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The South African NiGEM expansion*

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Abstract

This paper presents a new macroeconometric model for South Africa that forms part of the global system of models based on the National Institute Global Econometric Model (NiGEM). NiGEM is used by many central banks as well as the Organisation for Economic Co-operation and Development. The NiGEM-SA model, which provides a more detailed representation of South Africa's financial sector, is a new tool in the South African Reserve Bank's (SARB's) suite of models. It will complement the SARB's other models and help with understanding the impact of global economic shocks and the cyclical impacts of climate-related shocks. This paper presents key features of NiGEM-SA and illustrates its properties through a series of simulations. The simulation results indicate that model responses are in line with estimates in the empirical literature.

JEL classification

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Keywords

Forecasting, monetary policy, macroeconomic models

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1. Introduction

Central banks across the world rely on a variety of models to perform different functions and answer different questions. As no single model can address all policy questions and provide forecasts,[1] central banks develop and maintain a suite of models.

The South African Reserve Bank (SARB) is no different. Its main forecasting workhorse is the quarterly projection model (QPM). The QPM is a *gap* (output gap, real exchange gap, inflation gap) model, which quantifies the impact of economic developments on the gaps that develop when the economy deviates from its equilibrium (Botha et al. 2017).

The QPM is supported by other models to improve forecast accuracy and narrative. For example, the SARB has various vector regression and machine-learning models, which are focused on understanding the commodities market and other price dynamics in the economy. These, along with the core model,[2] serve as a benchmark for the QPM. This benchmarking is an essential part of the entire model process within the SARB, and new models are continuously being investigated to enhance this process.

The National Institute Global Econometric Model for South Africa (NiGEM-SA) is a new tool in the SARB's suite of models that will help with understanding the impact of global economic shocks and the cyclical impacts of climate-related shocks. The model was developed jointly with the National Institute of Economic and Social Research (NIESR) and follows the same structure as NiGEM models for other countries.

The extended South African model has a detailed demand side (consumption, government, investment and net exports) and a supply side with a constant elasticity of substitution (CES) production function. These aspects are underpinned by the standard (Taylor-rule type) interest rates and exchange rate blocks. NiGEM also incorporates

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1 Blanchard (2017), for example, distinguishes between theoretical and policy models, and advocates for their appropriate use.

2 The core model is a stylised structural error-correction model that is estimated based on South Africa's historical economic relationships. It is a large macroeconomic model with various components of aggregate demand modelled separately (such as consumption, investment, government expenditure and net exports). Other key channels in the model include prices, the current account, balance sheets of households and the banking sector.

different energy sources in the production process, enabling the assessment of certain climate-related shocks. Finally, the South African model includes financial sector dynamics. These changes enhance our ability to analyse policies and forecast outcomes using the NiGEM model.

The different country models are part of a global macroeconomic system, referred to as the NiGEM model, which covers over 60 countries and regions (regional economies) and forecasts over 5 000 macro variables. The entire system is updated every quarter and generates economic forecasts and analysis of policy actions. The individual models and the bigger system can assist with answering policy questions in areas such as fiscal and monetary policy, commodity price shocks, labour dynamics, trade policy and climate change.[3] NiGEM is widely used by central banks and other institutions such as the Organisation for Economic Co-operation and Development (OECD) and the Network for Greening the Financial System.[4]

This paper provides an overview of the South African NiGEM model. It outlines the model's general structure, theoretical background and features. The model's properties are illustrated by shocks to the exchange rate and carbon prices. The paper ends with a discussion of the banking dynamics implemented in the model.

2. Overview of NiGEM

NiGEM is a global flow-consistent model, where outflows from one country or region equal inflows into other countries and regions. As an econometric model, NiGEM's key behavioural equations are estimated using historical data. This approach ensures that the model's dynamics and key elasticities align with the primary characteristics of each country's data. NiGEM is a quarterly model, which allows a more comprehensive dynamic specification compared to models that rely on annual data, and reduces problems that may be encountered with identification and convergence. A quarterly model is also more suited for monetary policy deliberations that have a horizon of four to six quarters.

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3 See, for example, Manteu and Martins (2009) and Millard (2024).

4 See, for example, Darracq et al. (2023).

From a theoretical perspective, NiGEM falls into the category of global general equilibrium macroeconomic models, which are essentially based on Walrasian general equilibrium theory.[5] NiGEM strikes a balance between the theoretical principles guiding economies towards long-term market equilibria and the data-driven individual country characteristics that reflect real-world data outcomes.

In terms of general methodological approach, NiGEM incorporates micro-founded and theoretically based long-run relationships – sharing some properties of standard dynamic stochastic general equilibrium (DSGE) models – with more flexible lag structures that are fitted to the data. This combination ensures that NiGEM is useful for both policy analysis and forecasting.

The model is based on a New Keynesian framework and incorporates many characteristics of DSGE models. Individual country models are grounded in textbook macroeconomic principles and feature elements such as sticky prices, rational or model-consistent expectations, endogenous monetary policy guided by a Taylor rule or other standard specifications, and long-run fiscal solvency. The structure of NiGEM is designed to correspond to macroeconomic policy needs. Country models are built around the national income identity, comprising the determinants of domestic demand, trade volumes, prices, current accounts and asset holdings. They also incorporate a well-specified supply side, which underpins the sustainable growth rate of an economy in the medium term and incorporates an energy mix, providing a framework with which to analyse climate transition policies.

NiGEM differs from the other SARB models in various ways. Compared to the core model, NiGEM is more forward-looking, with a rational and adaptive expectations structure and features such as sticky wages, while the core model's structure is more

5 Walrasian theory is the foundation for analysing the economy holistically, rather than as a collection of individual market phenomena. Models that follow the Walrasian approach are known as general equilibrium models. According to this approach, the economy is assumed to be in equilibrium across all markets in terms of demand and supply, with shocks analysed as deviations from this equilibrium.

backward-looking (adaptive expectations).[6] The two models use similar estimation methods for behavioural equations and rely on national account identities to build a more detailed picture of the economy. Although NiGEM's modelling of expectations is similar to that of the QPM, it also includes key channels of the economy that are not modelled in the QPM, such as macroprudential channels, credit and wealth channels and disaggregated expenditure components. This comes at the cost of increased complexity in understanding and communicating results compared to the QPM. The two models are also fundamentally different in their estimation approaches and structure. The QPM is estimated as a system[7] and its behavioural features are defined by closing various gaps such as the output gap. NiGEM relies on single equation estimations, which are further calibrated in the model system. Cointegrating relationships guide its long-term dynamics. One of the most significant differences is that NiGEM models the global economy through its various country components, while the core and QPM models use exogenous assumptions to represent global economic activity.

3. Model structure

Country models are built around the national income identity and contain the determinants of domestic demand, trade volumes, prices, current accounts and asset holdings, as shown in **Error! Reference source not found.**. They incorporate a well-specified supply side, which underpins an economy's sustainable growth rate in the medium term. The supply side is derived from a CES production function, with labour, capital and energy as factor inputs, and productivity driven by labour-augmenting technical progress. Technical progress in NiGEM is assumed to be exogenous and can be shocked[8] to explore productivity-enhancing supply-side reforms. This specification of the supply side sets NiGEM apart from the core model, which treats most supply-side aspects as exogenous. In NiGEM, the energy inputs are further split into coal, gas, oil and non-carbon. This allows for climate scenarios to be modelled as energy mixes change with new policies. Energy prices are taken from world commodity markets with

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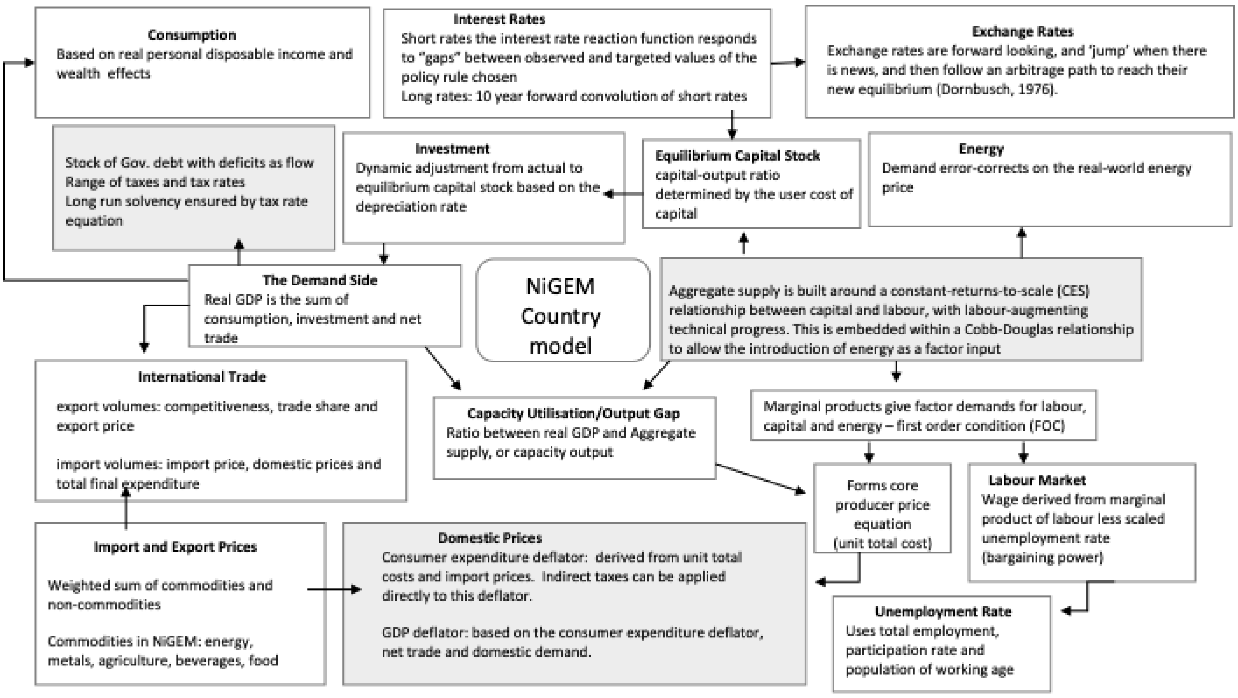
6 The SARB is developing a semi-structural expectations model, which is similar to the core model but more forward-looking, including a model expectations channel. This will address some of the core model's expectations shortcomings, aligning it with NiGEM and the QPM.

7 This means that all equations are estimated simultaneously.

8 These shocks are typically related to economic phenomena such as climate change policy and fiscal policy. However, in theory, any development that affects production can be a shock.

local carbon taxes applied, based on carbon produced through use. The energy mix is based on historical data. The impact of carbon taxes in simulation therefore depends on reliance on fossil fuels.

Figure 1: Full country structure overview



Source: NIESR (2024)

Deviations of actual output from potential output lead to adjustment processes that bring the economy back to potential in the long run, primarily through the impact on wages and prices. If demand exceeds supply, prices rise and real gross domestic product (GDP) decreases, and vice versa, all other things being equal.

Country models are linked through trade in goods and services, the influence of trade prices on domestic inflation, the impacts of exchange rates, and the patterns of asset holdings and associated income flows. The structure of the trade bloc ensures overall global consistency of trade volumes and trade values, which are linked via Armington matrices[9] (Armington 1969). As such, outflows from one country or region are matched

9 The basis of trade is the demand for goods that are either unavailable locally or differentiated from locally produced goods. Armington matrices characterise trade system-based consumers demanding each country's differentiated goods. This 'trade force' combined with goods substitution (constant elasticity of substitution) explains trade flows between countries.

by inflows into other countries and regions to ensure flow consistency. Global assets and liabilities are also aligned, as well as their respective income flows. This requires that the stock of government debt does not increase exponentially and that solvency is imposed on the government sector through endogenous fiscal rules. NiGEM is similar for different countries, the only difference being how each country calibrates its model. For example, the Armington elasticities of South Africa differ significantly from those of the United States.

The South African country model, however, also incorporates the banking sector. Bank activity is modelled using a balance sheet approach, where total assets equal total liabilities. There is a demand and supply curve for key assets. For example, demand for credit depends on factors such as income levels, economic activity and relative prices, while supply is influenced by the costs of providing assets and the risks associated with supplying them, such as the rate of company liquidations. Through these channels, the banking sector is affected by the real economy. In turn, it affects the real economy through lending spreads above the central bank policy rate for corporate and consumer credit, which consequently influences consumption and business investment.

4. Expectations

NiGEM allows users to experiment with different types of expectations in a range of markets. Rational or model-consistent expectations are assumed by default in defining monetary policy rules and financial market behaviour, including exchange rates, long-term interest rates and equity prices. In other words, the variance of future shocks does not affect agents' current expectations. This is very different to the SARB core model, which is based on adaptive expectations. Wage bargaining is also assumed to be settled based on a country-specific degree of rational expectations. Consumption behaviour is assumed to be more myopic, in line with empirical evidence; however, it does react to changes in forward-looking financial wealth (Berg 2013). The housing market is also treated as adaptive by default. Users can modify the defaults to run any scenario with forward-looking or adaptive expectations in any of these markets, depending on the desired narrative of their simulation. This provides significant flexibility when it comes to policy simulations, as large shocks such as COVID-19 have the potential to amplify economic and financial impacts through changing how expectations are formed in different markets.

Table 1 lists the default settings for NiGEM simulations in rational mode. For further discussion of these assumptions, see Barrell and Davis (2007) or Hantzsche, Lopresto and Young (2018).

Table 1: Default settings for NiGEM simulations in rational mode

Agents	Key variables affected	Default setting
Consumers	Consumption	Backward
Workers	Wages	Forward
Firms	Investment	Forward
Monetary authorities	Interest rates	Forward
Financial markets	Long real rates House prices Equity prices	Forward Backward Backward
Foreign exchange markets	Exchange rates	Forward

The decision of whether to use adaptive or rational expectations will change depending on the scenario or shock to be explored. For example, a fiscal policy tightening shock could use forward-looking consumers if the narrative assumes that the government signals very clearly that tax increases will happen in the future. If, on the other hand, the government is assumed to have a weak commitment to fiscal stability, the scenario may assume backward-looking consumers who do not expect tax increases in the future. This will have implications for the multiplier of any fiscal-related action.

5. Estimation and calibration

Often there are trade-offs between the theoretical foundations of the model and its fit with actual economic and financial data (Blanchard 2017). NiGEM strikes a balance between theory-based and data-driven modelling approaches. For a macroeconometric model to be useful for policy analyses, particular attention must be paid to its long-term equilibrium properties. At the same time, short-term dynamic properties must be consistent with data. Long-run relationships in NiGEM are specified in line with standard macroeconomic theory, imposing cross-equation restrictions where required.

As far as possible, the same theoretical structure has been adopted for each country model. Model parameters are determined primarily through estimation and calibration, employing standard time series and panel estimation methods to obtain robust estimates. Parameters are calibrated to minimise forecast errors and constrained so that the dynamic responses to shocks of key variables, such as GDP and inflation, match findings in the empirical and theoretical macroeconomic literature. The South African model expansion followed the same methodology.

Core behavioural equations are specified in a cointegrating error correction framework, like the SARB core model. This has the advantage that the long run, as embodied in the cointegrating relationship, can be modelled in a theoretically consistent manner, while the short run can be modelled to best fit the data. The error correction mechanism ensures that the system moves towards the long run in the absence of shocks. As such, both policy analysis and forecasting can be encompassed in the same framework.

Cointegrating relationships can be estimated as part of a two-step process: for example, applying dynamic ordinary least squares (OLS) procedures to first identify the long-run equations and then fit the dynamics around the cointegrating relationships, or by applying instrumental variable techniques in a single equation framework that jointly estimates the cointegrating relationships and the short-term dynamics. We also employ constrained estimation techniques to ensure that all estimated parameters lie within theoretically plausible boundaries and that the model produces a coherent outlook for the future, which takes precedence over explaining the past.

In general, equations are estimated for each country individually to capture as many idiosyncratic behaviours as possible. In some cases, panel estimation methods are adopted, where common elasticities are imposed across countries for global consistency. In other cases, theory is used to define relationships. In the South African case, both approaches were used to ensure model consistency.

When estimating, non-linear OLS is used for standard equations. Outliers are identified as falling over three standard deviations from the mean and excluded to ensure a consistent long-run relationship. Data after 2019 are automatically excluded due to the adverse effects of COVID-19 and the Ukraine war exhibiting idiosyncratic behaviour that distorts regression results. The wage/price/employment equation is estimated as a system of equations using seemingly unrelated regression due to the common coefficients between variables and correlated residuals. Theory is given precedence over estimation. If regression estimation provides results that do not fit with economic theory, this is assumed to occur from bias in the estimation procedure and outliers in the data. In such instances, constrained estimation is used to ensure that parameters fall within a range congruent with economic theory and that they contribute to a stable long-run forecast. Once estimated, simulation results are calibrated to ensure consistency with historical shocks and stability in the long run. In this way, calibration and estimation are seen as complementary rather than substitutes (Cooley 1997).

South African equations were checked against the literature to ensure that responses to policy shocks were of the correct magnitude. For example, a two-year government consumption shock indicated an average fiscal multiplier of 0.3. This is congruent with findings in the literature that suggest multipliers of less than 1 in the South African economy after 2013 (Janse van Rensburg, de Jager and Makrelov 2021; Kemp 2020; Makrelov et al. 2018; Havemann and Hollander 2024). This is largely driven by the fact that South Africa is an open economy, and an increase in government expenditure leads to a similar increase in imports, dampening the final impact on GDP. Furthermore, in line with the literature, the size of the multiplier changes depending on whether government solvency is turned on or off (if turned on, the government increases taxes to pay for the increased expenditure dampening consumption; if turned off, the government debt stock increases, increasing insolvency risk, which raises the term premium and makes investment more expensive, dampening GDP through a different channel). The former option is how fiscal dynamics are modelled in the QPM.

6. Model properties

In the next sections, we illustrate the properties of the model through a series of common shocks applied to the system. We model the impact of an exchange rate depreciation and a carbon tax increase.

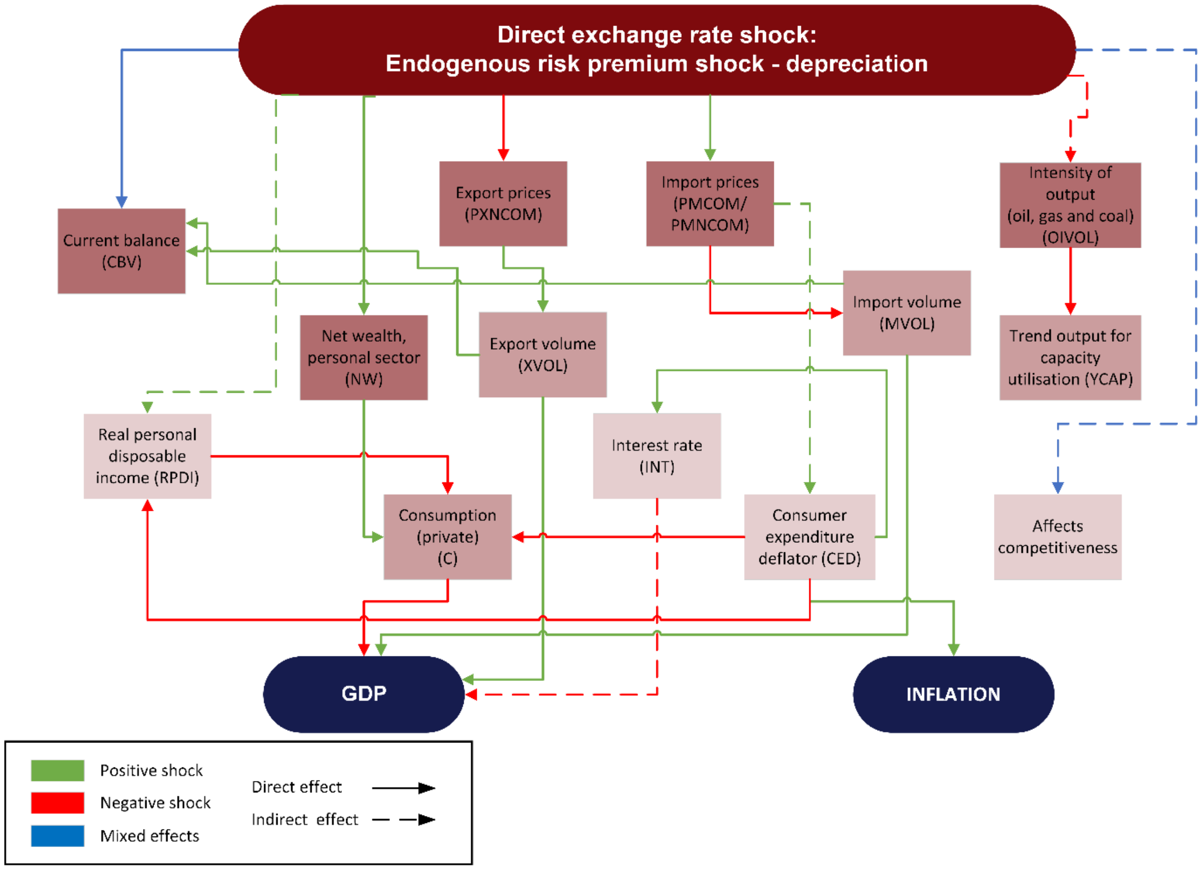
6.1 Exchange rate simulation

This section simulates the impacts of an endogenous exchange rate shock, which is a temporary 1% depreciation of the rand/US dollar exchange rate that lasts two years. The narrative is that some exogenous factor has increased the risk premium associated with the South African rand, depreciating the currency. As the variable is endogenised in the simulation (both for the initial two-year period and beyond), monetary policy will take effect to mitigate the inflationary effects of the depreciation, which feeds back into the exchange rate when the forward-looking uncovered interest rate parity exchange rate setting is used.

6.1.1 Transmission channels

As a weaker currency implies that more rands are required per US dollar, the first and most immediate effect is an increase in the rand price of imports and a decrease in the dollar price of exports. Responding to this price shift, import demand decreases and export demand increases (as exports are made more competitive), improving real GDP in the immediate and very short run. However, an increase in the price of imports also flows through into the consumer expenditure deflator – prices increase as imported goods become more expensive. As a consequence, headline inflation increases. The central bank responds to inflation above target by raising interest rates. The full impact of interest rate increases is detailed in the previous section, but they essentially dampen real GDP and somewhat counteract the initial depreciation of the currency. The flow chart in Figure 2 provides an overview of the key variables and linkages within the model when there is a shock to the exchange rate.

Figure 1: Transmission of exchange rate shock

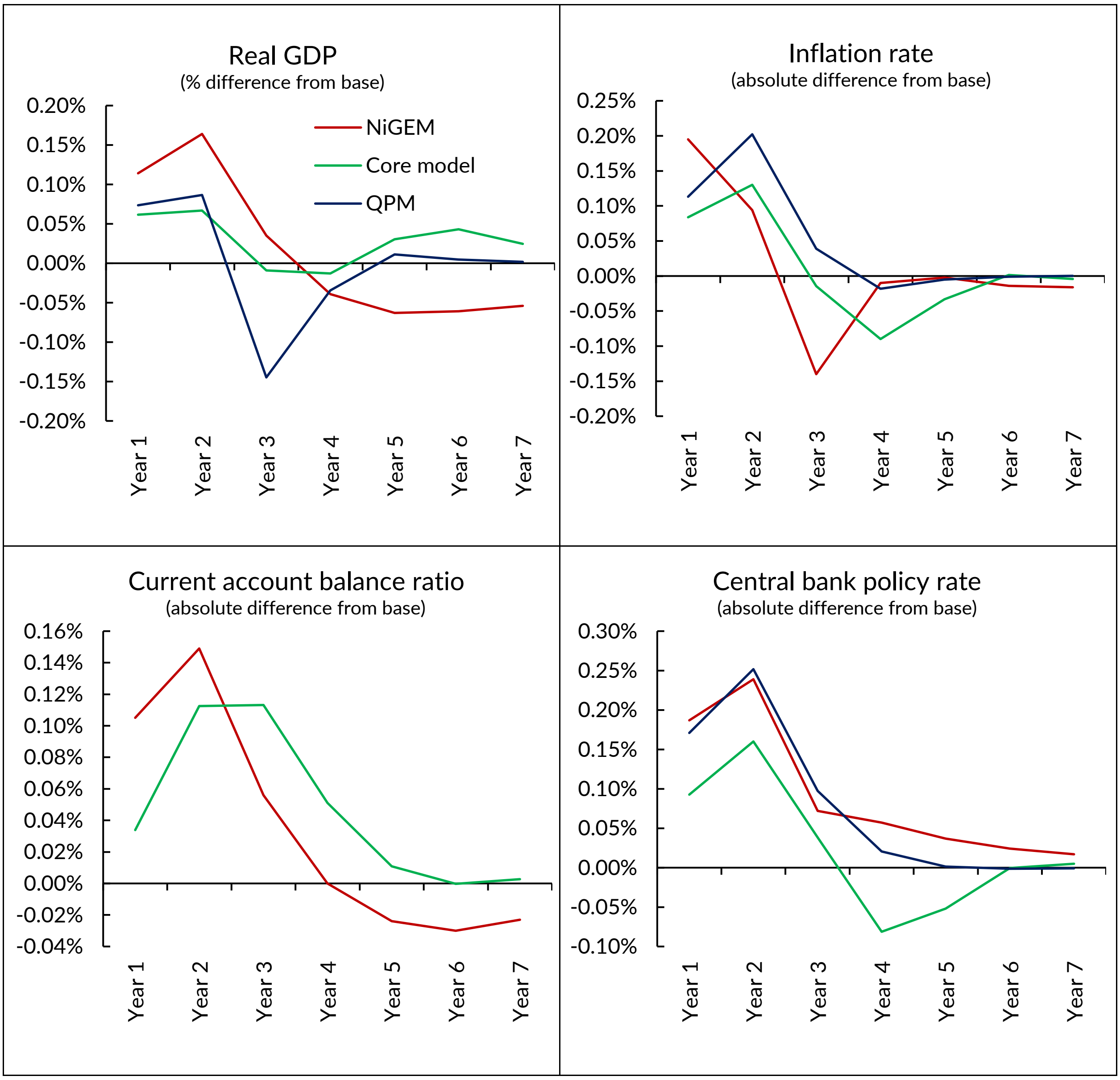


Source: NIESR (2024)

6.1.2 Results

The simulation results (shown in Figure 3) demonstrate the effect of the transmission channels indicated above. There is an improvement in the current account balance and real GDP as exports increase and imports decrease. However, inflation increases by about 0.2 percentage points in the first year. This is brought back down to the central bank's inflation target by lifting the policy rate by about 25 basis points. These results are similar when compared to the equivalent QPM and core model responses (Figure 3).

Figure 2: Reaction of key macroeconomic variables to an exchange rate depreciation[10]



Source: NiGEM simulation, NIESR (2024) and SARB

10 Note that the QPM does not model the current account; the SARB obtains its current account forecast from the core model. In addition, the QPM is a gap model, which means that compared to the core model and the NiGEM model (which are structural), it will at some point overreact to shocks. This explains the sharper real GDP reaction.

6.2 Carbon tax simulation

This section simulates an increase in the carbon tax rate. The shock will be a permanent increase in the price of carbon by US$5 per ton of carbon (an increase of about 50%, given the carbon tax in 2024/25 of R190).

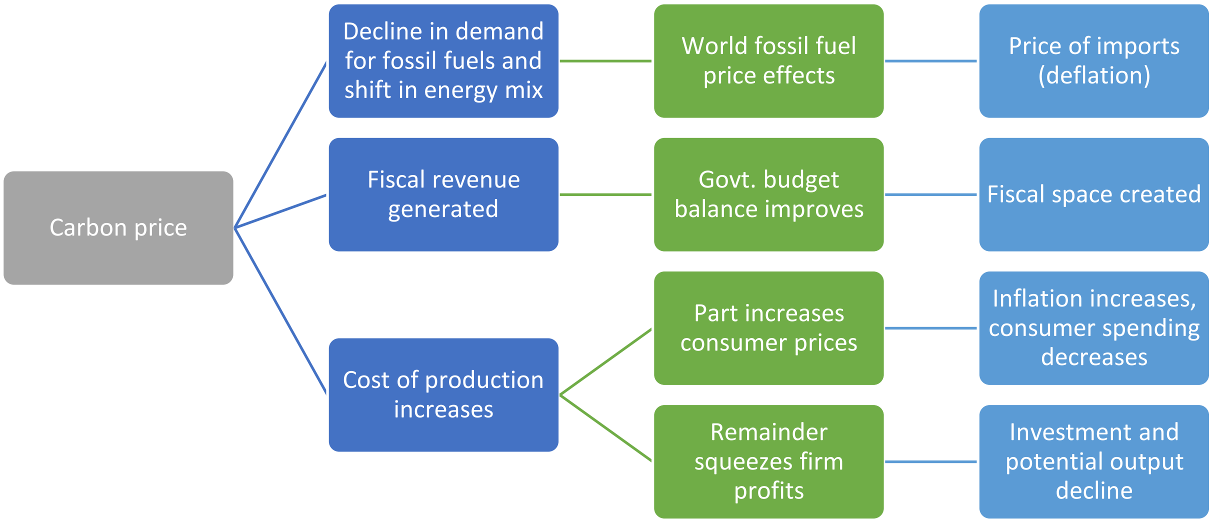
There are several important considerations with regard to carbon taxes. The first is whether the tax is done on an individual country basis or whether there is coordinated global action. If the former, the increase in taxes and subsequent monetary policy response serves to weaken the economy, especially through the international trade channel as the exchange rate shifts lead to an increase in imports and a decrease in exports. If the carbon tax is adopted globally, however, and as all countries experience inflation and increases in interest rates, there is not such a significant change in relative prices between countries and the impact will be country specific. The second consideration is how the government recycles carbon tax revenues. This choice has important economic implications. Finally, the counterfactual is important in determining what the results say. For example, in this simple scenario the counterfactual is a climate-neutral base without any of the impacts from the chronic physical damage of climate change. These simulation results therefore show the negative impacts of introducing a carbon tax without considering the positive impact on the economy of mitigating the effects of climate change.

6.2.1 Transmission channels

The carbon tax propagates through the economy in several ways (see Figure 4). Firstly, there is a decline in demand for fossil fuels, shifting the energy mix. If the tax is global, this can cause a significant decline in the world price of oil. If done individually, however, the effect is much less significant. Secondly, the cost of production increases. This is partly passed on to consumers, creating inflationary pressures. The rest of the cost is absorbed by producers, hampering the supply side of the economy and lowering productivity. The carbon tax also generates fiscal revenue, which can improve the government's budget balance. However, this effect can also depend on country specifics – a rise in the tax rate may initially be offset by a shrinkage in the tax base.

In this simulation, the carbon tax was assumed to be applied locally and not globally, and government expenditure did not change (that is, any gain or loss in income would transmit directly into government debt, with tax and expenditure not changing based on this). NIGEM offers other recycling options, such as through taxation and transfers. The counterfactual is a climate-neutral base. This scenario therefore simulates what would happen if a carbon tax were imposed without any positive effects gained from mitigating the effects of climate change.

Figure 3: Transmission channels of a carbon tax



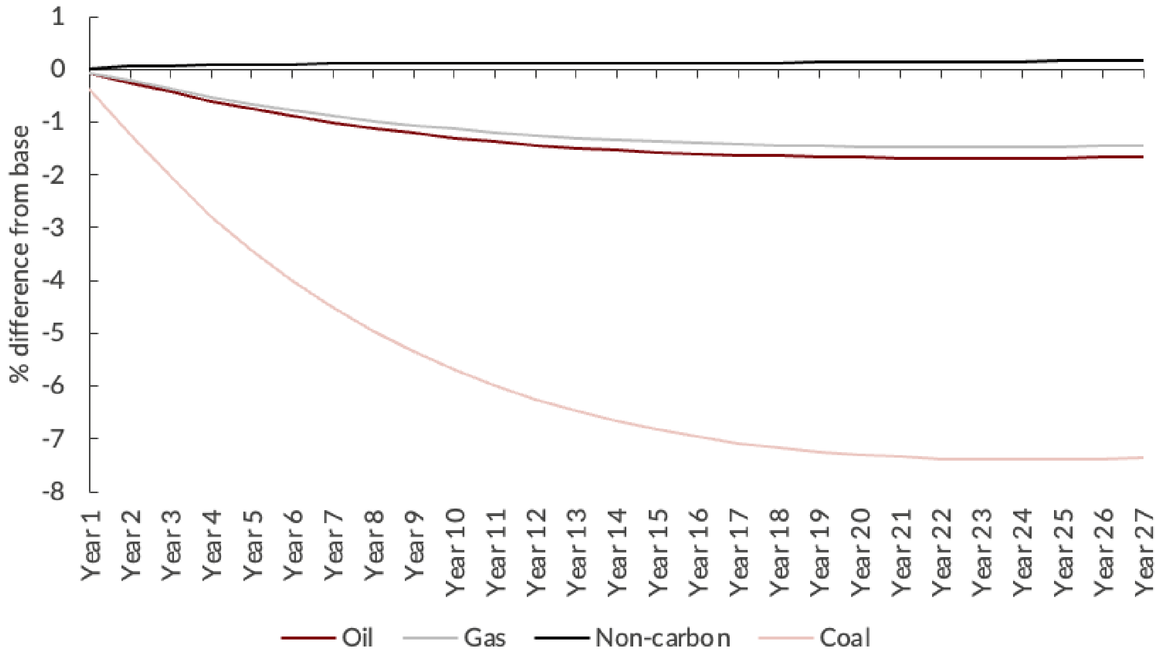
Source: NIESR (2024)

6.2.2 Results

The change in economic activity is largely determined by a country's exposure to energy types and the carbon intensity of those types. The results from the simulation suggest that South Africa's coal industry would be hit the hardest, with its volume of energy consumption as a share of GDP declining by 7.35% by the end of the simulation period (Figure 5). Oil and gas both decline by about 1.5%, while non-carbon sources increase by an insignificant amount.

In NiGEM, technological progress is exogenously determined and, as such, use of non-carbon does not capture increased investment in non-carbon or potential efficiency gains (such as the energy loss when moving between primary and useful energy). As a result, combined energy use decreases in absolute terms. Additional climate scenarios can be explored that take into account technological change and changes in investment behaviour driven by technology (as opposed to changes in the user cost of capital), but these need to be exogenously determined and then inputted into NiGEM.

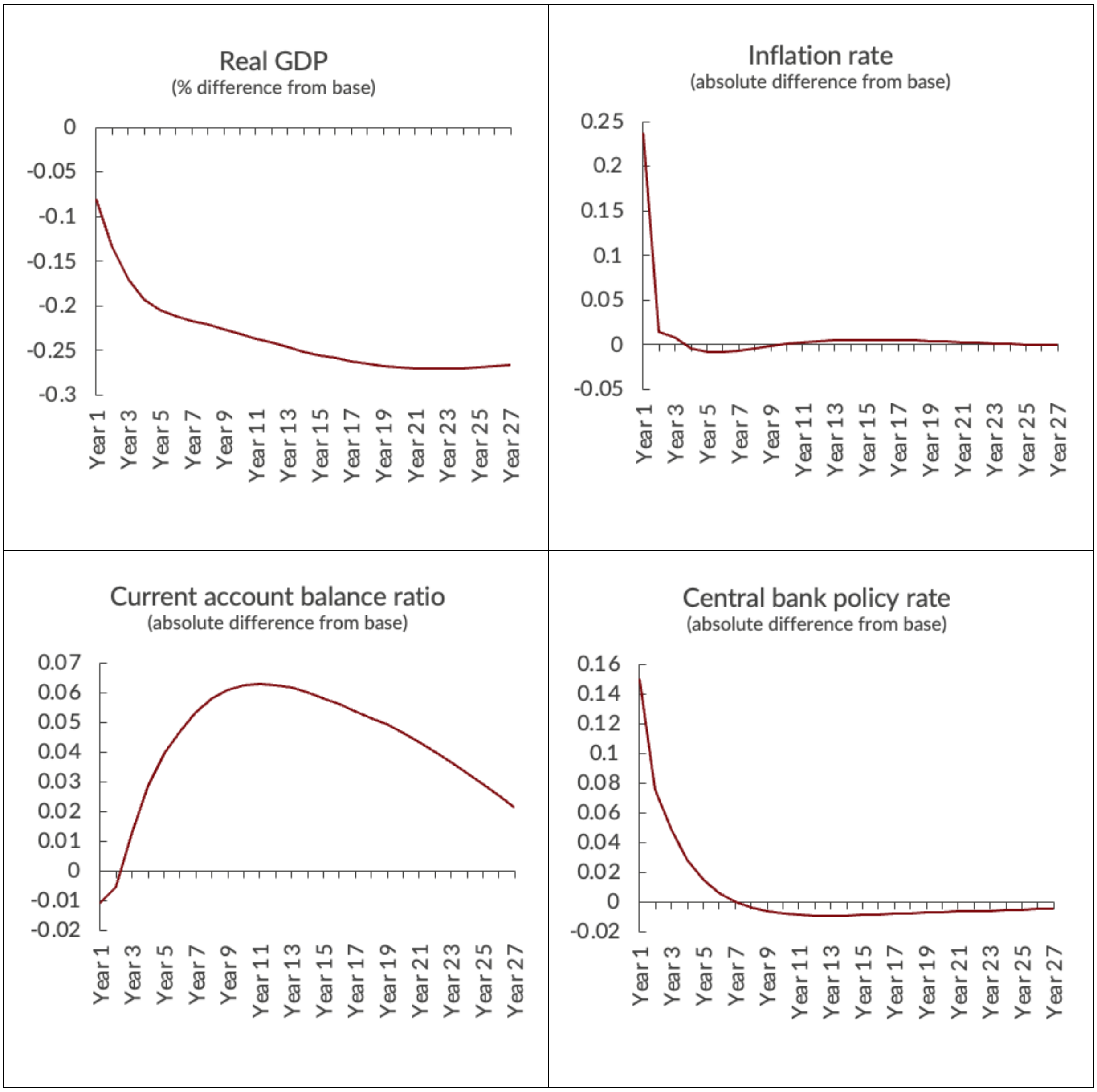
Figure 4: Change in energy mix (volume of energy consumed as % of GDP) as a reaction to an increase in the carbon tax



Source: NiGEM simulation, NIESR (2024)

Inflation initially increases as costs are passed on to consumers. The central bank raises interest rates accordingly. At the same time, production decreases. Overall, this leads to a decline in real GDP in the short run. In the long run, once inflation is controlled, the central bank lowers the interest rate below the baseline scenario as productivity falls and lower rates are required to stimulate economic growth. Real GDP remains below baseline as producers do not fully pass on the costs of the carbon tax to consumers, face higher costs of production and therefore produce relatively less. Foreign exchange markets react to this reduction in the interest rate and the currency depreciates, leading to an increase in import prices and a subsequent reduction in imports. This leads to an improvement in the current account balance ratio. Exports increase as a result of the depreciation. However, the unilateral increase in carbon taxes also increases the relative price of exports. As a result, the two effects effectively cancel each other out in the long run. Employment is affected as GDP growth and productivity slow down; however, this effect is only in the aggregate and does not show the sectoral decomposition.

Figure 5: Reaction of key macroeconomic variables to an increase in the carbon tax



Source: NiGEM simulation, NIESR (2024)

7. Banking sector model extension

South Africa has a well-developed financial sector; therefore, it is important to include financial market dynamics in the model. Regulations that alter liquidity and capital requirements in effect act as a tax on bank activity and therefore can change bank behaviour by, for example, reducing bank lending to households and firms.[11] Banks would increase rates in such a way that their net interest income can offset any increases in the costs they incur from the change in regulations.

In NiGEM, short-run fluctuations in activity are driven by the demand side; however, the supply side (labour, capital and technical progress) is what governs the long-run path of the economy. Financial markets are by default forward-looking, so when the spread between borrowing and lending rates faced by firms is changed, this will in turn affect the user cost of capital, investment and the equilibrium level of output and capital in the economy in the medium to long term (see Barrell et al. 2009). For households, a larger borrowing-lending spread would alter consumption and savings decisions, and thus domestic demand.

7.1 Model

In creating this model, we build on previous work that incorporates financial dynamics in large models.[12] The banking sector model in NiGEM was first developed by Barrell et al. (2009) and then improved by Davis and Liadze (2012). Banking activity is derived from the balance sheet approach, where total assets equal total liabilities and the framework sets out supply (price) and demand curves for the main assets. Demand in the banking sector depends on the level of income, banking activity or relative prices. Supply is driven by the costs of providing assets and the risks associated with supplying them. On the assets side, four main assets are modelled: (i) secured loans (mortgages), (ii) unsecured loans (consumer credit), (iii) loans to corporates, and (iv) liquid assets. Mortgages have a borrowing rate, consumer credit has a higher borrowing cost than mortgages, and for corporate loans, the interest rate is calculated as the risk-free long-run interest rate with a mark-up. Furthermore, liquid assets are modelled as a residual at a fixed percentage of the balance sheet and other assets are also modelled as a residual. Any shock to the banking sector or regulatory changes that lead to banks changing their capital adequacy ratios will also require a change in their balance

11 See, for example, Sibande and Milne (2024) and Pillay and Makrelov (2024).

12 See De Jager et al. (2022) and Makrelov, Davies and Harris (2021).

sheets.[13] Financial institutions accept deposits, issue equities and bonds, and provide loans at a higher interest rate than deposits because a mark-up is added, reflecting these institutions' profit motive. The size and net return on the portfolio generate capital endogenously via retained earnings. A list and description of variables can be found in Annexure 1.

7.2 Banking model link to the macroeconomy

Different types of borrowing by consumers and firms will have a different final impact on the economy due to different economic and financial channels. Figure 7 shows the different channels. Secured and unsecured borrowing by consumers primarily affects consumption and savings decisions, which is depicted in the current account balance. For example, higher borrowing costs would alter the net interest income of consumers but also reduce house prices and thus housing wealth.[14] As a result, consumers may delay or discourage consumption altogether, leading to a rise in the savings rate in the wider economy. This effect would be noticeable in the current account balance, particularly for a small open economy.

For non-financial corporations, an increase in the cost of borrowing faced by firms on loans increases the user cost of capital. This reduces borrowing by firms and reduces investment. In turn, this lowers capital accumulation and productivity, which consequently weighs on current equilibrium output and potential output levels. The flow chart below details the various banking sector linkages.

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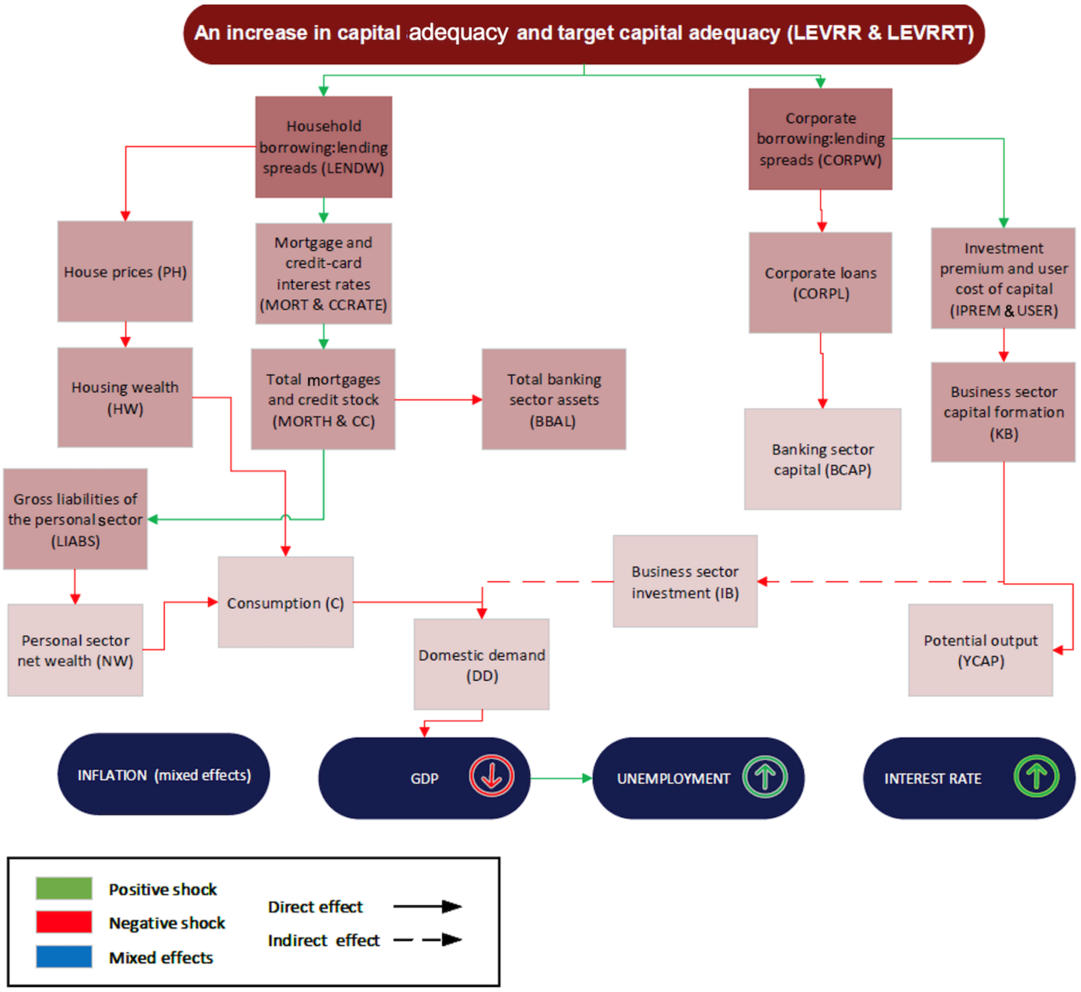
13 See Davis and Liadze (2012) for an explanation of the role of shadow banks when spreads increase significantly.

14 Or the retail sector.

Figure 6: Capital adequacy shock scenario



Source: NIESR (2024)

The following equations demonstrate how the demand for loans is modelled, depending on the type of loan provided (secured or unsecured) and the agents demanding the loan (households or firms).

Secured consumer loans market

The volume of secured loans in the form of mortgages is given by:

$$\mathrm{LOG}(\mathit{SAMORTH}) = -\beta 0 + \mathrm{LOG}(\mathrm{SACED}) + \mathrm{LOG}\left(\frac{\mathrm{SAMORTH}(-1)}{\mathrm{SACED}(-1)}\right) - \beta 1 * \left(\mathrm{LOG}\left(\frac{\mathrm{SAMORTH}(-1)}{\mathrm{SACED}(-1)}\right) - \beta 2 * \mathrm{LOG}\left(\frac{\mathrm{SAPH}(-1)}{\mathit{SACED}(-1)}\right) - \beta 3 * \mathrm{LOG}(\mathrm{SARPDI}(-2)) + \beta 4 * \left(\mathrm{SARMORT}(-2) - \left(\frac{(\mathrm{SACED}(-2)}{\mathit{SACED}(-3)}\right) * 4 - 1\right) * 100\right)\right) + \beta 5 * \mathrm{LOG}\left(\frac{\mathrm{SAPH}(-1)/\mathrm{SACED}(-1)}{\mathit{SAPH}(-1)/\mathit{SACED}(-2)}\right)$$

This equation shows that the volume of mortgages depends on real personal disposable income (*sarpdi*), the real house price (*saph/saced*) and the prevailing mortgage rate (*samort)*. Moreover, the level of borrowing and its dynamics are impacted by the level and the rate of change in real house prices.[15]

$$
\begin{aligned}
SAMORT = \; & -\beta 0 + \; SAMORT(-1) - \beta 1 \\
& * \Big(SAMORT(-1) - \big(SAINT(-1) + SALENDW(-1)\big) + \beta 2 \\
& * \big(SAINT - SAINT(-1)\big) + (1 - \beta 2) * \big(SAINT(-4) - SAINT(-5)\big) \\
& + (SALENDW - SALENDW(-1)\Big)
\end{aligned}
$$

The interest rate charged on mortgages by banks (*samort*) is shown above. It is calculated as the central bank interest rate (*saint*) plus a mark-up above costs (*salendw*).

$$
\begin{aligned}
SALENDW = \; & -\beta 0 + SALR - SAINT + \beta 1 * SAARR(-3) - \beta 2 \\
& * (\big(SALENDW(-2) - SALR(-2) + SAINT(-2)\big) \\
& - \big((SALENDW(-3) - SALR(-3) + SAINT(-3)\big) + \; \beta 3 * \; SALEVRR(-2) \\
& + \; \beta 4/SAHEAD(-1)
\end{aligned}
$$

The mark-up that banks charge above the SARB rate can be influenced by banking sector regulations but also the risk of lending to the borrower. Therefore, *salendw* is determined by the risk-adjusted capital adequacy ratio (*salevrr*), personal disposable income (*sarpdi*), actual output (*say*), nominal house prices (*saph)* and mortgage arrears (*saarr*).

15 In all the equations the prefix SA refers to South Africa. The number in parenthesis after a variable refers to its lag order. *saced* is the consumer expenditure deflator.

$$SAARR = \beta0 + SAARR(-1) - \beta1 * (SAARR(-1) - \beta2 * LOG\left(\left(\frac{SALIABS(-1)}{\frac{SACED(-1)}{SARPDI(-1)}}\right) - \beta3 * SAINT(-2)\right) - \beta4 * \left(LOG\left(\frac{SAPH(-1)}{SACED(-1)}\right) - LOG\left(\frac{SAPH(-2)}{SACED(-2)}\right)\right) - \beta5 * (LOG(SAY) - LOG\big(SAY(-1)\big))$$

The mortgage rate (saarr) depends on the policy rate (*saint)*, real household prices *(saph/saced),* real output (*say*) and real disposable income (*sarpdi*). Subsequently, an increase in the capital adequacy ratio would increase the mortgage rate charged to consumers and in turn reduce demand for mortgages.

Unsecured consumer loans market

Credit cards (*sacc*) are dependent on real personal disposable income and the cost of extending this credit to consumers – the interest rate charged on consumer credit balances.

$$LOG(SACC) = \beta0 + LOG(SACC(-1) + LOG\left(\frac{SACED}{SACED(-1)}\right) - \beta1 * \left(LOG\left(\frac{SACC(-1)}{SACED(-1)}\right)\right) - \beta2 * LOG\big(SARPDI(-1)\big) + \beta3 * \left(SACCRATE(-1) - \left(\left(\frac{SACED(-1)}{SACED(-2)}^4 - 1\right) * 100.0\right)\right)$$

The interest rates on credit card balances (*ssccrate*) are driven by changes in the borrowing lending rate spread (*salendw*) and the central bank interest rate (*saint*):

$$SACCRATE = \beta0 + SACCRATE(-1) - \beta1 * \Big(SACCRATE(-1) - \big(SAINT(-1) + SALENDW(-1)\big)\Big) + \beta2 * \big(SAINT - SAINT(-1)\big) + \beta3 * \big(SACCRATE(-1) - SACCRATE(-2)\big)$$

The interest rates charged on credit cards are higher than the charges in the secured lending market.

Corporate non-financial sector loans market

The total number of loans borrowed by the corporate non-financial sector is denoted by *sacorpl*, and it is dependent on corporate sector profitability and the cost of borrowing – that is, the risk-free long-run rate plus the mark-up banks charge non-financial corporations *(sacorpw*), and the consumer expenditure deflator (*saced*). Corporate sector profitability is given by the gross operating surplus, but can also be proxied by real GDP (*say*).

$$
\begin{aligned}
LOG(SACORPL) & \\
&= -\beta 0 + LOG(SACED) + LOG\left(\frac{SACORPL(-1)}{SACED(-1)}\right) - \beta 1 \\
&* LOG\left(\frac{SACORPL(-1)}{SACED(-1)}\right) + \beta 2 * LOG\big(SAY(-1)\big) - \beta 3 * SACORPW(-1) \\
&+ \beta 4 * LOG\left(\frac{\frac{SACORPL(-2)}{SACED(-2)}}{\frac{SACORPL(-3)}{SACED(-3)}}\right)
\end{aligned}
$$

Similar to the borrowing and lending spread faced by consumers (*salendw*), the interest rate spread between corporate borrowing and lending (*sacorpw*) is dependent on the prevailing real interest policy rate (*saint*) and risk-adjusted capital adequacy ratio (*salevrr*), as per the equation below:

$$
\begin{aligned}
SACORPW = {} & -\beta 0 * \left(LOG\left(\frac{SAYCAP}{SAY}\right)\right) + \beta 1 * SALEVRR + \beta 2 * LOG(SAINSOLR) \\
& + \frac{\beta 3}{SAHEAD} + \beta 4 * SAARR
\end{aligned}
$$

In addition to capital adequacy and policy, the output gap, which is the difference between actual output (*say*) and potential output *(saycap*), is included to account for cyclicality. The corporate sector insolvency rate (*sainsolr*) is included to account for the risk in lending to businesses. The gap between the actual and target level of capital (*sahead*) is included to account for non-linear effects of shortages in capital on lending behaviour by banks. Finally, mortgage arrears (*saarr)* are included, capturing increases in risk in the housing sector. As capital levels fall below the target level, banks respond by both reducing lending and increasing borrowing costs to build up additional capital. As the gap between the actual and target level of capital tends to zero, borrowing costs would rise non-linearly.

The insolvency rate (*sainsolr*) is modelled as a function of the output gap (*saycap/say*), policy rate (*saint*), corporate lending spread (*sacorpw*) and investment premium (*saiprem)* as follows:

$$SAINSOLR = \beta 0 + \beta 1 * \left(LOG\left(\frac{SAYCAP}{SAY}\right)\right) + \beta 2 * SAINT(-1) + \beta 3 * SAIPREM(-1)$$

$$SAIPREM = \beta 1 * SACORPW(-1)$$

7.3 The balance sheet

A shock to any of the assets in the banking sector set out above will affect capital adequacy levels (*levrr*) and banks will be forced to adjust their capital and asset structure. Therefore, to analyse the impact of a change in regulation such as capital adequacy, a complete banking sector balance sheet for assets is required. Moreover, the adjustment of bank capital adequacy must occur either by adjusting lending or accumulating additional capital. The unweighted balance sheet equation is shown below:

$$SABBAL = SACORPL + SAMORTH + SACC + SABRA + SABBSOA$$

It incorporates the main banking sector assets (*sabbal)*, which are outlined above, in addition to other assets that grow in line with the rest of the balance sheet. That is, *sacorpl* is non-financial corporate debt, *samorth* is mortgage debt of households, *sacc* is consumer credit, *sabra* is liquid assets of the banking sector and *sabbsoa* is other assets not previously captured.

Economic, financial and regulatory shocks initiate an adjustment process to a new equilibrium, which operates through changes in prices and demand for different assets and liabilities. This process needs to consider the risk profile of different instruments. Hence, to evaluate the portfolio adjustment process in response to a shock and subsequent change in *levrr*, we need a risk-weighted balance sheet. This is captured in the below equation, where *sabrwa* is the bank sector risk-weighted assets:

$$SABRWA = SACORPL + 0.5 * SAMORTH + SACC + 0.2 * SABRA + 0.3 * SABBSOA$$

7.4 Capital adequacy simulation

To raise more capital, banks can either issue rights or absorb some of the gross operating surplus (or profit) by appropriating it as capital. This is modelled by the following equation:

$$\begin{aligned} SABCAP = {} & SABCAP(-1) + \left(\left(1 - \left(\frac{SALEVRR(-1)}{SALEVRRT(-1)}\right) + 3\right)\right) * 1.5 * \beta 1 \\ & * \left(\frac{SALENDW(-1)}{400}\right) * \left(SAMORTH(-1) + SACC(-1)\right) \\ & + \left(\left(\left(\frac{SACORPW(-1)}{400}\right) * SACORPL(-1)\right)\right) - \beta 2 * \left(\frac{SAARR - 2.39}{400}\right) \\ & * (SAMORTH + SACC) - \beta 3 * \left(\frac{SAINSOLR - 0.84}{400}\right) * SACORPL \end{aligned}$$

The first line in the equation gives the speed of adjustment for bank capital to divergence in the risk-weighted ratio of capital to assets (*levrr*) to the risk-weighted capital target ratio (*levrrt*).

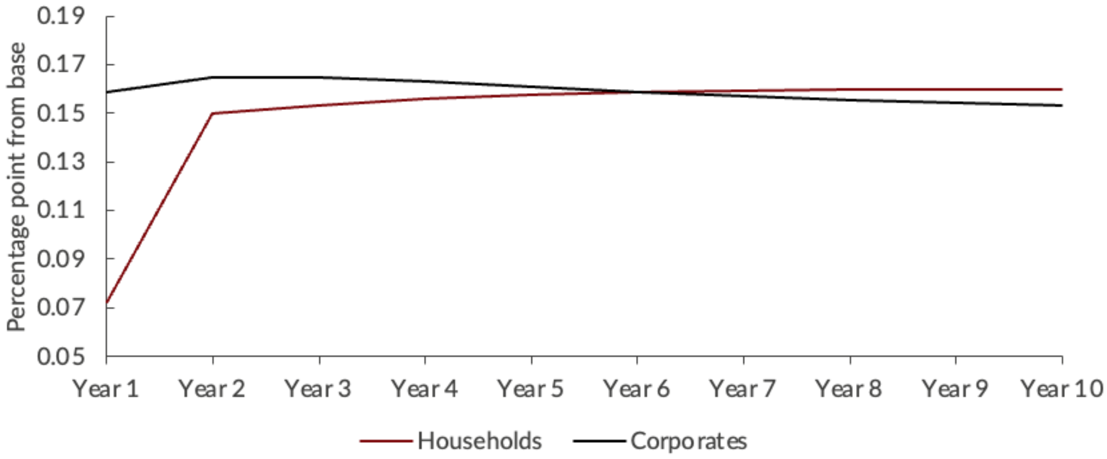
The gross operating surplus of the banking system represents the gross margin on three types of lending multiplied by the total value of each lending category's stock, as indicated by the second line in the equation above.

Adjustments in the speed of adaptation affect short-run outcomes but do not influence the long-run effects of changes in capital adequacy targets. This equation includes endogenous arrears and insolvencies to account for losses to bank capital caused by defaults.

When the leverage ratio (*levrr*) falls below its target level, given the desired buffer, a portion of profits will go towards replenishing bank capital and strengthening the buffer, while operating margins on consumer lending will be raised.

The NiGEM-SA model provides a much richer representation of the financial sector compared to the core model,[16] with many of the elements of the stock and flow model developed by Makrelov, Davies and Harris (2021) but with richer short-term dynamics informed by empirical analysis. An unexpected percentage point increase in the required capital adequacy for banks (with an accompanying exogenous shock to the banks' leverage ratio to meet this target) acts as a tax on banks and would increase the cost of borrowing significantly. The results are depicted in Figures 8 to 14. Banks would be pushed closer to their target or regulatory level of capital adequacy by reducing lending and accumulating a higher proportion of their profit margins. In South Africa, many banks tend to use retained earnings to achieve their target level of capital.[17]

Figure 7: Household and corporate interest rate spreads

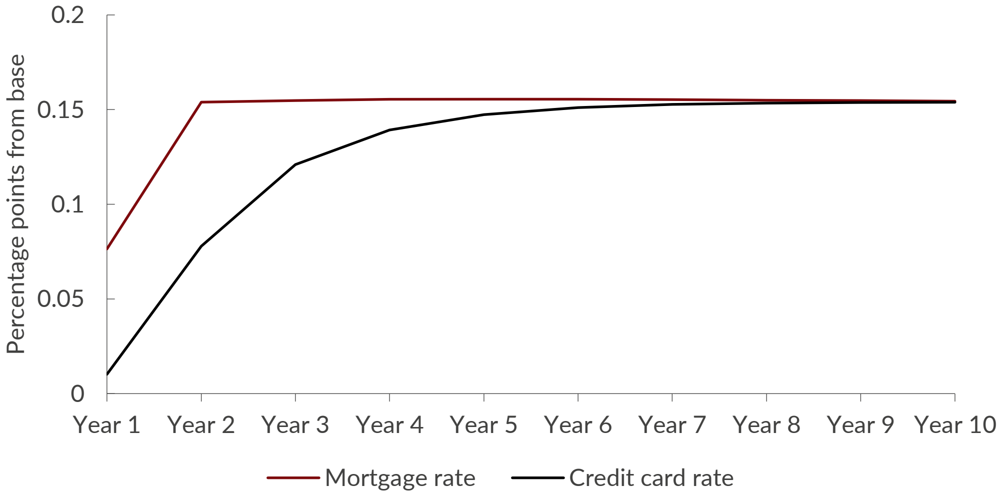


Source: NiGEM simulation, NIESR (2024)

16 See De Jager et al. (2022).

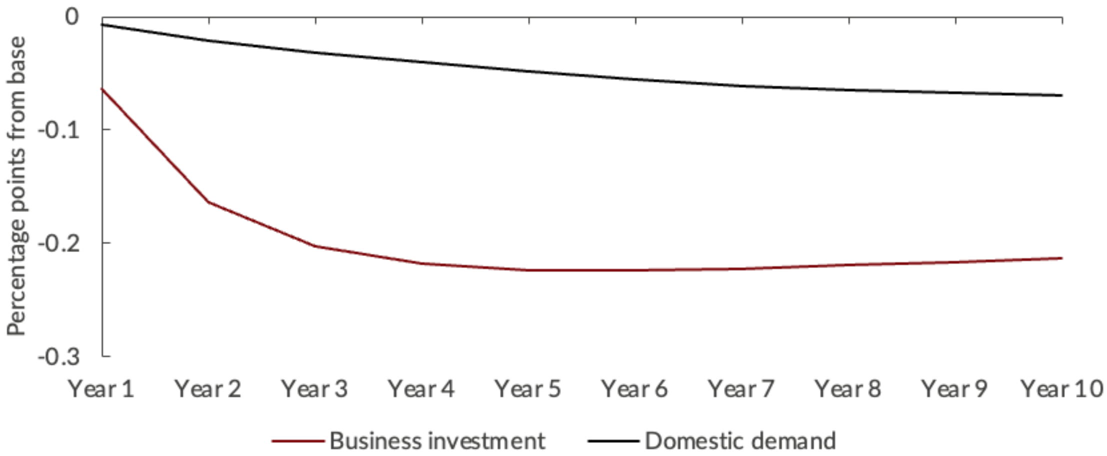
17 See Pillay and Makrelov (2024).

Figure 8: Interest rates



Source: NiGEM simulation, NIESR (2024)

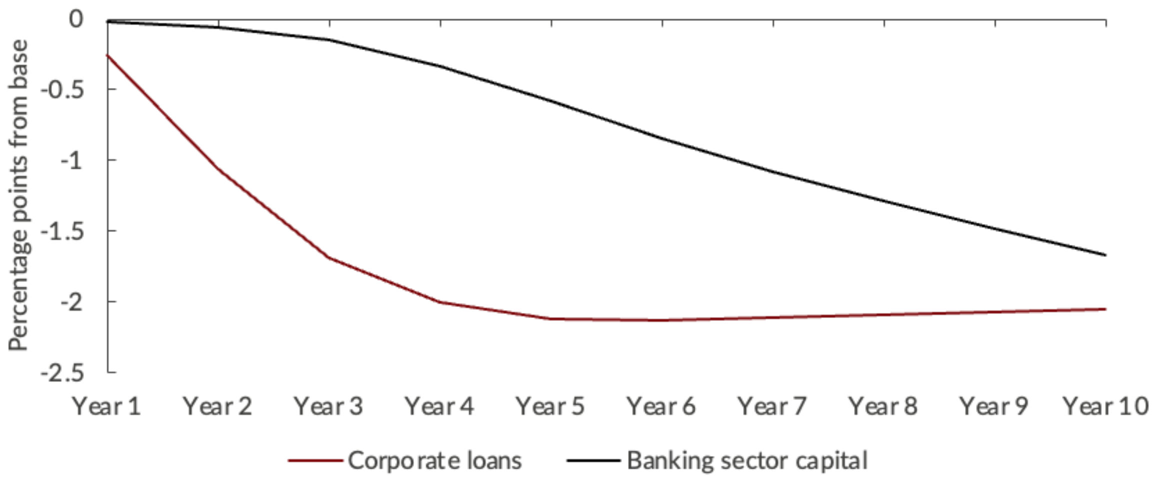
Figure 9: Business investment and domestic demand



Source: NiGEM simulation, NIESR (2024)

The reduction in the supply of credit by banks to households and businesses, and the subsequent rise in borrowing costs depicted by higher spreads for businesses (Figure 8), increases the user cost of (physical) capital. The higher user cost of capital discourages capital accumulation in the economy and weighs on long-run potential output. It also reduces current GDP through its negative impact on business investment and domestic demand (Figure 10). Lower borrowing by non-financial corporations in the wake of higher borrowing spreads would reduce the total stock of corporate loans and banking sector capital as bank profitability declines (Figure 11). The corporate loan book is permanently lower by 2 percentage points on average over the medium term.

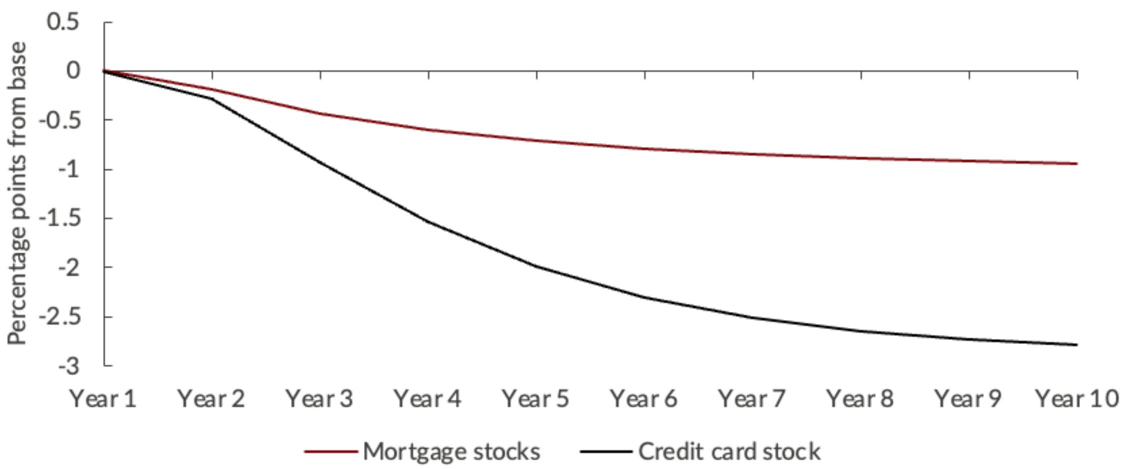
Figure 10: Corporate loans and banking sector capital



Source: NiGEM simulation, NIESR (2024)

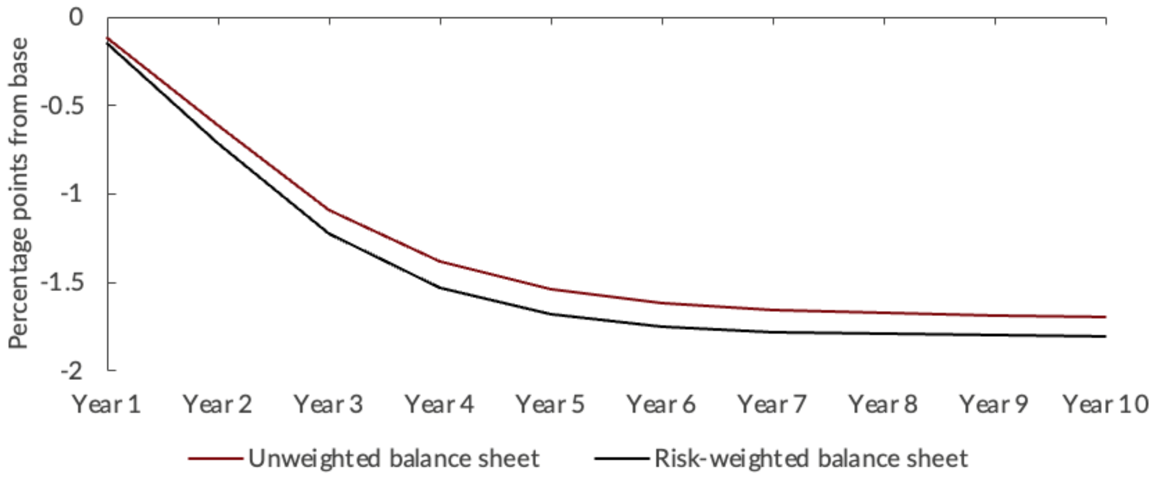
Higher borrowing spreads for consumers translates into higher real mortgage rates and consumer credit card rates, which reduces household lending in the economy (Figure 12). The size of the banking sector balance sheet declines relative to the baseline, particularly over the medium term (Figure 13). The risk-weighted balance sheet contracts by more as the higher capital requirement forces banks to also shift their portfolio towards less risky assets (Figure 12).

Figure 11: Mortgage and credit card stock



Source: NiGEM simulation, NIESR (2024)

Figure 12: Banking sector balance sheet

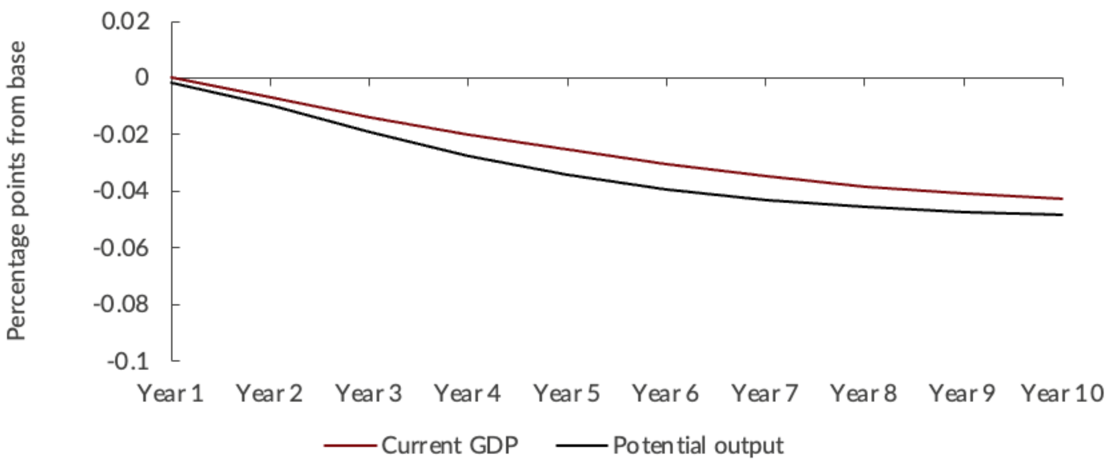


Source: NiGEM simulation, NIESR (2024)

Higher borrowing-lending spreads for consumers have a negative knock-on effect on the growth in house prices and also reduce other personal income as consumers pay more on loans and receive less interest income on savings, which in turn dampens housing wealth and overall personal sector net wealth. This in turn reduces consumption relative to the baseline.

The final impact on both current and potential output from the rise in capital adequacy is a permanent negative shock, with current GDP remaining half a percentage point lower in the long run (Figure 14).

Figure 13: GDP



Source: NiGEM simulation, NIESR (2024)

This impact, however, does not take into account the positive effects associated with improved financial stability. The real economy is affected by the banking sector primarily through the corporate lending wedge (*sacorpl*) channel; this is treated as a random walk in the standard model but is endogenised with the banking sector running. This flows directly into the investment premium (*saiprem*) component of the user cost of capital (*sauser*). Another key channel is the house price channel – lending wedges affect house prices (*saph*), which affect net wealth and, ultimately, consumption (*sanw* and *sac*).

These results are in line with simulation studies for South Africa, such as those presented by De Jager et al. (2022) and Makrelov, Davies and Harris (2021), as well as recent empirical analysis of the impact of capital requirements on lending (see Sibande and Milne 2024; Pillay and Makrelov 2024). The results tend to be more muted compared to other countries as the adjustment to a higher capital ratio is generally via appropriation of retained earnings.

8. Conclusion

Central banks need different models to answer different policy questions and forecast economic activity. The periods after the global financial crisis and the COVID-19 crisis showed the importance of a flexible approach to economic modelling, recognising the need for different tools that reflect the dynamic nature of economies. Models need to be updated continuously.

NiGEM-SA is an additional model in the SARB's suite of macroeconomic models. It will be used primarily for policy analysis to study international spillovers and the impact of climate change policies in the short to medium term. The model's key contribution is its ability to link banking sector financial dynamics to real economic activity. This is crucial for exploring emerging policy areas such as the effect of macroprudential policy or the impact of climate change transition policies on the financial sector.

Annexure 1: Description of variables in NiGEM

Variable name	Variable description
SAARR	Rate of household mortgage arrears
SABBAL	Banking sector assets (total); ZAR bn
SABBLL	Banking sector liabilities (total); ZAR bn
SABBSOA	Banking sector other assets; ZAR bn
SABBSOL	Banking sector other liabilities; ZAR bn
SABCAP	Banking sector capital; ZAR bn
SABLAR	Banking sector liquidity ratio
SABLART	Banking sector liquidity ratio target
SABRA	Banking sector liquid assets
SABRWA	Bank assets (risk weighted); ZAR bn
SACC	Consumer credit held by households; ZAR bn
SACCRATE	Household unsecured borrowing rate
SACED	Consumer expenditure deflator
SACORPL	Non-financial corporate debt; ZAR bn
SACORPW	Non-financial corporate sector lending wedge
SAHEAD	Headroom (difference between risk-weighted capital ratio and target capital adequacy ratio)
SAINSOLR	Rate of company liquidations
SAINT	Central bank rate
SAIPREM	Investment premium
SALENDW	Central bank rate plus mark-up
SALEVRR	Risk-weighted capital to asset ratio
SALEVRRT	Risk-weighted capital to asset ratio target
SALIABS	Gross liabilities of households; ZAR bn
SAMFIL	Bank lending to non-financial and households; ZAR bn
SAMORT	Effective mortgage rate
SAMORTH	Mortgage debt of households; ZAR bn
SAPH	Nominal house prices; ZAR
SARD	Banking sector retail deposits; ZAR bn
SARPDI	Real disposable income; ZAR bn
SAWSD	Banking sector wholesale deposits; ZAR bn
SAY	Real GDP; ZAR bn

Note: ZAR is the South African rand and bn is billion.

References

Armington, P S. 1969. 'A theory of demand for products distinguished by place of production'. *International Monetary Fund Staff Papers* 16(1): 159–178.

Barrell, R and Davis, E P. 2007. 'Financial liberalisation, consumption and wealth effects in seven OECD countries'. *Scottish Journal of Political Economy* 54(2): 254–267.

Barrell, R, Davis, E P, Karim, D and Liadze, I. 2009. 'Banking crises and optimal bank regulation'. Brunel Business School, Brunel University, London.

Berg, E. 2013. 'Are poor people credit-constrained or myopic? Evidence from a South African panel'. *Journal of Development Economics* 101: 195–205.

Blanchard, O. 2017. 'The need for different classes of macroeconomic models'. Peterson Institute for International Economics, 12 January.

Botha, B, de Jager, S, Ruch, F and Steinbach, R. 2017. 'The Quarterly Projection Model of the SARB'. *South African Reserve Bank Working Paper Series*, WP/17/01.

Cooley, R L. 1997. 'Confidence intervals for ground-water models using linearization, likelihood, and bootstrap methods'. *Groundwater* 35(5): 869–880.

Darracq, P, Matthieu, S D, de Gaye, A, Parisi, L and Sun, Y. 2023. 'NGFS climate scenarios for the euro area: role of fiscal and monetary policy conduct'. ECB Occasional Paper 2023/336.

Davis, E P and Liadze, I. 2012. 'Modelling and simulating the banking sectors of the US, Germany and the UK'. National Institute of Economic and Social Research Discussion Papers, no. 396.

De Jager, S, Loewald, C, Makrelov, K and Sibande, X. 2022. 'Leaning against the wind with fiscal and monetary policy'. *SARB Working Paper Series*, WP/22/12.

Hantzsche, A, Lopresto, M and Young, G. 2018. 'Using NiGEM in uncertain times: introduction and overview of NiGEM'. *National Institute Economic Review* 244: R1–R14.

Havemann, R and Hollander, H. 2024. 'Fiscal policy in times of fiscal stress (or what to do when r > g)'. *Journal of Policy Modelling* 46(5): 1020–1054.

Janse van Rensburg, T, de Jager, S and Makrelov, K. 2021. 'Fiscal multipliers in South Africa after the global financial crisis'. *South African Journal of Economic and Management Sciences* 25(1): 41–91.

Kemp, J H. 2020. 'Empirical estimates of fiscal multipliers for South Africa'. WIDER Working Paper 2020/91.

Makrelov, K, Arndt, C, Davies, R H and Harris, L. 2018. 'Fiscal multipliers in South Africa: the importance of financial sector dynamics'. WIDER Working Paper 2018/6.

Makrelov, K, Davies, R and Harris, L. 2021. 'The impact of higher leverage ratios on the South African economy'. *Studies in Economics and Econometrics* 45(3): 184–207.

Manteu, C and Martins, C. 2009. 'Assessing the economic impact of the fiscal stimulus plans with the NiGEM model'. *Banco de Portugal Economic Bulletin*: 41–55.

Millard, S. 2024. 'NiGEM topical feature: to what extent has the recovery and resilience facility supported the EU recovery from Covid?' *National Institute Global Economic Outlook* 14(B): 54–64.

Pillay, N and Makrelov, K. 2024. 'The lending implications of banks holding excess capital'. *SARB Working Paper Series*, WP/24/02.

Sibande, X and Milne, A. 2024. 'The impact of Basel III implementation on bank lending in South Africa'. *SARB Working Paper Series*, WP/24/04.