A Computable General Equilibrium Model as a Banking Sector Regulatory Tool in South Africa

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Abstract

A Computable General Equilibrium (CGE) model is used as a regulatory tool for the banking sector in South Africa. The model is used to determine the effects of regulatory penalties, capital adequacy requirements (CAR), and the monetary policy on the economy.

Our results indicate that there is a trade off between the default and the CAR regulation. For example, when reducing the default penalty the banks profits increase whereas reducing the CAR violation penalty banks profits decrease. Changes to the default penalty have a stronger impact than changes in the CAR violation penalty (i.e. when both penalties are reduced, the banks profits increase). Moreover, regulatory policies that are targeted at different banks produce asymmetric results, as well capitalized banks with richer portfolios swiftly readjust their balance sheet and transfer the default externality to the more constrained banks and/or the private sector agents.

keywords - Computable general equilibrium; Banking regulation; Capital requirement; Base money; Policy rate

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1 Introduction

It is argued in Falkena et al. (2001) that the financial sector, in particular the banking industry, has undergone major structural changes internationally and regulators have been challenged to keep up with these changes. The South African regulatory structure followed the international trend whereby regulators hardly looked beyond their borders. Capital requirements were based on ratios of capital to total assets (Botha and Makina, 2011). The regulation of the banking sector became the sole responsibility of the South African Reserve Bank (SARB) in 1987.

One of the SARB's main responsibilities is inflation targeting. It serves to discipline monetary policy and increases the SARB's accountability (Van der Merwe, 2004). The aim of the inflation targeting regime is to keep inflation, defined in the case of South Africa as the consumer price index (CPI), in a fixed range. The SARB's inflation target range is 3% to 6%. This target is achieved through periodic adjustments of the repurchase (or repo) rate. The repo rate is the rate at which the South African banks borrow money from the SARB. The SARB sets the repo rate to achieve its inflation target. A CGE model may potentially assist in determining the appropriate repo rate. In addition, CGE models could assist in estimating the impact of actions taken by the SARB, for example the effects of changes in the policy rate on the banks and the economy as a whole. This is crucial especially during periods of global uncertainty and systemic risk, such as the Covid-19 pandemic, which has induced the SARB to reduce the policy rate by 3.0% from January to July 2020 in order to ensure inflation remains within its target range and also contain its negative impact on GDP.

Banking regulations, especially those related to capital requirements, have positive effects. Capital acts as a buffer against losses. Therefore a good implementation of CAR may prevent bank failures. In addition, with limited liability in place, the tendency for banks to take higher risk is reduced when there is more skin in the game (Barth et al., 2004). CAR also helps to align the incentives of the shareholders of the bank with those of the depositors and the creditors of the bank. CAR may also have negative effects. For instance, it may increase the risk taking behavior of the banks as they may want to increase their profits. Increasing profit allows them to retain funds to further increase their capital in order not to violate the minimum capital required. Also, higher capital requirements in a general equilibrium context may induce banks to demand lower deposits which could lead to liquidity problems (Gorton and Winton, 2017).

Few South African banks failures have occurred since the beginning of the 21st century. The prominent cases are Saambou bank in 2002, African Bank in 2014 and VBS bank as recently as 2018. Apart from Saambou bank's failure which resulted in a few other small bank runs, the failures did not generate systemic risk. It is also interesting to note that South Africa did not experience any bank failures during the 2008 global financial crisis. This is partly attributed to the SARB increasing CAR before the crisis (Havemann, 2019). This indicates that prudent pre-emptive implementation of banking sector regulation could prevent the occurrence of a financial crisis.

Recently, there has been a variety of general equilibrium papers that try to address how to model financial stability and financial frictions. Research on general equilibrium (GE) models with incomplete markets have illuminated the complex and important relationship between banks, their customers and the regulators. This interrelationship impacts upon financial stability. In most of the existing literature, dynamic stochastic general equilibrium (DSGE) modeling is used. This class of models attempts to explain economic phenomena, such as economic growth and business cycles, and the effects of economic policy, through econometric models based on applied general equilibrium theory and microeconomic principles. Financial frictions were introduced into the DSGE framework (De Walque et al., 2010; Leao and Leao, 2007; Vasco and Woodford, 2009). However, they did not take into account the simultaneous effects of liquidity, agent heterogeneity, money, and default risk. Many of these models consider default modeling as an out-of-equilibrium phenomenon. Put differently, defaults do not occur in equilibrium. Nevertheless, these models have played an important part towards reasonable explanation for development during and after the 2008 global financial crisis. A paper that had originally made some headway in this regard is Martinez and Tsomocos (2011)(later published as Martínez and Tsomocos (2018)).

An important element still lacking in mainstream DSGE models is the absence of liquidity constraints faced by agents, as goods are not fully exchangeable. Introducing liquidity constraints to a dynamic framework is critical to gauge the effect of the financial and real shocks. This allows assessing the impact of a liquidity shock in both the short and the medium term. In addition, a dynamic setting enables us to parameterize different liquidity environments and analyze how shocks impact the economic variables in each case. This idea has been introduced in models exploring financial stability. In this regard, Tsomocos (2003) introduced a GE model that included heterogeneous banks and capital requirements with incomplete markets, money, and default. This was followed by Goodhart et al. (2006a) which included the possibility of capital requirements violation 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 was capable of characterizing the UK's financial stability. The next step was an introduction of an additional (third) bank for the model Goodhart et al. (2005). This bank could have represented all of the remaining UK banks but only the seven largest banks were covered. Hence, the third bank comprises of the five remaining banks. In all this analysis, two time periods were used. An attempt was made to extend the analysis to an infinite time period Goodhart et al. (2006b) but only succeeded with a finite period. It was pointed out that standard dynamic models, which have an active role for banks, assume that the horizon over which rational banks maximise their expected discounted profits is infinite. In other words, bank managers will behave as if they were shareholders and therefore care about the expected profits over the expected lifetime of the banks. However, they argue that, owing to their conflict with shareholders, banks managers may have an incentive to take into account the expected profits of their banks only up to a finite horizon, based on the number of periods they expect to remain in charge of their banks. It was then shown that this is equivalent to assuming that the values of the discount factors of these banks' managers beyond a certain finite horizon approach zero. For simplicity, they assume that such a horizon is equal to one period. So, at the end of period t, banks make their optimal decisions on their portfolios to maximise their expected level of profits in the next time period $t + 1$. Such a framework allows models based on general equilibrium with incomplete markets to match time series data of a given country or region. Apart from the the model being used successfully to analyze financial fragility in the UK, 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.

However, there is other pioneering literature on bank CGE Models (augmented with asset markets) such as (Bourguignon et al., 1989; Taylor, 1990; Adam and Bevan, 1998; Makrelov et al., 2019) that provide important insights. Bourguignon et al. (1989) built a model which combines the microeconomics characteristics of a CGE model with the usual components of a macroeconomic model for the economies of Côte d'Ivoire and Morocco. This allowed the social impact of adjustment (which involves a number of macroeconomic measures with the effects on income and poverty which are microeconomics factors) to be estimated. In Taylor (1990), many studies on how structuralists formulate and apply CGE models in economies in the developing world are covered. Most relevant to our work is the implementation of a CGE model for Mexico which includes portfolio balances. It allowed capital flight, capital gains or losses on assets and liabilities, the banking system and the public sector accounts to be considered together. Also covered in this book is a model designed for Thailand which is one of the first CGE models to incorporate financial variables, which discussed how monetary policy affects macroeconomic equilibrium in a relatively open economy. Adam and Bevan (1998) discuss the integration of asset markets into standard trade-focussed CGE models. Starting from a core specification of the real economy, calibrated to data for Zambia (a low-income, commodity-dependent economy), the full asset market model was built from a simple flow model in the mid-1990s. There are three main differences between the full asset market model and the simple flow model. First, the model includes a detailed specification of the banking sector and the Central Bank that intermediate between households, the public and private sectors. Second, it combines the flow equilibrium constraints of the real model with fully articulated stock constraints, defined by the portfolio choices of all the agents and the monetary authorities. Finally, it introduces an explicit set of policy rules governing the nominal exchange rate and the financing of the government's domestic budget balance. Makrelov et al. (2019) develop 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, consistent, with stock and flow models.

As compared to the work on general equilibrium models, we modify the classical general equilibrium model with additional default and liquidity constraints that also includes the possibility of capital requirements as a regulatory tool for the South African banking sector. This paper is the second in a series of papers which focus on using the Goodhart, Sunirand and Tsomocos model to calibrate the

South African Banking Sector using data available from the SARB. In the first paper, we used the model for risk assessment. One of the scenarios we considered was the impact of a restrictive regulatory policy on some key variables of the model. In that paper (Beyers et al., 2020), we built a CGE model for the South African banking sector. In the current paper, the model has been used as a regulatory tool. We set out a banking sector CGE model to determine the effect of banking regulation on the South African economy. We extend the analysis to assess how changes in default and CAR regulations affect banks profits, GDP among other endogenous variables. We also look at the combined effects and trade-offs of these penalties and consider them under two regimes - one where the Central Bank sets interest rate and the other where the Central Bank controls the money supply. In addition, the effect of changing the CAR (by changing the risks weights attached to banks assets) on key variables, especially the banks profits and GDP, are determined. We do so in the absence of an exchange rate channel and also without alternative funding sources to the banking sector. These limitations do not impact on our model significantly because our focus is on the "bank-based" aspect of the economy as has been done for other countries such as the UK, Goodhart et al. (2004, 2005, 2006b), Jamaica, Lewis (2010), Colombia, Saade et al. (2007) and Brazil, Tabak et al. (2013). Thus the financial regulation of the entire economy is outside the scope of our work. In addition, South Africa, unlike the USA and the UK, is definitely not mostly a market-based financial system. It is also not considered a bank-based model like Japan and Germany. Indeed, some authors such as Demirguc-Kunt and Levine (1999) and Demirgüç-Kunt and Maksimovic (2002) classify South Africa as bank-based and others Rateiwa and Aziakpono (2015) classify South Africa as market based. So South Africa may be considered a "mixed" economy. The banking industry is usually the largest component of the financial sector of any economy Falkena et al. (2004). Its functioning affects all aspects of the economy and hence the performance of the economy of that particular country. South Africa is not an exception. The share of the financial assets of the banking industry, excluding the SARB, is over 30% of the total financial assets of the financial sector as at the end of 2018[1]. The financial sector comprises of banks, insurance companies, pension funds, public financial institutions, other financial intermediaries and the SARB. In addition, we focus only on banking regulations and thus we have not included a stock market. In

[1]Financial Stability Review First Edition 2019: SARB

our model, we have introduced cash in advance constraints and capital requirement constrains that are only observed by the banking sector.

The results are considered with reference to established propositions such as the Liquidity Structure of Interest Rate Proposition, the Quantity Theory of Money Proposition and the Fisher Effect Proposition. In addition, we also establish a proposition that explains why net lenders in the interbank market reduce their credit extension and eventually become net borrowers when the default regulation becomes milder. Similarly, net borrowers reduce their borrowings and eventually become net lenders when the default penalty regulation is stricter. These happen in the case where the Central Bank sets interest rate.

The rest of the paper is organized as follows. Section 2 sets out the CGE model for the banking sector with the details relegated to the Appendix. In section 3, we justify why the banking sector CGE model can be considered a regulatory tool and we perform regulatory policy analysis for the South African banking sector in section 4. Finally, in section 5, we offer concluding remarks.

2 The Banking Sector CGE Model

In Beyers et al. (2020), we developed a banking sector CGE model for South Africa and used it for risk assessment. We now use the model for macroprudential regulation policy. For completeness, we give a brief overview of the model. The model 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 the case of South Africa, all the major banks can be represented in the model. In this paper, we considered the largest six banks by assets which is in line with the analyses done in the UK were the largest eight banks were considered (Goodhart et al., 2005, 2006a,b). 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. 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. So a bank in deficit can borrow from a bank with a surplus or from the Central Bank. The model is presented in Fig. 1 The time horizon can be

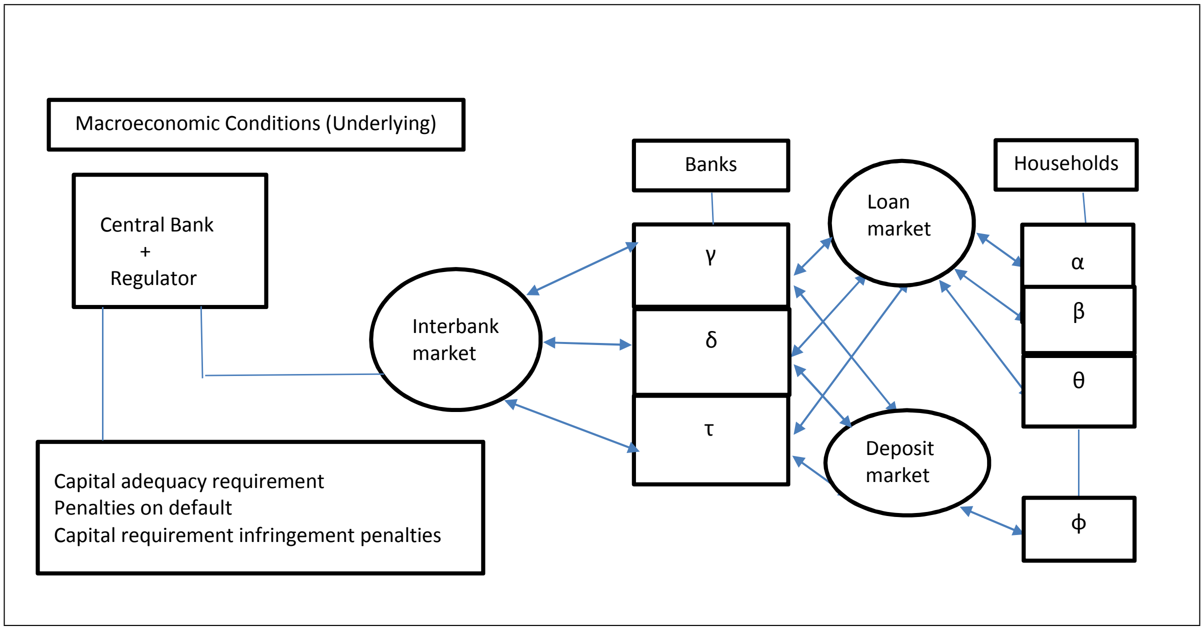

Figure 1: The structure of the model (See (Lewis, 2010))

infinite $t \in T = \{1, ..., \infty\}$ or finite, e.g. two time periods, $t \in T = \{1, 2\}$ (Goodhart et al., 2005). In the case of two time periods, it can only be used to reproduce realistic features of the country's banking operations at a particular point in time and not to determine trend where an infinite period is required as in the case of (Aspachs et al., 2007; Goodhart et al., 2006b; Lewis, 2010). For forecasting purposes (Goodhart et al., 2006b), an infinite period is used. It is assumed that there are two possible states. One state is the good/normal state and the other is the bad/extreme/crisis state. The good state is represented by i and has a probability p of occurring and the bad state is denoted by ii with probability of occurring, $1 - p$. These probabilities are constant over time and are assumed to be known by the private sector agents. The expected value is taken over all possible states. The time structure of the model is presented in Fig. 2. 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 default or capital

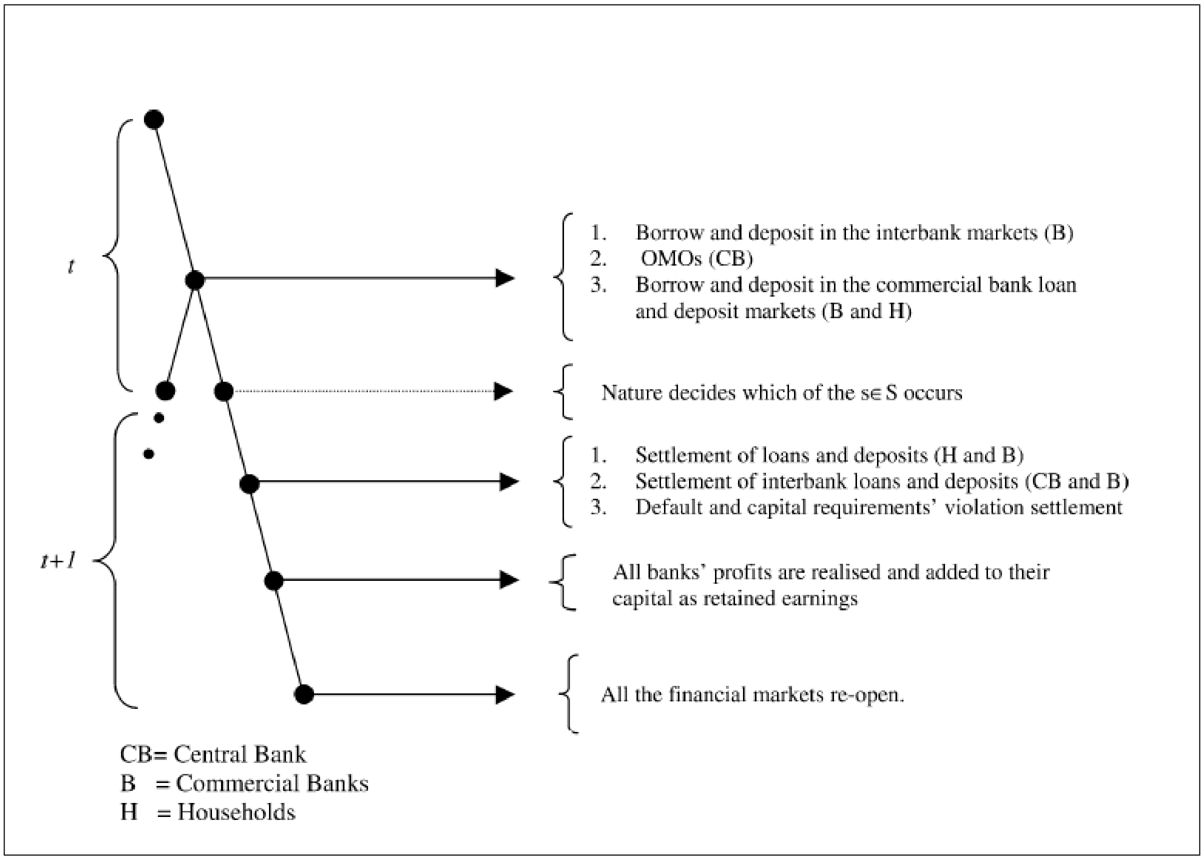

Figure 2: Time structure of the model

infringements. The balance sheet structure for a bank is given in Table 1. Capital is carried over, i.e.

Table 1: Balance Sheet Structure of the bank

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

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.

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 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 obligation. However, default could be strategic or due to ill fortune and lenders are 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 is when a bank is genuinely unable to honour its obligations as a result of not having adequate funds. The default rate is defined as the probability of the bank shutting down. Hence it is assumed that, if banks are not able to repay their loans fully when due, they are forced to shut down. The default rates for deposits and the interbank market for each bank are assumed to be the same. Hence, banks cannot choose to pay their depositors and decide not to pay their fellow bank and/or the Central Bank.

In the model, banks are allowed to infringe on their capital adequacy requirement. However each infringement is punished by the regulator imposing a capital requirement infringement penalty. In reality, most banks' capital will be above the capital requirement and hence the penalty may not be applicable. However, in order to avoid 'corner equilibria', the capital requirement can be enhanced such that all the banks violate the capital requirement so that the penalty applies in all cases. The size of the penalty is proportional to how far the level of capital is from the minimum level set by the regulator. 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 modeled as it is extremely difficult to obtain data such as amounts borrowed by individual households. As a result, reduced form equations are used. The rest of the description of the model is in Appendix A.

The calibration exercise which is based on the balance sheet data of South African banks as at the end of 2016 was initially presented in our paper (Beyers et al., 2020), and for the sake of completeness is included in Appendix B. It is important to emphasize that 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. These parameters or 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. With this in mind, the coefficients of elasticity for the reduced form equation for future GDP(equation (10) of Appendix A) were estimated using regression analysis. The rest of the elasticities were chosen arbitrarily. However this was done by ensuring that the deviations between the predicted values and the observed values were minimized. In addition, as the endogenous variables of the model are not necessarily the endogenous variables of the system of equations, we were able to 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))

3 Justification of the CGE model as a Regulatory Tool

We present the features of our model in Fig. 3. As discussed in recent work which incorporates the banking sector as a financial intermediary with a CGE model (Giesecke et al., 2017; Nassios et al., 2020; Bernanke and Blinder, 1988; Kashyap and Stein, 1995), there are three main conditions that a model must satisfy to possess a distinct lending channel. First, the liabilities of agents such as financial capital raised by loans from banks or other sources, including the foreign sector, must be viewed as imperfect substitutes because of the differing default rates and credit risks. Similarly, banks must view financing of deposit and other sources as imperfect substitutes. Last, but not the least, there must be a nominal rigidity that prevents monetary shocks from having no impact on the real economy. Our work goes beyond that by incorporating other financial frictions such as default and liquidity constraints. The implicit assumptions in our model, such as different sources of finance having different default rates (i.e. the fact that money borrowed from interbank market have different

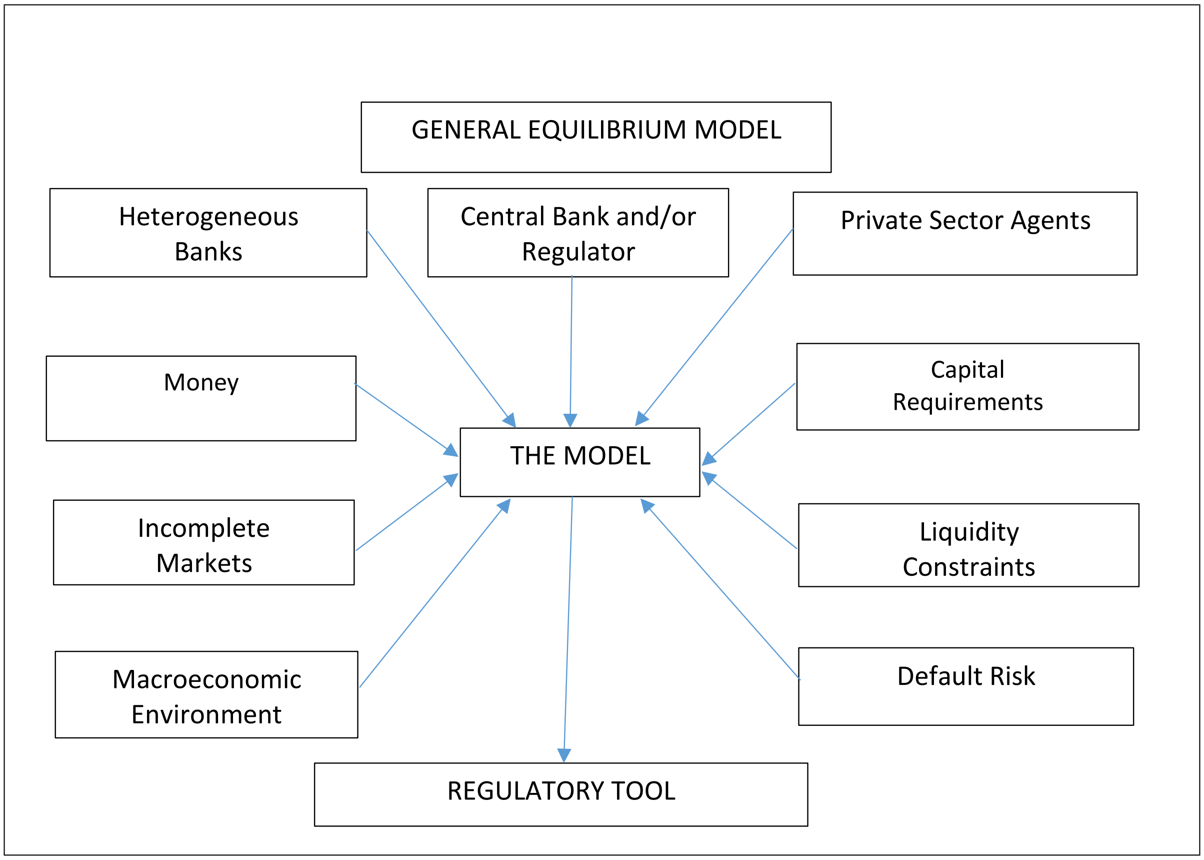

Figure 3: Features of our model

repayment rates from that of the loan market), the cash advance constraint and incomplete markets satisfy the first two conditions. The final condition is satisfied by our model due to the presence of capital buffers (or enhanced CAR). We need to mention though that the imperfect substitutability constraint is not completely satisfied by our model. This is because the private sector agents have alternative sources of funds available to them and that if bank CAR rises, they may switch some of their credit demand to other financial agents. These other agents might be regulated differently from the banks or even unregulated, like the non-bank intermediaries. However, the impact is minimal as in the case of South Africa, these alternative sources constitute a smaller percentage (compared with market-based economies).

A summary of the model is as follows:[2]

Maximize the expected payoff which is expected profitability *less* capital infringement penalty *less*

[2] Detailed explanation can be found in our first paper (Beyers et al., 2020) and also in Appendix A.

penalty on default of interbank obligations $less$ penalty on default on deposits (reflected in equation (1) of Appendix A), subject to two conditions: the balance sheet constraint and the budget constraint (equations (2) and (3) of Appendix A). Profit is defined as money received from assets $less$ money paid on liabilities. The capital at period $t + 1$ is given by capital at period t $plus$ profit earned, and capital adequacy ratio equals the ratio of capital to the risk-weighted assets. These definitions are reflected in equations (4) to (6) of Appendix A.

The private sector agents are considered to be the investors and so investments are reflected in the reduced form equations (7) to (9) of Appendix A.

There exist seven markets (three consumer loan markets, three deposit markets, and one interbank market) in the model. All the 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 realized defaults. Each of the three different markets determines the corresponding interest rates in equilibrium. The equilibrium in the economy in each period is described by a vector of all choice variables of agents such that banks maximize their payoffs and markets clear. In particular, the loan, the deposit, and the interbank markets clear and the banks' expected repayment rates are realized.

The emphasis of our work was not on the role that foreign investors play in South Africa so we did not include the exchange rate channel. Nevertheless, our model can in theory be extended to include the foreign sector as was done in Peiris and Tsomocos (2015). Moreover, in Rumler (1999), a 2-country CGE model was used to establish the effect of monetary and fiscal expansion on the economy of two countries. Also Giesecke et al. (2017); Nassios et al. (2020), argued that bank regulation changes impact offshore activity by domestic banks (changing foreign capital outflows), and the supply of foreign finance (via changes in the current account balance and the nominal exchange rate). We intend to cover some of these issues in our future work.

The model also allows users to study how other domestic forms of finance provision influence the results of regulatory reform. It all depends on the scenario considered by the policy maker and some of these scenarios, such as capital shocks and deposit supply shocks to a particular bank, were considered in our first paper (Beyers et al., 2020).

4 The Model as a Banking Sector Regulatory Tool

The model that performed well as a tool for risk assessment for South Africa (Beyers et al., 2020), is now used for banking regulation. In that paper, one of the scenarios considered was the impact of restrictive regulatory policy where the effects of each of the penalties (the default penalty and the CAR violation penalty) on key variables were determined. In this paper we extend the analysis to cover how changes in these penalties affect the key variables, with a focus on banks profits and GDP. We also look at the combined effects and trade-offs of these penalties and consider them under two regimes - one where the Central Bank sets interest rate and the other where the Central Bank controls the money supply. In addition, the effect of changing the CAR, by changing the risks weights attached to banks assets on key variables, especially the banks profits and GDP, are determined.

4.1 Equilibrium Characterization

We explain the results of all the shocks using the propositions and the associated trade offs given below. The three propositions (in sections 4.1.1 to 4.1.3 below) were established in Goodhart et al. (2004) and Goodhart et al. (2006a) .

4.1.1 Liquidity Structure of Interest Rate Proposition

Since base money is fiat and the horizon is finite, in the end no household will be left with fiat money. Thus, all households will finance their loan repayments to commercial banks via their private monetary endowment and the initial capital endowments of banks. However, since we allow for defaults, the total amount of interest rate repayments is adjusted by the corresponding anticipated default rates. In sum, aggregate ex post interest rate payments adjusted for default to commercial banks is equal to the total amount of outside money. In this way, the overall liquidity of the economy and endogenous default co-determine the structure of interest rates.

4.1.2 Quantity Theory of Money Proposition

The model possesses a non-trivial quantity theory of money. Velocity will always be less than or equal to one. However, since quantities supplied in the markets are chosen by agents, the real velocity of money, that is how many real transactions can be moved by money per unit of time, is endogenous. The upshot of the analysis is that nominal changes affect both prices and quantities.

4.1.3 Fisher Effect Proposition

The nominal interest rate is equal to the real interest rate plus the expected rate of inflation. That is the nominal interest rate charged by the bank is equal to the real rate of interest which is the marginal depreciation rate of cosumption tomorrow plus the expected rate of inflation.

4.1.4 Default Trade Off

There is a trade off between the marginal benefit and the marginal cost of defaulting payment on deposit and interbank obligations. Thus banks choose their optimal expected level of profitability by equating the derived marginal benefit with the corresponding marginal cost. In other words, there is a marginal benefit derived from defaulting and consequently as a result we have the marginal cost which depends on the regulatory penalty.

4.1.5 CAR Violation Trade Off

There is a trade off between the marginal benefit from violating capital adequacy requirement and the marginal cost of violating capital adequacy requirement. Put differently, there is a trade off between the profit from the extra interest obtained by the banks extending their credit extension and the cost of the regulatory penalty for the capital falling below the associated CAR.

4.2 Default and Capital Violation Penalties

Penalties have to be applied for the banks to act in accordance with certain regulatory objectives. For instance if no penalties are used, the banks will have the freedom to act arbitrarily. They could charge very low interest just to get business and when in trouble default their repayment without any repercussions. In reality, any bank defaulting on its deposits will be forced to close down. However, Tsomocos and Zicchino (2012) showed that endogenous default provides microfoundations to exogenous probabilities of default. So in the model, a bank's default rate is interpreted as a probability that such a bank goes bankrupt and closes down, and hence defaults completely on its financial obligations in the short run. In other words, a bank's decision to increase its default rates is equivalent to its decision to adopt a riskier strategy in pursuit of higher expected profitability. A default penalty also ensures that the banks take responsibility for their repayments either in the interbank market or for deposits they receive from the private sector agents. Just as banks can default on their deposits, the model also allows banks to violate their CAR. Again, in reality, each bank's capital to asset ratio may be above the regulator's requirement and so will not be subjected to any CAR violation penalty. However, we assume each bank wants to have a buffer above the regulator's requirement and so the ratio is always binding. What that means is that each bank's self-imposed enhanced capital requirement is always above the actual value of that regulatory capital to asset ratio. The level of enhanced capital is signaling to the market either potential problems or financial health of the bank. Hence there is a non-pecuniary cost. In this section we start with the penalties used at the initial equilibrium. We then change the penalties to see how the banks react and the impact on their profits as well as the economy.

4.2.1 Default penalty effects

The model is run with the capital violation penalties fixed at their initial level (i.e. maintained at their values at the initial equilibrium position) and the default penalty set one percentage point below and above their initial level at equilibrium to determine their effects. The main effects of reducing the default penalty by 1% are shown in Table 2 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.

As expected, the profits for all the three banks increase in both states. There is a reduction in both the deposit and the lending rates for the banks which are net lenders in the interbank market and an

Table 2: Default Penalty 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	-1.441	-0.873		8.268	98.910	2.793	14.467	-0.340	-1.204		
γ	-1.430	-0.837	2.687	8.614	67.407	2.053	0.537	-0.230	-0.091	-0.040	-0.040
τ	2.687	2.236		9.654	135.611	2.728	24.170	-0.198	-1.421		

increase in both the deposit and the lending rates for the bank which is a net borrower in the interbank market. The capital adequacy ratios for all the banks increase in both states. The interbank rate increases and the GDP drops. The reason for this is that the banks adopt an aggressive strategy of choosing higher profits as they are now relaxed about the default penalty they could face. Since a lower default penalty will decrease the marginal cost of defaulting, it will also increase liquidity demand since the Central Bank will increase the interest rate charge to incorporate the increased default risk premium. In general, the interbank rate is higher than the deposit rate but lower than the lending rate, so the net lenders adjust their portfolios by lending less in the interbank market, more in the customer loan market and taking less deposits. This adjustment of their portfolios increases the interbank rate and puts pressure on both their lending and the deposit rates, making them reduce accordingly. Bank τ, the net borrower, on the other hand takes more deposits and borrows less in the interbank market, as this market is now more expensive. It also lends less in the customer loan market. These actions increase both its deposit and lending rates. The strength of the pressure caused by the banks and the household portfolio adjustments in general depends on the relative elasticities of demand and supply of such a market.

With more credits for banks δ and γ, given the liquidity structure of interest rate proposition, we expect that their interest rates would be lower and consequently we observe that their rates decrease. Similarly, the interest rate for bank τ increases given that its credit supply reduces. Although the profits of the banks increase, we observe that the extent of the increase in the combined credit extension of banks δ and γ was lower than the decrease in bank τ's credit supply. This leads to a reduction in the cumulative credit supply and negatively affects household liquidity and income. With lower income and liquidity, it is expected from the quantity theory of money proposition, that economic activities (prices of goods) will fall. Hence chances of both the banks and household defaulting on their debt increases and their repayment rates fall in both states. This is expected since, given that the default penalty is lower, by the default trade off, the marginal benefit of default increases more than the marginal cost and consequently banks default more, hence leading to a reduction in their repayments. This results in a decrease in economic activities leading to a reduction in GDP. Lower economic activities (lower prices of goods) imply higher real rates and so according to the Fisher effect proposition should lead to higher interest rates. However, only bank τ's interest rate increases. With the other two banks, their credit extension in the consumer loan market and the demand for low deposits overshadow the effects of the lower economic activities, so that their rates reduce. We also observe that all the banks violated less their capital adequacy requirements and so suffer less capital adequacy violation penalties. This is because the overall credit extension is lower and the higher default probability causes the repayment rate of households to decrease, consequently the risk weighted assets of the banks decrease.

The opposite effect is observed when the default penalty is increased. In other words the following effects are observed when the default penalty is increased by 1%. There is a reduction in profits for all the three banks. Both the deposit and the lending rates for the net lending banks in the interbank market, increase whilst both the deposit and the lending rates for the net borrowing bank in the interbank market, decrease. The capital adequacy ratios for all the banks decrease in both states. The interbank rate reduces and the GDP increases in both states. These effects are more pronounced as the default penalty is increased.

The percentage changes in key variables of a 1% increase in the default penalty are shown in Tables 3.

Table 3: Default Penalty Increased 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	1.430	0.868		-8.268	-98.910	-2.790	-14.628	0.339	1.203		
γ	1.420	0.832	-2.666	-8.614	-67.407	-2.051	-0.536	0.229	0.094	0.039	0.039
τ	-2.666	-2.217		-9.574	-135.501	-2.695	-24.050	0.197	1.415		

4.2.2 Capital violation penalty effects

The default penalty is fixed at the initial level (maintained at its level at the initial equilibrium) and the capital violation penalty is set a percentage point below and above their initial levels to determine their effects. The main effects of reducing the capital violation penalty by 1% are shown in Table 4 and are as follows: There is a reduction in profit for each of the three banks in both states. Both the deposit and the lending rates for the banks δ and γ, the net lenders in the interbank market, increase. However, there is a reduction in both the deposit and the lending rates for bank τ which is the net borrower in the interbank market. The capital adequacy ratios for all the banks decrease in both states. The interbank rate decreases and the GDP increases in both states.

Table 4: Capital Violation Penalty decreased 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	0.028	0.006		-0.082	-0.939	-0.028	-0.139	0.002	0.011		
γ	0.027	0.010	-0.011	-0.043	-0.322	-0.011	-0.003	0.001	0.000	0.001	0.001
τ	-0.011	-0.024		-0.121	-1.673	-0.034	-0.297	0.001	0.016		

These effects are in the opposite direction to that of the change in the default penalty and the magnitude of the changes are much smaller. The banks adopt a conservative strategy of choosing lower profitability since they are now less concerned about infringing on the capital adequacy requirements as it is less costly. The net lenders in the interbank market increase their investment there. In other words they lend more in the interbank market. They do this by lending less in the loan market and taking more deposit in the deposit market. Their actions increase both their lending and deposit rates. The interbank rate decreases as a result of an increased investment from the net lenders.

The other bank τ, takes advantage of the reduced interbank rate and borrows more in that market and reduces the intake of deposits, so its deposit rate reduces. It also lends more in an attempt to improve its profit. This puts pressure on its lending rate thereby reducing it. Given reduced credit supply for bank δ and bank γ, their rates increase, as expected from the liquidity structure of interest rates proposition. By this same proposition, bank τ's interest rates reduce as a result of higher credit extension. The combined profit of the banks reduces but there is an increase in the cumulative credit supply which overshadows the reduction in profits. This improves household liquidity and income.

Hence chances of both the banks and household defaulting on their debt reduces, improving on their repayment rates. The result is an increase in the GDP as a result of an increased economic activities. From the quantity theory of money, the higher liquidity and income ensure that economic activities improve. Higher economic activities (higher prices) imply lower real rate of interest and so by the Fisher effect proposition nominal interest rates must rise, which it did for bank τ.

Given that the CAR violation penalty is lower, by the CAR violation trade off, the marginal benefit of violating CAR increases more than the reputational cost of violating the CAR, consequently the banks violates their CAR even more leading to their capital adequacy ratio decreasing in both states.

On increasing the capital violation penalties, the following are observed which are in the opposite direction to the effects of reducing the capital violation penalty, as expected. Profits for all three banks increase. There is a reduction in both the deposit and the lending rates for the banks which are the net lenders in the interbank market and an increase in both the deposit and the lending rates for the bank which is a net borrower in the interbank market. The banks capital adequacy ratios increase in both states. The interbank rate increases and the GDP decreases in both states. These observations result from the fact that banks try to increase the values of their capital to asset ratios since violating capital requirement is now costly for all of them. The banks also adopt a riskier strategy of choosing higher expected profitability since they are now more concerned about infringing on the capital adequacy requirements because it is costly. This allows them to suffer fewer capital violation penalties. The banks also adjust their portfolios so that the size of the risk-weighted assets decrease, which helps in further reducing the capital violation penalties.

Again, the effects are more pronounced as we increase the magnitude of the changes in the penalties. The percentage changes in key variables of a 1% increase in capital violation penalty are shown in Table 5.

Table 5: Capital Violation Penalty Increased 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	-0.028	-0.006		0.082	0.939	0.028	0.140	-0.002	-0.011		
γ	-0.027	-0.010	0.011	0.043	0.322	0.011	0.003	-0.001	-0.000	-0.001	-0.001
τ	0.011	0.024		0.121	1.673	0.034	0.297	-0.001	-0.016		

4.2.3 Combined effects of default and capital violation penalties

The default penalty and the capital violation penalty are both reduced by 1%. The effects are in the same direction to the effects when the default penalty alone was reduced by 1% . This is due to the fact that the magnitude of the changes for a change in the default rate far exceeded that of a change in the capital violation penalty. This is possible due to the fact that banks regard defaulting on their deposits more seriously than infringing on their capital adequacy requirements. There is therefore a trade off between the banks defaulting on their deposits and the interbank obligations, and the reputation cost of violating their capital adequacy requirement. In our case, the effect of the cost of the defaults dominates that of the capital adequacy requirement. Due to the fact the effects of the two penalties oppose each other, the magnitude of the changes were slightly lower than that of just reducing the default penalty by 1%. As mentioned in our paper, (Beyers et al., 2020), the banks prefer to default less and suffer the CAR penalty rather than default more and suffer less of CAR penalty. The percentage changes in key variables of a combination of a 1% reduction in capital infringement penalty and 1% reduction in default penalty are shown in Table 6. A similar result was obtained when

Table 6: Both Default and Capital Infringement Penalties 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	-1.412	-0.868		8.186	97.970	2.765	14.508	-0.338	-1.194		
γ	-1.403	-0.827	2.677	8.571	67.085	2.042	0.534	-0.229	-0.091	-0.039	-0.039
τ	2.677	2.212		9.532	133.934	2.694	23.871	-0.196	-1.404		

both the default penalty and the capital violation penalty were increased together by 1% each. That is the results were in the same direction as just increasing the default penalty by 1% with the magnitude being slightly lower. We show the percentage increases in the key variables with an increase in both penalties of 1% in Table 7.

Table 7: Both Default and Capital Infringement Penalties Increased 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	1.403	0.862		-8.186	-97.972	-2.762	-14.489	0.336	1.192		
γ	1.393	0.822	-2.655	-8.571	-67.085	-2.040	-0.533	0.228	0.093	0.039	0.039
τ	-2.655	-2.193		-9.453	-133.832	-2.661	-23.755	0.195	1.398		

4.3 Capital adequacy requirement

As 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 done by increasing the risk weights on loans akin to what was done in Goodhart et al. (2004). We thus increase the risk weights on loans by 10%. As expected the profits for all three banks decrease in both states. The deposit 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. There is a reduction in bank δ's lending rate whilst the other two bank's lending rates increase. Repayment rates for the banks in general increase and GDP increases slightly. The percentage changes in key variables as a result of the change are shown in Table 8: As far as the effects on the banks are concerned, tightening of the capital requirement regulatory policy is similar to a contractionary monetary policy. Therefore this leads to an increase in the interbank rate. 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 no more attractive to do so. As part of bank δ's portfolio adjustment, it takes more deposit in order to increase its credit extension in the consumer loan market. These adjustments increase its deposit rates and reduces its lending rates. It also ensures that its profitability is maintained.

Table 8: 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	0.010	-0.016		-0.067	-0.827	-0.841	-1.003	0.001	0.008		
γ	0.022	0.004	0.027	-0.033	-0.264	-0.773	-0.825	0.0001	-0.0003	0.0003	0.0003
τ	0.027	0.005		-0.053	-0.918	-0.533	-0.725	0.0001	0.009		

Bank γ, on the other hand is more concerned about avoiding capital requirements' violation penalties, so it further reduces its credit extension in the consumer loan market and take on more deposits leading to an increase in both its lending and deposit rates. In order not to be unduly affected in terms of profitability, it also lowers its repayment in the bad state. It could do all this because it is not limited in terms of the size of it's portfolio. This suggests that banks with many investment opportunities and sufficient capital are able to turn things around in terms of adverse shocks and which in the end negatively affects private sector agents and banks with limited opportunities and funds. Bank τ, the net borrower, haven't reduced it borrowing in the interbank market, it offers a higher deposit rate in order to attract more deposits instead and reduces its credits in the consumer loan market to avoid excess capital requirements violation penalties. Its action increases its lending rate as well. The increase in the deposit rates of the banks is reinforced by the fact that agent ϕ lowers its deposits to the banks in anticipation of higher defaults. As the shock is equivalent to tightening monetary policy, less credit becomes available and by the liquidity structure of interest rates, the interest rates should increase and indeed they increase except for bank γ, whose lending rate declines. This exception from bank γ was possible because it reduces its lending in both the consumer loan market and the interbank market because it was not constrained by funds and so could transfer the negative shock to the other two banks and the private sector agents. As bank τ, the net borrower in the interbank market, increases its deposit demand and reduces its interbank borrowing, it is able to increase its repayment of deposits and reduces its repayment of interbank borrowing.

More funds become available to agents ϕ and β as agent ϕ benefits from the increased deposit rates and agent β benefits from the reduction in the lending rate of its nature selected bank δ. This increase in funds outweighs the reduction in funds from the other two agents who suffer as a result of their nature selected banks increasing their lending rates. Therefore, by the quantity theory of money proposition, economic activities (prices of goods) increase from the improved income and liquidity which leads to a slight improvement in GDP. Finally, the profits of the banks reduce as a result of higher payments on CAR violation penalties, higher interest payments on deposits to agent ϕ and in the case of bank δ, reduced interest receipt to its nature selected customer as well. As the banks violate their CAR in the initial condition, it may be regarded as an adverse economic condition. Therefore we conclude that as CAR is tightened during periods of economic downturn, banks profits further reduce.

4.4 Monetary policy instrument

So far we have used the base money as the monetary policy instrument. In this section, we consider also the policy rate as the monetary policy instrument. In other words we fix the policy rate and allow the base money to be solved endogenously in the model. This is different from using the base money as the monetary policy instrument since in that case the base money is fixed and the policy rate is solved endogenously in the model. We then look at the differences in results with a focus on the effects on the banks profits and the GDP.

We hasten to add that we will investigate equilibria where agents will not be on both sides of the market. Put differently, banks will either be in a position of a lender or a borrower but not both. This simplification does not alter our result since we can establish that:

Proposition

Given any equilibrium, when an agent is on both sides of the market (both supply and demand), there exists another equilibrium where the agent is on one side of the market and support the same allocation.

Proof

Suppose that $d^b, \mu^b \geq 0$. We have three banks. We will prove this for bank γ and the same argument applies for banks δ and τ too.

Since a bank cannot be a net lender and at the same time a net borrower, then for bank γ, either $d^\gamma = 0$ or $\mu^\gamma = 0$. If $d^\gamma - \mu^\gamma > 0$ then set $\hat{\mu}^\gamma = 0$ and $\hat{d}^\gamma = d^\gamma - \mu^\gamma$ (ie a net lender). If $d^\gamma - \mu^\gamma < 0$ then set $\hat{d}^\gamma = 0$ and $\hat{\mu}^\gamma = \mu^\gamma - d^\gamma$ (ie a net borrower).

The same argument applies for d^δ and μ^τ too,

where, d^b = bank b's interbank lending, and μ^b = bank b's interbank borrowings.

4.4.1 Profits

There is a linear relationship between the changes in profits and the changes in the default penalties for all banks in both the good and the bad states when the Central Bank sets the base money as its monetary policy instrument. As the default penalty is increased, the profits reduce. This is also the case when the policy rate is the monetary policy instrument except for the net borrower, bank τ, whose profit increases with an increase in the default penalty. With the policy rate as the monetary policy instrument, the policy rate is fixed so the banks are not able to improve their profits through the interbank market. They can only do so through the consumer loan and deposit markets. As the default penalty is increased, the profits reduce.

We observe that as the default penalty is reduced, the net lenders reduce their lending in the interbank market and eventually become net borrowers. Bank γ is the first to become a net borrower and that happens when the default penalty is reduced by 2%. Bank δ becomes a net borrower when the default penalty is reduced by 3%. In the same way, when the default penalty is increased the net borrower reduces its borrowing in the interbank market and eventually becomes a net lender in the interbank market. This happens when the default penalty is increased by 0.2%. To illustrate the point that the net lenders could become net borrowers and vice versa, before we run the model (i.e. at the initial equilibrium), we determine whether a bank is a net borrower or a net lender in the interbank market. This we do by subtracting the banks borrowing from its lending in the interbank market. If it is positive, we say that bank is a net lender and we allocate the value as d. If it is negative, we say the bank is a net borrower and we allocate the absolute value as μ. So for the initial run, the two banks which were net lenders (δ and γ) had their values allocated as d. The other bank, the net borrower (τ) had its value allocated as μ and no d. We then change the exogenous variable (in this case the default penalty) we want to shock and run the model and depending on the size of the default penalty, d or μ may become negative. If d for a particular bank becomes negative after the run we say that, that bank has moved from a net lender to become a net borrower and vice versa. The values used for our initial run are in Table 9.

We show the split of the profits when the monetary policy instrument is the policy rate at equilibrium,

Table 9: Net lender/Borrower Position at Initial Equilibrium

Bank	Delta	Gamma	Tau
Lending	1.5006	2.3066	0.4392
Borrowing	0.6713	1.4591	0.4966
Difference	0.8293	0.8474	(0.0574)
So	$d = 0.8293$	$d = 0.8474$	$\mu = 0.0574$

for the cases where the default penalty is reduced by 3% and when it is increased by 3% in Tables 10, 11 and 12 respectively. In the case of a capital infringement penalty, the profits increase as the capital infringement penalties increase under both monetary policy instruments. However, the increases are

[3] Negative value in the income section indicates net lender has become net borrower

[4] Negative value in the outgo section indicates net borrower has become net lender

Table 10: Breakdown of Profit: Equilibrium Position - Policy Rate as Monetary Policy Instrument

		GOOD STATE	
BANK	Delta	Gamma	Tau
Total income	**14.94520**	**29.07745**	**10.39616**
Loan market	10.31290	20.50923	8.15220
Investment	3.74584	7.66240	2.24396
Interbank market	0.88646	0.90581	-
Total Outgo	**14.54027**	**28.47300**	**10.19870**
Interbank market	-	-	0.06136
Deposit market	9.89267	22.03690	8.14589
Capital	0.81180	1.98300	0.55870
Others	3.83580	4.45310	1.43276
Profit	**0.40493**	**0.60445**	**0.19746**
		BAD STATE	
BANK	Delta	Gamma	Tau
Total income	**14.00031**	**27.37803**	**9.71239**
Loan market	9.41148	18.85425	7.46842
Investment	3.74584	7.66240	2.24396
Interbank market	0.84298	0.86138	-
Total Outgo	**14.10456**	**27.39211**	**9.79614**
Interbank market	-	-	0.05835
Deposit market	9.45696	20.95601	7.74634
Capital	0.81180	1.98300	0.55870
Others	3.83580	4.45310	1.43276
Profit	**(0.10425)**	**(0.01408)**	**(0.08376)**

Table 11: Breakdown of Profit: Default Penalty Reduced by 3% - Policy Rate as Monetary Policy Instrument

	GOOD STATE		
BANK	Delta	Gamma	Tau
Total income	**14.91311**	**29.02995**	**11.27187**
Loan market	11.47279	22.81871	9.02790
Investment	3.74584	7.66240	2.24396
Interbank market	(0.30552)	(1.45117)[3]	-
Total Outgo	**14.41029**	**28.27131**	**11.08361**
Interbank market	-	-	0.91739
Deposit market	9.76269	21.83521	8.17477
Capital	0.81180	1.98300	0.55870
Others	3.83580	4.45310	1.43276
Profit	**0.50282**	**0.75863**	**0.18825**
	BAD STATE		
BANK	Delta	Gamma	Tau
Total income	**14.00298**	**27.43862**	**10.56932**
Loan market	10.53922	21.11607	8.32536
Investment	3.74584	7.66240	2.24396
Interbank market	(0.28209)	(1.33984)	-
Total Outgo	**13.80595**	**27.42461**	**10.38612**
Interbank market	-	-	0.84702
Deposit market	9.15835	20.98851	7.54765
Capital	0.81180	1.98300	0.55870
Others	3.83580	4.45310	1.43276
Profit	**0.19703**	**0.01401**	**0.18320**

Table 12: Breakdown of Profit: Default Penalty Increased by 3% - Policy Rate as Monetary Policy Instrument

		GOOD STATE	
BANK	Delta	Gamma	Tau
Total income	**14.97333**	**29.11139**	**9.37526**
Loan market	8.96907	17.83401	7.13130
Investment	3.74584	7.66240	2.24396
Interbank market	2.25842	3.61498	-
Total Outgo	**14.66531**	**28.66035**	**9.15829**
Interbank market	-	-	(0.93860)[4]
Deposit market	10.01771	22.22425	8.10543
Capital	0.81180	1.98300	0.55870
Others	3.83580	4.45310	1.43276
Profit	**0.30801**	**0.45104**	**0.21697**
		BAD STATE	
BANK	Delta	Gamma	Tau
Total income	**14.08595**	**27.47848**	**8.72108**
Loan market	8.11491	16.25429	6.47712
Investment	3.74584	7.66240	2.24396
Interbank market	2.22519	3.56180	-
Total Outgo	**14.48861**	**27.52051**	**9.05284**
Interbank market	-	-	(0.92479)
Deposit market	9.84101	21.08441	7.98618
Capital	0.81180	1.98300	0.55870
Others	3.83580	4.45310	1.43276
Profit	**(0.40266)**	**(0.04203)**	**(0.33176)**

slightly higher for the case where the monetary policy instrument is the base money. The profits increase because the banks take action to increase their profits and hence capital in order to reduce the magnitude of the cost incurred from infringing on their CAR. With the dominant effect of the default penalty over capital violation penalty, when both penalties are changed the effects are similar to when only the default penalty is changed under both monetary policy instruments.

4.4.2 Gross Domestic Product

With the base money as the monetary policy instrument, as the default penalty is increased, GDP decreases. When the policy rate is used as the monetary policy instrument, there is a linear relationship between the changes in default penalty and the GDP. GDP increases as the default penalty is increased at a very slow pace. This effect is in the opposite direction to the case where the monetary policy instrument is the base money. There is a linear relationship between GDP and capital violation penalties no matter which of the monetary policy instruments is used by the Central Bank. However, whilst the GDP increases with capital violation penalties in the case where the monetary policy instrument is the base money, the GDP decreases at a much faster pace when the policy rate is used as the monetary policy instrument.

5 Concluding Remarks

In this paper, we apply a CGE model to the South African economy as a regulatory tool for the banking sector. As we increase the default penalty, the profits of the banks decrease. However, as we increase the CAR violation penalty the profits of the banks increase. Hence, there is a trade off in profit changes as we tighten both the default and the CAR violation penalties. The change in default penalty dominates that of the CAR penalty. Moreover, there is almost a negative linear relationship between the changes in profits and the changes in the default penalties (within a narrow range) for all banks when the Central Bank sets the money supply. However, this is not the case when the Central Bank sets the policy rate. In this case, it depends on whether a bank is a net lender or a net borrower. For net lenders, as the default penalty is increased, profits decrease and for net borrowers, profits increase.

With the capital infringement penalty, profits behave in a similar manner under the two monetary policy instruments. In both cases profits increase as the capital infringement penalties increase even though the increase is slightly higher for the case where the monetary policy instrument is the base money. Since the default penalty dominates the capital violation penalty, profits "increase somewhat" when both penalties are reduced. Profits increase because the banks take action to increase profits and hence capital in order to reduce the magnitude of the cost incurred from infringing on their capital requirements.

We observe that the net lenders in the interbank market reduce their lending in the interbank market when the default penalty is reduced, and eventually become net borrowers when the Central Bank sets interest rates. The first order effects are more powerful than the case when the Central Bank controls the money supply. Similarly, net borrowers in the interbank market reduces their borrowing in the interbank market when the default penalty is increased, and eventually become net lenders. Banks with many investment opportunities and adequate capital react quite well to adverse shocks compared to those with less diversified portfolios, as they are able to readjust their portfolios to counteract the negative effects of exogenous shocks eventualities and in doing so worsen the predicament of the private sector agents and smaller banks. Finally, during periods of adverse economic conditions, tightening regulatory requirements further worsens the banks profitability.

In sum, the CGE model performed satisfactorily as a regulatory tool for South Africa. However, further research is warranted to provide an integrated CGE model to assess regulatory and monetary policy contemporaneously. Hence, one may potentially assess substitutability and/or complementarities of various regulatory tools and monetary policy.

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References

Adam CS, Bevan DL (1998) Costs and benefits of incorporating asset markets into CGE models: Evidence and design issues. Institute of Economics and Statistics, University of Oxford

Aspachs O, Goodhart CA, Tsomocos DP, Zicchino L (2007) Towards a measure of financial fragility. Annals of finance 3(1):37–74

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

Barth JR, Caprio G, Levine R (2004) Bank regulation and supervision: what works best? Journal of Financial intermediation 13(2):205–248

Bernanke BS, Blinder AS (1988) Credit, money, and aggregate demand. American Economic Review 78(2):435–439

Beyers CF, De Freitas A, Essel-Mensah KA, Seymore R, Tsomocos DP (2020) A computable general equilibrium model for banking sector risk assessment in South Africa. Annals of Finance pp 1–24

Botha E, Makina D (2011) Financial regulation and supervision: Theory and practice in South Africa. International Business & Economics Research Journal (IBER) 10(11):27–36

Bourguignon F, Branson W, de Melo J (1989) Macroeconomic adjustment and income distribution: A macro-micro simulation model. Tech. rep., OECD Publishing

De Walque G, Pierrard O, Rouabah A (2010) Financial (in) stability, supervision and liquidity injections: a dynamic general equilibrium approach. The Economic Journal 120(549):1234–1261

Demirguc-Kunt A, Levine R (1999) Financial structures across countries: stylized facts. Washington, DC: World Bank Policy Research Working Paper 2143

Demirgüç-Kunt A, Maksimovic V (2002) Funding growth in bank-based and market-based financial systems: evidence from firm-level data. Journal of financial Economics 65(3):337–363

Falkena H, Bamber R, Llewellyn D, Store T (2001) Financial regulation in South Africa. In: South Africa: SA Financial Sector Forum

Falkena H, Davel G, Hawkins P, Llewellyn D, Luus C, Masilela E, Parr G, Pienaar J, Shaw H (2004) Competition in South African banking. Task Group Report for the National Treasury and the South African Reserve Bank

Giesecke JA, Dixon PB, Rimmer MT (2017) The economy-wide impacts of a rise in the capital adequacy ratios of Australian banks. Economic Record 93:16–37

Goodhart CA, Sunirand P, Tsomocos DP (2004) A model to analyse financial fragility: applications. Journal of Financial Stability 1(1):1–30

Goodhart CA, Sunirand P, Tsomocos DP (2005) A risk assessment model for banks. Annals of Finance 1(2):197–224

Goodhart CA, Sunirand P, Tsomocos DP (2006a) A model to analyse financial fragility. Economic Theory 27(1):107–142

Goodhart CA, Sunirand P, Tsomocos DP (2006b) A time series analysis of financial fragility in the UK banking system. Annals of Finance 2(1):1–21

Gorton G, Winton A (2017) Liquidity provision, bank capital, and the macroeconomy. Journal of Money, Credit and Banking 49(1):5–37

Havemann RC (2019) Lessons from South African bank failures 2002 to 2014. PhD thesis, Stellenbosch: Stellenbosch University

Kashyap AK, Stein JC (1995) The impact of monetary policy on bank balance sheets. In: Carnegie-rochester conference series on public policy, Elsevier, vol 42, pp 151–195

Leao ER, Leao PR (2007) Modelling the central bank repo rate in a dynamic general equilibrium framework. Economic Modelling 24(4):571–610

Lewis J (2010) A computable general equilibrium (CGE) model of banking system stability: Case of Jamaica. Journal of Business, Finance and Economics in Emerging Economies 5:81–120

Makrelov K, Davies RH, Harris L (2019) The impact of capital flow reversal shocks in South Africa: a stock-and flow-consistent analysis. Economic Research and Statistics Department, South African Reserve Bank

Martinez J, Tsomocos D (2011) Liquidity effects on asset prices, financial stability and economic resilience. Unpublished manuscript

Martínez JF, Tsomocos DP (2018) Liquidity and default in an exchange economy. Journal of Financial Stability 35(C):192–214

Van der Merwe E (2004) Inflation Targeting in South Africa. Citeseer

Nassios J, Giesecke JA, Dixon PB, Rimmer MT (2020) What impact do differences in financial structure have on the macro effects of bank capital requirements in the United States and Australia? Economic Modelling 87:429–446

Peiris MU, Tsomocos DP (2015) International monetary equilibrium with default. Journal of Mathematical Economics 56:47–57

Rateiwa R, Aziakpono MJ (2015) The structure of financial systems and economic growth in africa's three biggest economies: A time series evidence

Rumler F (1999) Computable general equilibrium modeling. numerical simulations in a 2-country monetary general equilibrium model. Inst für Volkswirtschaftstheorie und-politik, WU Vienna University of Economics and Business

Saade A, Osorio D, Estrada D (2007) An equilibrium approach to financial stability analysis: the Colombian case. Annals of Finance 3(1):75–105

Tabak BM, Cajueiro DO, Fazio DM (2013) Financial fragility in a general equilibrium model: the Brazilian case. Annals of Finance 9(3):519–541

Taylor L (1990) Socially relevant policy analysis: Structuralist computable general equilibrium models for the developing world. MIT press

Tsomocos DP (2003) Equilibrium analysis, banking, contagion and financial fragility. Bank of England Working Paper

Tsomocos DP, Zicchino L (2012) On modelling endogenous default. LSE FMG Discussion paper 548 (2005). In: Goodheart CAE, Tsomocos DP (eds) The Challenge of Financial Stability, Edward Elgar, chap 6, pp 134–52

Vasco C, Woodford M (2009) Credit Spreads and Monetary Policy. National Bureau of Economic Research

Appendices

A Banks' optimisation problem

We are using the (Goodhart et al., 2006a) model. 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

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

(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:

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

(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),

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

(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

$$\pi^b_{t+1,s} = v^{h^b}_{t+1,s}(1+r^b_t)\bar{m}^b_t + (1+r^A_t)A^b_t + \check{R}_{t+1,s}d^b_t(1+\rho_t) - ((1+\rho_t)v^b_{t+1,s}\mu^b_t + (1+r^b_{d,t})v^b_{t+1,s}\mu^b_{d,t} + e^b_t + O^b_t) \quad (4)$$

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

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

$$e^b_{t+1,s} = e^b_t + \pi^b_{t+1,s} \quad (5)$$

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

The capital adequacy ratio is

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

(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_t^b = lending rate offered by bank $b \in B$ at time t,

$r_{d,t}^b$ = deposit rate offered by bank $b \in B$ at time t,

ρ_t = interbank rate at time t,

r_t^A = rate of return on market book, A, at time t,

$v_{t+1,s}^{h^b}$ = 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,

$\breve{\omega}$ = risk weight on market book, and

ω = risk weight on the interbank lending.

A.1 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 modeled. The following reduced-form equations are assumed.

A.1.1 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:

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

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, $a_{h^b,1}$, $a_{h^b,2}$, $a_{h^b,3}$, and $a_{h^b,4}$ are the coefficients or the elasticities of the model.

A.1.2 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:

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

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.

A.1.3 Household's 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:

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

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.

A.2 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 also the case in South Africa where the Central Bank is SARB and who is 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 bond 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 and market book investment.

A.3 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:

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

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

A.4 Equilibrium

A.4.1 Market clearing conditions

The equations for the market clearing conditions are as follows: There are three consumer loans, three deposits, and one interbank markets which make up a total of seven markets in the model. 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.

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

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.

A.4.2 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.

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

Also, let $\eta \equiv \{r_t^{\gamma}, r_t^{\tau}, r_t^{\delta}, r_{d,t}^{\tau}, r_{d,t}^{\delta}, M_t, \bar{B}_t\}, B^b(\eta) = \{\sigma^2 : (3.7) - (3.10) \text{ hold}\}$. 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 given $E\{(e_t^b, O^b, A^b)_{b\in B}; p; (\bar{k}_{t+1,s}^b, \lambda_s^b, \lambda_{ks}^b, \hat{\omega}, \omega, \check{\omega})_{b\in B, s\in S}; r_t^A; \rho\}$
only if

(i) $\sigma^b \in ArgmaxE_t(\Pi_{t+1}^b(\pi_{t+1}^b)), b \in B$ so all banks optimise their payoff function

(ii) all markets clear according to equations (11) - (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)

(iv) $\sigma^{h^b}, \sigma^{\Phi}$, and $GDP_{t+1,s}$, for $h \in H$ and $s \in S$ satisfy the reduced-form equations (7) - (10).

B Calibration Methodoloy

If one excludes Lagrange multipliers then from conditions (i) - (iv) of the "Equilibrium conditions" 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.

The balance sheet items for the initial period were calibrated against annual account data for the banking sector as at the end of December 2016. 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. 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 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 SARB and the value was $\rho_t = 0.07$ [5]. 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 ω = $\tilde{\omega}$ = 0.2 (Bank for International Settlements. Committee on Banking Regulations and Supervisory Practices, 1988). 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, most banks capital is above the minimum regulatory capital requirements. As we mentioned earlier, 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 $\bar{k}^b > k^b_s$. The values of default and capital violation penalties (λ^b_s and λ^b_{ks}, b∈B, s∈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. 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 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. In addition, the repurchase rate which is the interbank rate is

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

assumed to be default free and so does not include a default premium whilst the return on asset must include some margin. 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 $GDP_{(t+1,i)} = 4.700$[6] and $GDP_{(t+1,ii)} = 4.512$

The elasticities or the coefficients of the reduced form equation for future GDP equation (10) 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).

Given the chosen values of the variables mentioned above, we are now left with a system of 56 equations with 56 unknown variables. By solving such system, the values of the remaining variables are obtained. The exogenous variables and the resulting initial equilibrium position are as shown in Table 13 below:

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

Table 13: Initial equilibrium position

	Initial Equilibrium			Exogenous variables in the model	
E	$r^{\gamma} = 0.0943$	$k_i^{\delta} = 0.1083$	$e_{ii}^{\gamma} = 1.9689$	$O^{\gamma} = 4.4531$	$a\alpha_{,1}^{\gamma} = 1.0135$
	$r^{\delta} = 0.0872$	$k_{ii}^{\delta} = 0.0685$	$e_i^{\delta} = 1.12167$	$O^{\delta} = 3.8358$	$a\beta_{,1}^{\delta} = 0.3139$
	$r^{\tau} = 0.0956$	$k_i^{\tau} = 0.0879$	$e_{ii}^{\delta} = 0.7076$	$O^{\tau} = 1.4328$	$a\theta_{,1}^{\tau} = 0.0883$
	$r_d^{\gamma} = 0.0659$	$k_{ii}^{\tau} = 0.0600$	$e_i^{\tau} = 0.7562$	$g\alpha_{,i,1}^{\gamma} = -0.4405$	$z_{\gamma,1} = 2.7943$
	$r_d^{\delta} = 0.0658$	$\pi_i^{\gamma} = 0.0604$	$e_{ii}^{\tau} = 0.4749$	$g\alpha_{,ii,1}^{\gamma} = -0.6679$	$z_{\delta,1} = 1.9935$
	$r_d^{\tau} = 0.0700$	$\pi_{ii}^{\gamma} = -0.0141$	$\check{R}_i = 0.9990$	$g\beta_{,i,1}^{\delta} = -0.4332$	$z_{\tau,1} = 1.7927$
	$\mu_d^{\gamma} = 22.0590$	$\pi_i^{\delta} = 0.4049$	$\check{R}_{ii} = 0.9500$	$g\beta_{,ii,1}^{\delta} = -0.6679$	$c_i^{\gamma} = 0.0864$
	$\mu_d^{\delta} = 10.4572$	$\pi_{ii}^{\delta} = -0.1042$	$\mu^{\alpha\gamma} = 20.9492$	$g\theta_{,i,1}^{\tau} = -0.4370$	$c_{ii}^{\gamma} = 0.5377$
	$\mu_d^{\tau} = 8.1540$	$\pi_i^{\tau} = 0.1975$	$\mu^{\beta\delta} = 10.4572$	$g\theta_{,ii,1}^{\tau} = -0.6679$	$c_i^{\delta} = 0.1345$
	$k_i^{\gamma} = 0.1164$	$\pi_{ii}^{\tau} = -0.0838$	$\mu^{\theta\tau} = 8.2982$	$\mu_{i,1} = 0.4154$	$c_{ii}^{\delta} = 0.0495$
	$k_{ii}^{\gamma} = 0.0958$	$e_i^{\gamma} = 2.5874$		$\mu_{ii,1} = 0.3745$	$c_i^{\tau} = 0.2770$
				B = 1.7367	$c_{ii}^{\tau} = 0.0461$
C				$r^{A} = 0.0730$	$e_0^{\tau} = 0.5587$
	$\mu^{\tau} = 0.0574$	$d_{\gamma}^{\phi} = 20.6960$		$A^{\gamma} = 7.1411$	$\mu_{s,2}$ = 0, ∀s∈S
	$\rho = 0.0700$	$d_{\delta}^{\phi} = 9.2916$	$v_i^{\alpha\gamma} = 0.9790$	$A^{\delta} = 3.4910$	$\mu_{s,3}$ = 0.15637, ∀s∈S
	$\bar{m}_t^{\gamma} = 19.1436$	$d_{\tau}^{\phi} = 7.6206$	$v_i^{\beta\delta} = 0.9862$	$A^{\tau} = 2.0913$	$\omega = 0.2000$
	$\bar{m}_t^{\delta} = 9.6189$	$d^{\gamma} = 0.8474$	$v_i^{\theta\tau} = 0.9824$	$e_0^{\gamma} = 1.9830$	$\breve{\omega} = 0.2000$
	$\bar{m}_t^{\tau} = 7.5744$	$d^{\delta} = 0.8293$	$GDP_i = 4.7$	$e_0^{\delta} = 0.8118$	$\hat{\omega} = 1.0000$
A				$g_{h,s,2}$ = 0.0370, ∀h∈ H^b , ∀s∈ S	$\lambda_i^b = 0.9000$, ∀b∈ B
				$g_{h,i,3} = 0.0500$, ∀h∈ H^b	$z_b, 2 = 0.1400$, ∀b∈ B
				$g_{h,ii,3} = 0.0700$, ∀h∈ H^b	z_b, 3 = 0.5000, ∀b∈ B
				$\lambda_{ii}^b = 1.0200$ ∀b∈B	$z_b, 4 = -0.1000$, ∀b∈B
	$v_{ii}^{\alpha\gamma} = 0.0900$	$v_i^{\gamma} = 0.9990$	$v_{ii}^{\delta} = 0.9500$	$k_s^{\delta} = 0.1200$, ∀s∈S	$a^{hb}, 2 = 0$, ∀h∈ H^b
	$v_{ii}^{\beta\delta} = 0.9000$	$v_{ii}^{\gamma} = 0.9500$	$v_i^{\tau} = 0.9990$	$k_s^{\tau} = 0.1000$, ∀s∈S	$a^{hb}, 3 = 1.3540$, ∀h∈ H^b
	$v_{ii}^{\theta\tau} = 0.9000$	$v_i^{\delta} = 0.9990$	$v_{ii}^{\tau} = 0.9500$	$k_s^{\gamma} = 0.1300$, ∀s∈S	$a^{hb}, 4 = -0.6800$, ∀h∈ H^b
			$GDP_{ii} = 4.512$	$\lambda_{ks}^b = 0.1000$, ∀b∈B, ∀s∈S	p = 0.95

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