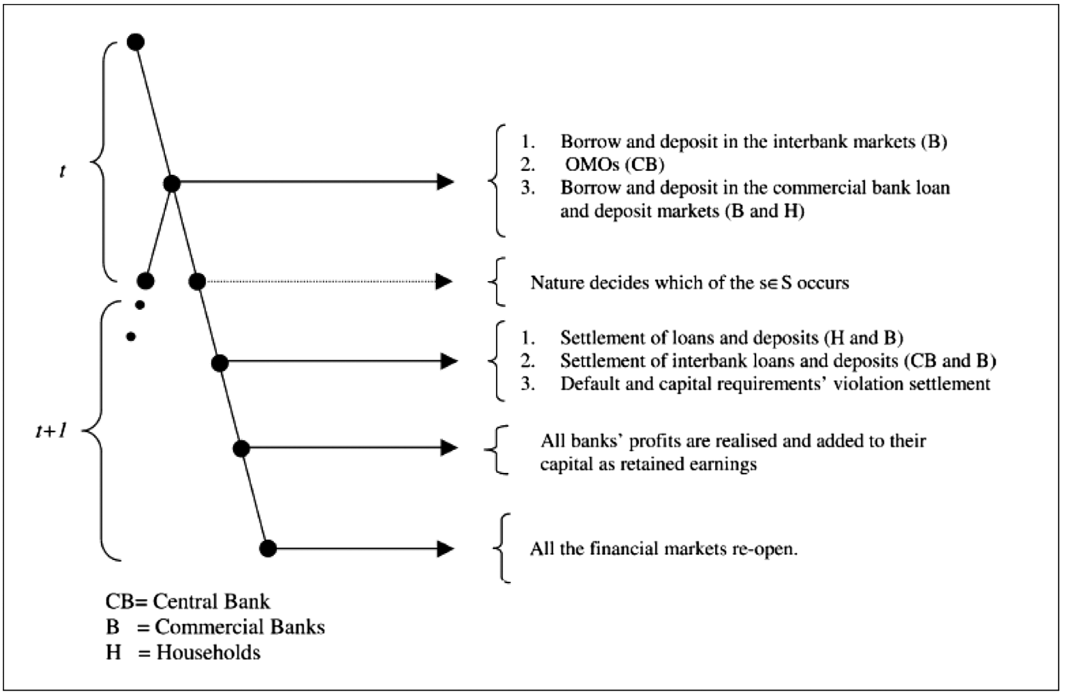

FIGURE A2 Time structure of the model.

TABLE A1 Balance sheet structure of the bank.

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

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.

A.2 | 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 maximise 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 deposits 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, default could be strategic or because of 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, whilst 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.[8] 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. In other words, banks pay their creditors pro rata. Hence, banks cannot choose to pay their depositors and decide not to pay their fellow banks and/or the Central Bank. In the model, banks are allowed to infringe on their capital adequacy requirements. However, banks are punished for each infringement by the regulator imposing a capital requirements infringement penalty on them. 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, the banks are subjected 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'. With this assumption, corner equilibria is ruled out and therefore one could focus the analysis entirely on well-defined interior solutions whereby banks violate their enhanced capital requirements. It also assumes that penalties are linear as capital declines from its ideal level.

The time horizon over which banks maximise their expected profit is taken as 1 year. 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 optimisation of their utility is not explicitly modelled as it is extremely difficult to obtain data such as amounts borrowed by individual households. As a result, reduced form equations are used.

A.2.1 | Banks optimisation problem

Each bank maximises 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 optimisation problem of bank b in period t is

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

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

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

[8]See, Tsomocos & Zicchino (2012) where the isomorphism between repayment rates and probability of default is discussed.

(*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) and

$$(1+\rho_t)v^b_{t+1,s}\mu^b_t + \left(1+r^b_{d,t}\right)v^b_{t+1,s}\mu^b_{d,t} + e^b_t + O^b_t \\ \leq v^{h^b}_{t+1,s}\left(1+r^b_t\right)\overline{m}^b_t + \left(1+r^A_t\right)A^b_t + \breve{R}_{t+1,s}d^b_t(1+\rho_t), s \in S, \tag{A.3}$$

(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

$$\pi^b_{t+1,s} = v^{h^b}_{t+1,s}\left(1+r^b_t\right)\overline{m}^b_t + \left(1+r^A_t\right)A^b_t + \breve{R}_{t+1,s}d^b_t(1+\rho_t) \\ -\left((1+\rho_t)v^b_{t+1,s}\mu^b_t + \left(1+r^b_{d,t}\right)v^b_{t+1,s}\mu^b_{d,t} + e^b_t + O^b_t\right), \tag{A.4}$$

(*i.e.* profit = money received from assets − money paid on liabilities).

The capital at period $t+1$ is given by

$$e^b_{t+1,s} = e^b_t + \pi^b_{t+1,s}, \tag{A.5}$$

(*i.e.* capital at period $t+1$ = capital at period t + profit earned).

The capital adequacy ratio is

$$k^b_{t+1,s} = \frac{e^b_{t+1,s}}{\widehat{\omega}v^{h^b}_{t+1,s}\left(1+r^b_t\right)\overline{m}^b_t + \omega\breve{R}_{t+1,s}d^b_t(1+\rho_t) + \breve{\omega}\left(1+r^A_t\right)A^b_t}, \tag{A.5}$$

(*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 $s \in S$,
$\overline{k}^b_{t+1,s}$ = 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 $t+1$,
$\overline{m}^b_t$ = 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 $t+1$,

$\breve{R}_{t+1,s}=$ repayment rate by banks from their interbank lending,
$\widehat{\omega}=$ risk weight on consumer loans,
$\breve{\omega}=$ risk weight on market book, and.
$\omega=$ risk weight on the interbank lending.

A.3 | 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 optimisation problem of households is not explicitly modelled. The maximisation problems are expressed in reduced form equations.

A.3.1 | Household borrowers demand for loans

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

$$\ln\left(\mu_t^{h^b}\right)=a_{h^b,1}+a_{h^b,2}trend+a_{h^b,3}\ln\left[p(GDP)_{t+1,i}+(1-p)(GDP)_{t+1,ii}\right]+a_{h^b,4}r_t^b, \tag{A.6}$$

where $\mu_t^{h^b}=$ amount of money that agent $h^b\in H^b$ 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, and $a_{h^b,1}$, $a_{h^b,2}$, $a_{h^b,3}$ and $a_{h^b,4}$ are the coefficients or the elasticities of the model.

A.3.2 | Supply of deposits

Unlike the loan markets, the limited participation assumption does not apply in the deposit markets. Thus, 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

$$\begin{aligned}\ln\left(d_{b,t}^{\theta}\right)=\;&z_{b,1}+z_{b,2}\ln\left[p(GDP)_{t+1,i}+(1-p)(GDP)_{t+1,ii}\right]+\\&z_{b,3}\left[r_{d,t}^{b}\left(pv_{t+1,i}^{b}+(1-p)v_{t+1,ii}^{b}\right)\right]+z_{b,4}\sum_{b'\neq b\in B}\left[r_{d,t}^{b'}\left(pv_{t+1,i}^{b}+(1-p)v_{t+1,ii}^{b'}\right)\right],\end{aligned} \tag{A.7}$$

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 $r_{d,t}^{b'}=$ competitor interest rate on deposits, $v_{t+1,i}^{b}=$ repayment rate of bank b in $t+1,s$ and $v_{t+1,ii}^{b'}$ is the repayment rate of bank b's competitors, and $z_{b,1}$, $z_{b,2}$, $z_{b,3}$ and $z_{b,4}$ are the coefficients or elasticities of the model.

A.3.3 | 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 rate of the households also depend on the combined credit supply in the previous period. Hence, the reduced form equation of the repayment rates of each household is of the form

$$\ln\left(v_{t+1,s}^{h^b}\right) = g_{h^b,s,1} + g_{h^b,s,2}\ln(GDP_{t+1,s}) + g_{h^b,s,3}\left[\ln\left(\overline{m}_t^{\gamma}\right) + \ln\left(\overline{m}_t^{\delta}\right) + \ln\left(\overline{m}_t^{\tau}\right)\right], \tag{A.8}$$

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 $\overline{m}_t^b$ 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.

A.4 | 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 SARB 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.

A.5 | Gross Domestic Product

From Equations (A.6)–(A.8), the households' actions are assumed to depend on their expected GDP in the second period. So, in this section, consideration is giving to endogenising GDP in both states of the second period. Also in the model, the Modigliani–Miller proposition does not hold. Therefore, higher credit extension as a result of loosening monetary policy, or any other shocks, generates a positive real balance effect that raises consumption demand and ultimately GDP. Hence, 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

$$\ln(GDP_{t+1,s}) = \mu_{s,1} + \mu_{s,2}trend + \mu_{s,3}\left[\ln\left(\overline{m}_t^{\gamma}\right) + \ln\left(\overline{m}_t^{\delta}\right) + \ln\left(\overline{m}_t^{\tau}\right)\right], \tag{A.9}$$

where $\mu_{s,1}$, $\mu_{s,2}$ and $\mu_{s,3}$ are the coefficients or the elasticities of the model.

A.6 | Equilibrium

A.6.1 | 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.*

$$1 + r_t^b = \frac{\mu_t^{h^b}}{\overline{m}_t^b}, h^b \in H^b, \forall b \in B, \tag{A.10}$$

Deposits market clears, *i.e.*

$$1 + r_{d,t}^b = \frac{\mu_{d,t}^b}{d_{b,t}^{\Theta}}, \forall b \in B, \tag{A.11}$$

Interbank market clears, *i.e.*

$$1 + \rho_t = \frac{\overline{B}_t + \sum_{b \in B} \mu_t^b}{M_t + \sum_{b \in B} d_t^t}, \tag{A.12}$$

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

A.6.2 | 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 maximise 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 $\sigma^b = \left\{\overline{m}_t^b, \mu_t^b, d_t^b, \mu_{d,t}^b, v_{t+1,s}^b, \pi_{t+1,s}^b, e_{t+1,s}^b, k_{t+1,s}^b\right\} \in R_+^4 \times R^4$.

for $b \in B$; $\sigma^{h^b} = \left(\mu_t^{h^b}, v_{t+1,s}^{h^b}\right) \in R_+ \times R$ for $h^b \in H^b$ and; $\sigma^{\phi} = \left(d_b^{\phi}\right) \in R_+$ for $b \in B$; and $GDP_{t+1,s} \in R$.

Also, let $\eta = \left\{r_t^{\gamma}, r_t^{\tau}, r_t^{\delta}, r_{d,t}^{\tau}, r_{d,t}^{\delta}, M_t, \overline{B}_t\right\}, B^b(\eta) = \{\sigma^2 : (13) - (16) \text{ hold}\}$. We say that the vector $\left(\left(\sigma^b\right)_{b \in B}, \eta, \left(\sigma^{h^b}\right)_{h^b \in H^b}, \sigma^{\phi}, (GDP_{t+1,s})_{s \in S}\right)$ is a *monetary equilibrium with banks and default* for the economy $E = \left\{\left(e_t^b, O^b, A^b\right)_{b \in B}; p; \left(\overline{k}_{t+1,s}^b, \lambda_s^b, \lambda_{ks}^b, \widehat{\omega}, \omega, \breve{\omega}\right)_{b \in B, s \in S}; r_t^A; \rho\right\}$.

only if,

(i) $\sigma^b \in \arg\max E_t\left(\Pi_{t+1}^b\left(\pi_{t+1}^b\right)\right), b \in B$ so all banks optimise their payoff function,
(ii) all markets clear according to Equations (A.10)–(A.12),
(iii) $\breve{R}_s = \frac{\sum_{b \in B} v_{t+1,s}^b \mu_t^b}{\sum_{b \in B} \mu_t^b}, s \in S$, (*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 (A.6)–(A.9).

APPENDIX B: TABLE OF RESULTS FOR THE ELASTICITIES OF THE REDUCED FORM EQUATIONS

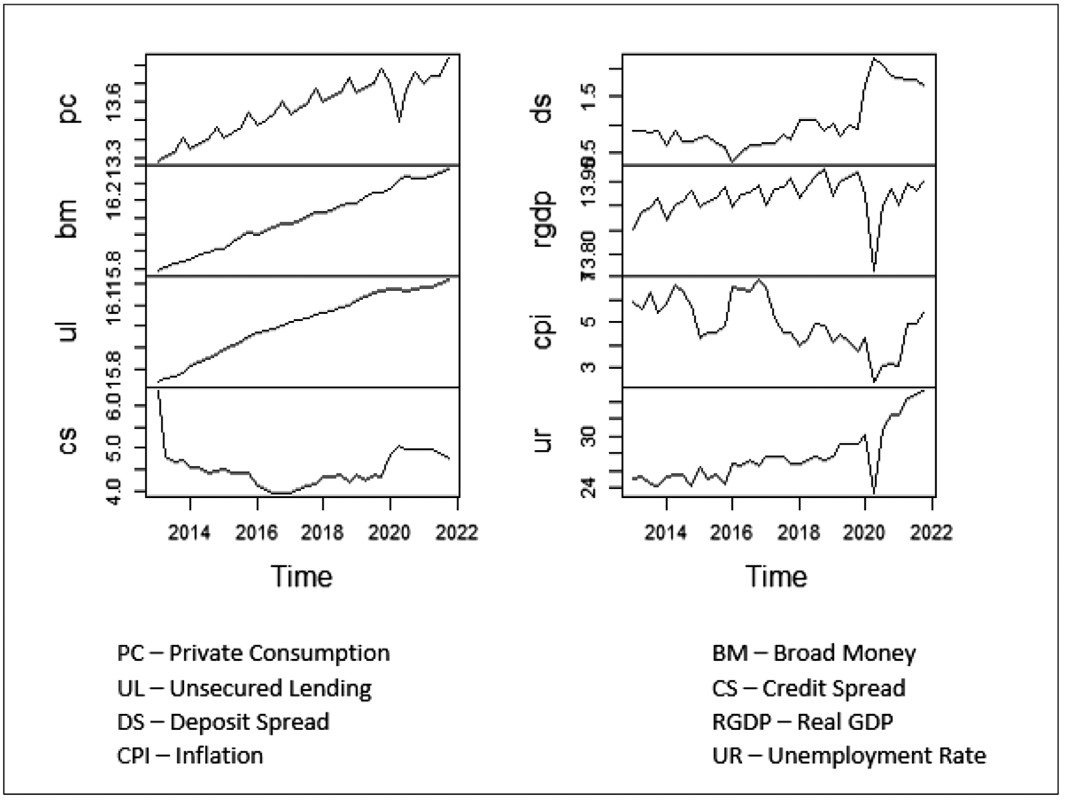

FIGURE B1 Time series of the loans demand variables.

TABLE B1 Augmented Dickey-Fuller (ADF) test for loans demand.

	ADF unit root tests		
Variable	Exogenous	Test stat	Critical value(5%)
Unsecured lending	Constant, trend	−0.5919	−3.5181
(natural log)	constant	−2.9127	−2.9314
	none	0.9932	−1.9487
Private consumption	Constant, trend	1.1304	−3.5266
(natural log)	constant	−2.2528	−2.9390
	none	0.3951	−1.9499
GDP	Constant, trend	0.7063	−3.5366
(natural log)	constant	−2.6052	−2.9369
	none	−0.0696	−1.9499

TABLE B2 Johansen cointegration tests.

No. of CV	Trace statistics	Critical value (5%)
None	270.3142	159.5257
At most 1	153.0614	125.5164
At most 2	104.0896	95.7537
At most 3	68.3766	69.8189
At most 4	41.7009	47.8561
At most 5	18.1338	29.7971
At most 6	4.3308	15.4947
At most 7	0.1986	3.8415
No. of CV	Max–Eigen statistics	Critical value (5%)
None	117.2528	52.3626
At most 1	48.9717	46.2314
At most 2	35.7131	40.0776
At most 3	26.6756	33.8769
At most 4	23.5671	27.5843
At most 5	13.8029	21.1316
At most 6	4.1322	14.2646
At most 7	0.1986	3.8415

TABLE B3 The loans demand variables.

Variable	Coefficients	Standard error	*t* stat	*p*-value
Credit spread	−0.0571	0.0297	−1.9189	0.0640
Real GDP	1.1458	0.0146	78.2306	0.0000
CPI	−0.0680	0.0121	−5.6061	0.0000
Unemployment rate	0.0240	0.0044	5.4351	0.0000

TABLE B4 The Hausman test.

Correlated random effects – Hausman test				
Test cross-section random effects				
Test summary		Chi-sq. statistic	Chi-sq. d.f.	Prob.
Cross-section random		90.3949	2	0.0000
Cross-section random effects test comparisons:				
Variable	Fixed	Random	Var (diff.)	Prob.
GDP	0.0643	0.0002	0.0000	0.0000
Total loan	−0.0292	0.0000	0.0000	0.0000

TABLE B5 The fixed effects model.

Dependent variable:	Natural log of non-performing loan		
Method:	Panel least squares		
Cross-sections included:	3		
Total panel (balanced) observations:	141		
Variable	Coefficient	Std. error	*t*-statistic
Constant	−1.1157	0.2727	−4.0918
GDP	0.0643	0.0113	5.7116
Total loan	−0.0250	0.0024	−10.3611
	Effects specification		
Cross-section fixed (dummy variables)			
R-squared	0.4477	Mean dependent variable	−0.0238
Adjusted *R*-squared	0.4314	S.D. dependent variable	0.0063
S.E. of regression	0.0048	Akaike info criterion	−7.8254
Sum squared residual	0.0031	Schwarz criterion	−7.7208
Log-likelihood	556.6880	Hannan–Quinn criteria	−7.7829
F-statistic	27.5569	Durbin–Watson statistic	0.3631
Prob(*F*-statistic)	0.0000		

TABLE B6 ADF test for the future GDP variables.

Variable	Exogenous	Test stat	Critical value (5%)
Total Loans	Constant, trend	0.4927	−3.5266
	constant	−2.8188	−2.9332
	none	1.6307	−1.9487
GDP	Constant, trend	0.7063	−3.5366
	constant	−2.6052	−2.9369
	none	−0.0696	−1.9499

TABLE B7 Johansen cointegration test for future GDP variables.

No. of CV	Trace statistics	Critical value (5%)
None	33.2823	15.4947
At most 1	6.8382	3.8415
No. of CV	Max–Eigen statistics	Critical value (5%)
None	26.6441	14.2646
At most 1	6.6382	3.8415

TABLE B8 The coefficients of the future GDP variable.

	Coefficients	Standard error	*t* stat	*p*-value
Intercept	11.2380	0.3749	29.9781	0.0000
Total loan	0.1672	0.0236	7.0980	0.0000