South African Reserve Bank Working Paper Series WP/25/13

Climate change shocks and monetary policy in South Africa: a simulation-based analysis

Admire Tarisirayi Chirume, James Hurungo and Brandon Aaron Chinoperekweyi

Authorised for publication by Konstantin Makrelov

21 August 2025

SOUTH AFRICAN RESERVE BANK

South African Reserve Bank Working Papers are written by staff members of the South African Reserve Bank and, on occasion, by consultants under the auspices of the South African Reserve Bank. The papers deal with topical issues and describe preliminary research findings and develop new analytical or empirical approaches in their analyses. They are solely intended to elicit comments and stimulate debate.

South African Reserve Bank Working Papers are externally refereed.

Information on South African Reserve Bank Working Papers can be found at
https://www.resbank.co.za/en/home/publications/Papers/working-papers.

Enquiries relating to the Working Paper Series can be addressed to:
Head: Economic Research Department
South African Reserve Bank
P O Box 427
Pretoria 0001

Tel. +27 12 313 3911

Climate change shocks and monetary policy in South Africa: a simulation-based analysis

Admire Tarisirayi Chirume,* James Hurungo† and Brandon Aaron Chinoperekweyi‡

Abstract

This study explores the effects of climate shocks on South Africa's macroeconomic stability and monetary policy dynamics through a simulation-based dynamic stochastic general equilibrium model. It incorporates climate variability as a key factor influencing inflation expectations, output and other macroeconomic variables. The paper examines how climate-induced disruptions such as changes in agricultural productivity, natural disasters and environmental conditions affect inflation, employment, exchange rates and interest rates over a 50-year horizon (2025–2075). The findings reveal that climate variability significantly affects inflation expectations and economic output, necessitating adaptive monetary policies that incorporate climate risks. The study underscores the importance of integrating climate considerations into macroeconomic frameworks to enhance the resilience of South Africa's economy, emphasising policy measures such as interest rate adjustments, climate-informed inflation targeting and long-term strategic planning to mitigate climate-related economic disruptions.

JEL classification

E50, E52, C50, C54

Keywords

Monetary policy, climate change, inflation, DSGE model, exchange rate, South Africa

* Durban University of Technology. Corresponding author: atchirume@gmail.com.

† Reserve Bank of Zimbabwe.

‡ Reserve Bank of Zimbabwe.

1. Introduction

The effects of climate change on weather variability in Southern Africa are substantial. General circulation models predict decreased precipitation trends with more intense rainfall events and longer dry spells in the region (Ngwira, Aune and Thierfelder 2014). As noted in the empirical literature, the negative economic implications of climate change have challenged monetary and financial stability. Climate change has profound effects not only on societies and economies, but also on the ability of central banks to deliver price stability in the future. Climate change affects the monetary transmission mechanism and the policy space available to central banks and has implications for the design of the monetary policy framework (Boneva, Ferrucci and Mongelli 2022). In particular, given the dynamic nature of the threat, the implied macroeconomic and financial consequences of climate change impose direct risks on the primary objective of price stability.

Through their monetary policies, central banks face a significant challenge in determining the optimal response to climate-induced shocks (Kara and Thakoor 2023). Whether the responses entail ‘mitigation’ and/or ‘adaptation’, it is generally agreed that governments, including central banks, need deliberate policy responses to the threats posed by climate change. Climate variability has detrimental consequences on economic and social development in a given region (Zhao, Gerety and Kuminoff 2018: 1; Baarsch et al. 2020). It poses a systemic risk to the global economy and the proper functioning of financial markets. Global average surface temperatures continue to rise, and the frequency and severity of climate shocks – including heatwaves, cyclones, coastal flooding and droughts – have risen sharply (Ojha, Pattnaik and Rout 2018; Kahn et al. 2021; Cevik and Jalles 2022). These events can have negative effects on macroeconomic outcomes (Ibarrarán et al. 2009; Economides and Xepapadeas 2018; Kara and Thakoor 2023). Persistent rises in mean temperatures, changing precipitation patterns and more volatile weather events can have long-term macroeconomic consequences by adversely affecting agricultural and industrial production, labour productivity and investment (Zhao, Gerety and Kuminoff 2018: 1; Kahn et al. 2021). Shifting climate patterns also affect production systems indirectly by changing ecological systems and biodiversity. This in turn affects soil moisture and fertility – and all the value chains linked to the agricultural sector (Ahmed et al. 2022).

In the absence of more stringent climate policies such as greenhouse gas (GHG) emission mitigation (McKibbin et al. 2017; Economides and Xepapadeas 2018), global emissions are set to keep rising (Diluiso et al. 2021). As noted by Lamperti et al. (2021), financial and banking systems play a key role in the interplay between climate risks and the real economy. Central banks ensure financial and price stability through the implementation of robust monetary policies that are formulated around climate-related risks. As such, this study aims to simulate and analyse the effects of climate shocks on monetary policy and its key variables in South Africa. This paper specifically aims to:

1. Model and assess the trends of key climate variables, such as GHG emissions, deforestation rates and temperature anomalies, and explore their direct and indirect impacts on the South African economy with a focus on inflation and economic growth.
2. Investigate the interaction between climate-induced environmental changes (e.g. temperature anomalies and rainfall variations) and population dynamics, and understand how these factors influence agricultural productivity, food security and inflationary pressures in South Africa.
3. Evaluate the role of industrial emissions and regulatory policies in influencing the economic outcomes of climate shocks, and consider how these factors affect monetary policy targets, including price stability and exchange rate volatility.
4. Simulate the potential responses of monetary policy (e.g. interest rate adjustments and inflation targeting) to climate shocks under various environmental scenarios and assess the effectiveness of these responses in stabilising inflation and supporting sustainable economic growth.
5. Provide policy recommendations for South Africa’s monetary authorities, focused on adaptive strategies that could enhance the country’s resilience to climate-related economic disruptions, including suggestions for improving macroeconomic stability through effective integration of climate-related factors in monetary policy design.

The next section looks at climate change in Africa, focusing on recent climatic developments and their effects on African economies. This is followed in section 3 by a discussion of how climate shocks are transmitted. Sections 4 and 5 present the literature review, data and methodology. Results are discussed in section 6 and conclusions in section 7.

2. Recent climatic developments and socio-economic progress in Africa

Africa is warming at a pace significantly above the global average, with far-reaching implications for socio-economic development and macroeconomic stability. By mid-century, average temperatures across the continent are projected to rise by 1.5°C to 3°C (Gemeda and Sima 2015). Under high-emission scenarios, mean annual temperatures could increase by 3°C to 6°C by 2100 (Pielke Jr, Burgess and Ritchie 2022). Southern Africa in particular has already experienced warming at nearly twice the global rate (Kusangaya et al. 2014). This trend is expected to intensify, leading to increasingly severe and frequent extreme weather events such as droughts, floods and heatwaves (Seneviratne et al. 2021).

Climatic changes have direct and cascading effects on livelihoods, ecosystems and economies. Prolonged droughts – especially in Eastern and Southern Africa – have reduced agricultural productivity, exacerbated food insecurity and stressed water systems. Notable cases include the 2015–2016 drought that affected more than 15 million people in Ethiopia, Kenya and Somalia (Kipngeno 2020), as well as the Western Cape drought (2015–2018), which led to water restrictions and economic losses in South Africa (Mahlalela et al. 2020; Dube, Nhamo and Chikodzi 2022). Meanwhile, extreme rainfall and floods have displaced communities, destroyed infrastructure and imposed fiscal burdens on governments (Frame et al. 2020; Munyai et al. 2021).

Underlying these patterns is anthropogenic climate change, driven by fossil fuel combustion, deforestation and industrial emissions (Höök and Tang 2013). Complex systems such as the El Niño-Southern Oscillation and the Indian Ocean Dipole exacerbate climatic volatility. In South Africa, the compounded effects of droughts and floods strain infrastructure and economic resilience, exposing critical sectors such as agriculture, energy and public health to recurrent shocks (Lottering, Mafongoya and Lottering 2021).

South Africa's economic exposure is heightened by its structural reliance on climate-sensitive sectors. Agriculture remains vital for employment and food supply, yet it is acutely vulnerable to shifts in rainfall and temperature (Parker et al. 2019; Wang et al. 2018). Reduced yields not only threaten food security but also contribute to inflationary pressures, particularly in staple goods – a dynamic consistent with cost-push inflation theory (Odongo et al. 2022). These climate-induced supply shocks challenge the South African Reserve Bank's (SARB's) ability to maintain price stability without compromising economic growth.

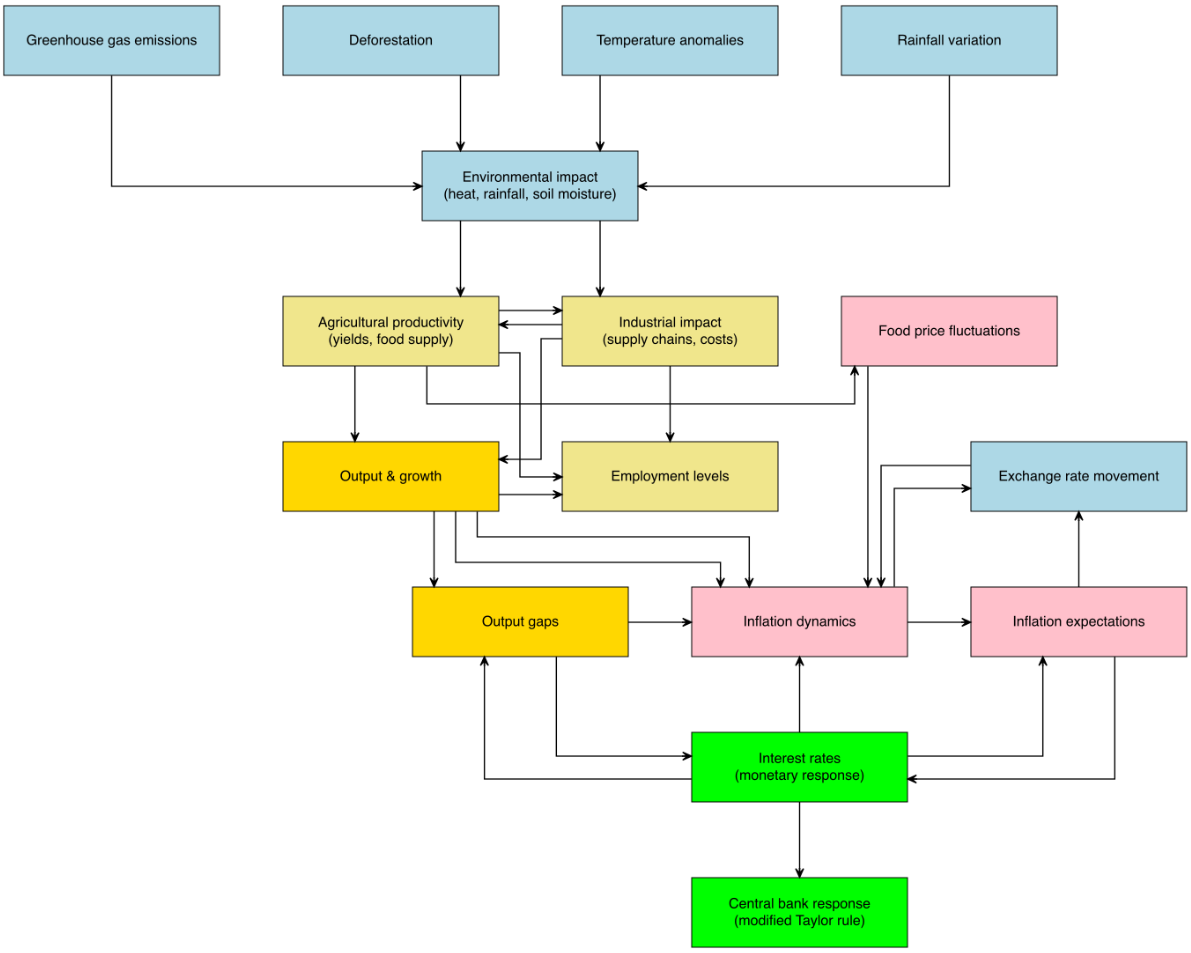
At the same time, demographic shifts, such as rapid urbanisation and internal migration, are intensifying pressure on natural resources and public services (Shackleton et al. 2018; Salahuddin et al. 2019). As rural livelihoods become less viable due to climate stressors, populations increasingly concentrate in urban centres, where infrastructure may be ill-equipped to absorb the influx of people. This transition, compounded by climate-induced crop failures, heightens demand for food and energy, further embedding inflationary risks (Hendrixson and Hartmann 2019; Baptista et al. 2022).

The industrial sector also plays a pivotal role in this nexus. South Africa's dependence on coal and emissions-intensive manufacturing contributes substantially to GHG outputs, placing it among the world's top emitters (Akinbami, Oke and Bodunrin 2021; Shikwambana, Mhangara and Kganyago 2021). Regulatory responses, such as carbon taxes and environmental compliance measures, are necessary for sustainability but risk increasing operating costs and inflation, especially in the short run (Santabárbara and Suárez-Varela 2022; Ferrari and Nispi Landi 2024). These complex trade-offs between environmental responsibility and economic efficiency must be accounted for in macroeconomic planning.

In this context, the role of monetary policy becomes increasingly complex. The SARB's mandate of inflation targeting may be tested by climate shocks that reduce output while raising prices. The central bank must navigate this tension by carefully calibrating interest rate policy to manage inflation expectations without undermining economic recovery (Hollander and van Lill 2019; Gupta, Kabundi and Modise 2010). Traditional models may fall short in capturing the nuanced and non-linear effects of environmental shocks on macroeconomic variables, suggesting the need for simulation-based approaches.

This study responds to that need. It adopts a simulation-based dynamic stochastic general equilibrium (DSGE) framework to assess how climate shocks spread through the South African economy, with particular attention to monetary policy effectiveness. The analysis aims to model key climate variables, such as emissions, deforestation and temperature anomalies, and their interaction with economic structures, especially agriculture and industry. It evaluates how climate-induced supply disruptions influence inflation, how demographic shifts affect food security and economic resilience, and how fiscal and regulatory responses can mitigate or exacerbate macroeconomic volatility.

Figure 1: Climate shocks transmission mechanism



This study uses a simulation-based analysis to explore how South Africa’s monetary authority, the SARB, can adapt its policy frameworks to mitigate the economic impacts of climate shocks. Modelling the intricate interactions between climate variables, macroeconomic indicators and monetary policy responses provides a comprehensive platform for testing adaptive strategies. These include integrating climate risk buffers, designing countercyclical fiscal measures and channelling green finance towards sustainable growth sectors. This study aims to deliver actionable policy recommendations that enhance South Africa’s resilience to climate-induced economic disruptions, while ensuring long-term macroeconomic stability in an increasingly uncertain world.

3. Literature review

Recent advances in climate macroeconomic modelling have seen a growing emphasis by central banks and international institutions (such as the Network for Greening the Financial System (NGFS), International Energy Agency (IEA) and Intergovernmental Panel on Climate Change (IPCC)) on the integration of environmental variables into macroeconomic frameworks. Among the various tools employed, integrated assessment models have become particularly influential in linking climate dynamics to economic outcomes. These models, which combine climate science with economic structures (often derived from computable general equilibrium or DSGE foundations), offer a versatile way to evaluate policy trade-offs in the context of climate uncertainty.

For example, Economides and Xepapadeas (2018) used a New Keynesian DSGE-based integrated assessment model to show how dependence on fossil fuel introduces a dual channel of influence. It enhances output in the short term but accelerates temperature increases, thereby worsening long-term productivity. While this duality underscores the urgency of climate-aware policymaking, the application remains largely theoretical and disconnected from region-specific vulnerabilities – such as those prevalent in Southern Africa. Our study builds on this logic but localises it by explicitly tailoring the model structure to South Africa’s economic and climatic context.

Nakov and Thomas (2023) further explore these trade-offs using a New Keynesian DSGE model and find that well-calibrated carbon taxes eliminate the conflict between price stability and climate targets. This reinforces a broader insight. In isolation, monetary policy is an insufficient tool for climate mitigation unless coordinated with well-designed fiscal and environmental policies. However, the rigid assumptions in their model do not fully capture the structural characteristics of developing economies, including exposure to external shocks, informal labour markets and food price volatility – all of which are central to the South African case.

Several other DSGE-based studies contribute to our understanding of environmental policy impacts on the macroeconomy. Annicchiarico and Diluiso (2019) and Chan (2020) use New Keynesian e-DSGE variants to analyse the macroeconomic outcomes of green fiscal spending and environmental regulation. Chen et al. (2021) extend this tradition by embedding hidden emissions and compliance heterogeneity into the DSGE framework. These approaches, while innovative, often emphasise advanced economies and overlook the unique socio-environmental dynamics facing sub-Saharan Africa.

In a more regionally grounded context, McKibbin, Konradt and Weder di Mauro (2021) argue for a rethinking of macroeconomic models used in central banking, particularly in light of climate-induced risks that affect the natural rate of interest, transmission mechanisms and inflation-targeting credibility. Their work suggests the urgent need for adaptive modelling frameworks – precisely the kind that this study develops – to assess the performance of monetary policy under adverse environmental scenarios.

Beyond the modelling literature, empirical studies highlight the disproportionate vulnerability of agricultural systems in developing regions. In Southern Africa, where agriculture remains a cornerstone of employment and food security, rising temperatures and erratic rainfall are already depressing maize yields (Jabeen et al. 2017; Nhamo et al. 2019; Zhao, Gerety and Kuminoff 2018). These findings are echoed globally. For example, Chen and Yang (2019) find strong evidence from China's firm-level data that temperature shocks adversely affect both agricultural and industrial output. What is lacking, however, is a macroeconomic simulation framework that explicitly quantifies how these sectoral shocks translate into inflationary pressures and monetary policy dilemmas – an analytical gap this study aims to fill.

Moreover, the degradation of natural resource bases, particularly water, has serious implications for hydropower, irrigation and energy infrastructure in Southern Africa (Reid et al. 2008; Falchetta et al. 2019; Javadinejad et al. 2020). These vulnerabilities contribute to regional food insecurity, yet they are rarely integrated into central banking models or inflation forecasting tools. This study attempts to address this by explicitly incorporating environmental shocks into both the production and demand blocks of a DSGE model calibrated for South Africa.

Several studies call for a more integrated approach to climate and monetary policy. Chen et al. (2021) propose a hybrid rule where climate targets are embedded within monetary policy frameworks. Similarly, Dafermos, Nikolaidi and Galanis (2018) model the feedback loops between financial fragility and climate shocks using the DEFINE model. Their results suggest that climate-related financial instability, whether through asset revaluation or productivity collapses, can undermine the effectiveness of central banks. In this paper, the analysis echoes this concern and builds on it by simulating SARB monetary policy responses under stochastic climate scenarios, including drought-induced output losses and carbon regulation costs.

In synthesising this literature, two clear gaps emerge. First, much of the current modelling work underrepresents the dynamics of emerging markets, where climate vulnerability intersects with institutional and economic fragility. Second, while many studies call for integrated policy responses, few explicitly model the joint behaviour of monetary policy and climate shocks in a way that is contextually grounded. This study addresses both gaps by developing a climate-augmented DSGE model tailored to the South African economy, simulating the interaction between climate variability, price dynamics and monetary policy transmission.

4. Data and methodology

In this section, we outline the simulation-based DSGE model used to analyse the effects of climate change shocks on monetary policy in South Africa. The DSGE models offer a micro-founded, internally consistent framework for capturing the dynamic responses of agents under uncertainty. Their capacity to simulate forward-looking behaviour, account for structural shocks and model the interactions between real and nominal variables makes them particularly well suited for assessing the long-run implications of climate and policy shocks.

4.1 The DSGE model

The use of DSGE models for environmental and climate analysis has gained prominence. For example, Nordhaus (2008) integrates climate dynamics into macroeconomic modelling using a dynamic integrated model of climate and the economy, while studies such as Dell, Jones and Olken (2014) and Lemoine (2016) introduce climate uncertainty into DSGE frameworks. In the context of developing economies, Ng and Motlanthe (2020) demonstrate how climate shocks alter growth trajectories and policy effectiveness. This study builds on this body of work but innovates by incorporating stochastic climate variables directly into the production functions and export demand equations, alongside a monetary and fiscal policy block tailored to the South African economy.

The model consists of four primary agents: households, firms (green and brown sectors), the government and the central bank. Households maximise their expected lifetime utility over consumption and sector-specific labour, subject to an intertemporal budget constraint that includes wages, asset returns and government transfers. The optimisation problem is represented by:

$$V_t = \max_{C_t, H_{b,t}, H_{g,t}, D_{H,t}, B_{G,t}, B_{F,t}} \{U(C_t, H_t) + \beta E_t[V_{t+1}]\} \tag{1}$$

Firms in the green and brown sectors use climate-sensitive Cobb-Douglas production functions, where the productivity terms $\Gamma_{g,t}$ and $\Gamma_{b,t}$ evolve as functions of a stochastic climate stress variable $C_{\text{climate},t}$. Export demand is reduced by climate stress, introducing an external channel through which climate impacts propagate into the macroeconomy. Prices are set under a Calvo mechanism, introducing nominal rigidities that affect inflation dynamics.

The government operates under an intertemporal budget constraint, financing its expenditures through tax revenues and bond issuance. Fiscal policy shocks are modelled as temporary deviations from baseline government spending or tax rates.

The central bank follows a Taylor-type interest rate rule that responds to inflation deviations, the output gap and exchange rate changes.

The climate block introduces exogenous stochastic processes for climate stress and its impact on sectoral productivity. Specifically, climate shocks follow:

$$C_{\text{climate},t+1} = \rho_c C_{\text{climate},t} + \sigma_c \varepsilon_{c,t} \tag{2}$$

where $\varepsilon_{c,t} \sim \mathcal{N}(0,1)$. These shocks feed into the climate damage terms $\Gamma_{j,t}$, which influence production and prices.

The simulation is conducted over a 50-year horizon using 500 Monte Carlo draws. Initial values for capital, employment and consumption are calibrated to reflect South African macroeconomic conditions. The model is run under four scenarios: (i) a deterministic baseline, (ii) stochastic climate shocks, (iii) a fiscal expansion shock and (iv) a tax policy shock. Each simulation path generates time series for key macroeconomic variables, including output, consumption, inflation, interest rates, employment and climate stress.

For each scenario, we compute pointwise quantiles (5th, 50th and 95th percentiles) of simulated outcomes to form confidence intervals. This allows for an uncertainty-aware comparison of policy impacts under different shock conditions.

To evaluate the effectiveness of fiscal policy, we estimate dynamic fiscal multipliers by computing the output difference between the fiscal shock and baseline scenarios, scaled by the change in government spending:

$$\text{Multiplier}_t = \frac{Y_t^{\text{fiscal}} - Y_t^{\text{baseline}}}{\Delta G} \tag{3}$$

This provides a time-varying measure of the output effect of fiscal stimulus under climate uncertainty.

Overall, this simulation-based methodology offers a robust alternative to empirical estimation methods, which often face identification problems, especially with rare or long-term climate events. By embedding stochastic climate dynamics into a structural model, we provide a forward-looking framework that is well suited for policy design in emerging economies such as South Africa that are vulnerable to climate impacts.

4.2 The model framework

The proposed DSGE model incorporates several key components: climate variables, economic variables, inflation and interest rate dynamics, employment, the exchange rate, the current account balance and real sector output. These components interact dynamically to capture the feedback loops between climate shocks and monetary policy.

4.3 Household maximisation problem

The household maximisation problem is described as households aiming to maximise their expected lifetime utility, which depends on consumption and sector-specific labour or activities (green and brown sectors). They do this subject to an intertemporal budget constraint that includes wages, returns on assets, government transfers and interest on debt. The problem involves choosing optimal levels of consumption, labour participation in green or brown activities, and asset holdings to ensure long-term utility maximisation while balancing income and expenses over time.

The household's value function is given by the following:

$$V_t = \max_{C_t, H_{b,t}, H_{g,t}, D_{H,t}, B_{G,t}, B_{F,t}} \{U(C_t, H_t) + \beta E_t[V_{t+1}]\} \tag{4}$$

where C_t is consumption at time t; $H_{b,t}$ and $H_{g,t}$ are engagements in brown (fossil-fuel-related) and green (renewable) household activities or investments; $D_{H,t}$ is household holdings of bonds or debt; $B_{G,t}$ and $B_{F,t}$ are green and fossil-fuel-related financial asset holdings; β is the discount factor; and $U(C_t, H_t)$ is the utility function.

The household budget constraint restricts the household's available resources for consumption and asset accumulation at each period. It ensures that the household's spending on consumption, bonds and other financial assets does not exceed its income and asset returns, adjusted for prices and other factors. The budget constraint is thus formulated as:

$$\begin{aligned} P_t C_t + D_{H,t} + B_{G,t} + e_t B_{F,t} \leq (1-\varpi) \sum_{j\in\{b,g\}} W_{j,t} H_{j,t} \\ + R_{D,t-1} D_{H,t-1} + R_{G,t-1} B_{G,t-1} \\ + e_t R_{F,t-1} B_{F,t-1} \\ + \text{dividends} + \text{bank dividends} + T_t \end{aligned} \quad (5)$$

where P_t is the price level; e_t is the exchange rate or a factor capturing relative prices or taxes related to fossil fuels; $W_{j,t}$ is wages for sector j (brown or green); $R_{D,t-1}, R_{G,t-1}, R_{F,t-1}$ is returns on previous period holdings; T is taxes or transfers; and ϖ is a parameter representing the share or taxation of certain activities.

4.4 Behaviour and climate-adjusted production by firm

In this model, the economy is characterised by a dual-sector structure in which firms operate either within a green (environmental) sector or a brown (fossil fuel) sector. Brown sectors are those whose operations are highly carbon-intensive and environmentally damaging. These sectors typically depend on fossil fuels either as an energy source or as a raw material, and they emit substantial quantities of GHGs, particularly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The environmental externalities produced by these sectors contribute directly to global warming, air pollution and ecological degradation. Examples of typical brown sectors in South Africa and other countries include:

- Coal-fired electricity generation, which emits large amounts of CO_2 through the combustion of coal.
- Oil and gas refining, involving high-emission processes to transform crude oil into fuels and petrochemicals.
- Cement production, where CO_2 is emitted both from fossil fuel use and from the calcination of limestone.
- Steel and aluminium manufacturing, characterised by energy-intensive production processes using coke and electricity from carbon-intensive sources.

- Automobile manufacturing focusing on internal combustion engine vehicles, both in terms of production and downstream fuel consumption.
- Chemical and petrochemical industries, which often rely on fossil-based feedstocks and generate GHGs through energy use and chemical transformations.
- Aviation and shipping, particularly where kerosene and bunker fuels are used without carbon offset mechanisms.
- Mining operations for non-renewable resources, especially when powered by diesel or coal-based electricity.
- Construction, especially where it relies on cement, steel and diesel-powered machinery.
- Industrial agriculture, particularly where synthetic fertilisers, diesel irrigation pumps and monocultures are prevalent, often leading to emissions of CH_4 and N_2O.

In contrast, green sectors are defined by their minimal environmental footprint and their contribution to decarbonisation, sustainability and climate resilience. Firms in these sectors either reduce GHG emissions through their products and processes or actively contribute to climate adaptation and mitigation. Green sectors are central to a low-carbon economic transition and feature prominently in climate-sensitive fiscal and monetary policy design. Examples of these include:

- Renewable energy production, such as firms operating wind farms, solar parks and hydroelectric plants.
- Public transport and electric mobility, including electric vehicle manufacturers and infrastructure providers (e.g. charging stations).
- Sustainable construction, such as green building materials, passive housing design and low-carbon cement alternatives.
- Energy efficiency solutions, including smart grids, insulation systems and LED lighting technologies.
- Sustainable agriculture, including organic farming, agroforestry and regenerative agricultural practices.

- Water and waste management, encompassing firms in recycling, wastewater treatment and circular economy services.
- Environmental consulting and climate risk analytics, providing tools for impact assessment, emissions tracking and adaptation planning.
- Sustainable finance, including green bonds and environmental, social and governance investment funds that direct capital towards environmentally beneficial projects.

Each firm seeks to maximise output by employing capital and labour, but with production processes explicitly modified to account for the impact of climate change. This is achieved by introducing a climate-adjustment factor, $\Gamma_{j,t}$, into each sector's production function, allowing productivity to vary over time in response to climate-related shocks.

The production technology for both sectors follows a Cobb-Douglas specification. For the green sector, the output is given by the following:

$$Y_{g,t}(i) = \Gamma_{g,t} A_{g,t} K_{g,t}^{\alpha} H_{g,t}^{\beta} \quad (6)$$

where $A_{g,t}$ represents total factor productivity, $K_{g,t}$ is capital, $H_{g,t}$ is labour and $\Gamma_{g,t}$ captures the influence of climatic conditions on output.

Similarly, firms in the brown sector follow the production function given by the following:

$$Y_{b,t}(i) = \Gamma_{b,t} A_{b,t} K_{b,t}^{\alpha} H_{b,t}^{\beta} \quad (7)$$

but here, the climate shock term $\Gamma_{b,t}$ reflects the heightened vulnerability of fossil-fuel-intensive production to adverse environmental factors.

The behaviour of firms is grounded in maximising their profits. Each firm chooses the optimal levels of capital and labour inputs to maximise profits given prevailing market prices and subject to their production technology. Importantly, firms are assumed to operate under perfect competition, taking input prices (wages and capital rental rates) and output prices as given.

A key assumption in this framework is constant returns to scale, implying $\alpha + \beta = 1$. This ensures well-defined marginal productivity of inputs and allows for tractable comparative statics in response to policy changes or environmental shocks. In addition, the model assumes frictionless factor markets, with no adjustment costs for reallocating labour and capital, and sectoral symmetry, meaning firms within each sector are structurally identical.

The climate impact multiplier $\Gamma_{j,t}$ adds an important dynamic layer to firm behaviour. In the green sector, climate-related shocks may have neutral or even positive effects on productivity if innovation or adaptive policy measures are in place. In contrast, the brown sector typically suffers from negative productivity shocks due to increased regulation, resource depletion and exposure to extreme weather events.

This modelling approach enables the simulation of sectoral divergence under climate stress. As climate effects intensify, the economy may shift resources from the brown to the green sector – a process driven by relative changes in productivity and profitability. This transition has macroeconomic implications for labour markets, inflation and monetary policy. For example, if climate shocks reduce output in the brown sector, input costs may rise, leading to inflationary pressures.

4.5 Price-setting and profit maximisation with climate effects

In the presence of climate change, firms in both the green and brown sectors operate under monopolistic competition and set prices following a Calvo-style staggered price adjustment mechanism. This implies that, in each period, only a fraction of firms are able to re-optimise their prices, while others maintain their previously set prices. Firms aim to maximise the expected discounted value of their profits, considering the probability of future price adjustments under climate-impacted production conditions.

The optimal price $P_{j,t}(i)$ for a firm in sector j (either green g or brown b) is determined by solving the following condition:

$$P_{j,t}(i) = E_t \sum_{k=0}^{\infty} (\beta_j \phi_j)^k \left(D_{j,t+k} - P_{j,t}(i) Y_{j,t}(i)\right) \tag{8}$$

Here, β_j is the firm's discount factor, ϕ_j is the Calvo probability of not adjusting prices and $D_{j,t+k}$ represents the profit at future period $t + k$. This pricing rule indicates that firms setting their current price consider not only present profitability but also the expected path of future profits, given nominal rigidities and the evolution of climate shocks.

Profit for each firm depends on revenue from output minus the costs of labour and capital. The profit function $D_{j,t}$ for sector j is expressed as:

$$D_{j,t} = eP_{j,t}Y_{j,t} - W_{j,t}H_{j,t} - R_{k,j,t}Q_{j,t-1}K_{j,t-1} + (1 - \delta_j)Q_{j,t}K_{j,t-1} \tag{9}$$

Here, e is the nominal exchange rate, $W_{j,t}$ is the wage rate, $H_{j,t}$ is labour employed, $R_{k,j,t}$ is the rental rate of capital, $Q_{j,t}$ is the capital price and δ_j is the depreciation rate. The last term represents the value of undepreciated capital carried into the next period, which is relevant for intertemporal capital decisions.

This structure shows that firms are sensitive to input prices, exchange rate movements and the productivity shocks arising from climate change in particular. The presence of climate-impacted total factor productivity, captured by $\Gamma_{j,t}$, influences how firms perceive the cost-benefit trade-offs in pricing and investment.

From the public finance side, the model incorporates the government's budget constraint, accounting for climate-related tax revenue and spending on capital and labour:

$$B_{G,t} + P_e e_t + \tau_{b,t}Q_{b,t}S_{b,t} + \tau_{g,t}Q_{g,t}S_{g,t} + \sum_{j=b,g} \varpi W_{j,t}H_{j,t} = R_{G,t-1}B_{G,t-1} + T \tag{10}$$

This equation balances government bond holdings $B_{G,t}$, export revenues and climate taxes $\tau_{j,t}$ on sectoral capital stocks $S_{j,t}$ against past debt servicing and fiscal transfers T. This fiscal interaction is crucial, as government climate policy – via taxes or subsidies – feeds directly into firm costs and thus into inflation dynamics and price setting.

The monetary policy framework used by the SARB follows a Taylor-rule specification, targeting inflation, output gap and exchange rate volatility:

$$R_{G,t} = R_G\left(R_{G,t-1}\right)^{\rho_R}(\pi_t - \pi)^{\mu_\pi}(Y_t - Y)^{\mu_y}(\Delta e_t - \Delta e)^{\mu_e}e^{\varepsilon_R} \tag{11}$$

This rule implies a smoothing parameter ρ_R, inflation-targeting weight μ_π, output gap sensitivity μ_y and exchange rate targeting μ_e. The stochastic shock ε_R introduces randomness in policy responses. Importantly, inflation in this model is partially driven by climate-induced cost-push factors, particularly from disruptions in brown-sector production and supply chains.

The dynamic behaviour of climate impact is modelled through a law of motion for the climate productivity factor $\Gamma_{j,t}$:

$$\Gamma_{j,t+1} = \rho_\Gamma \Gamma_{j,t} + \eta_j C_{\text{climate},t} + \varepsilon_{j,t} \tag{12}$$

where ρ_Γ is the persistence of climate effects, η_j represents the sector-specific climate sensitivity and $\varepsilon_{j,t}$ is a stochastic disturbance. This mechanism formalises how worsening climate stress $C_{\text{climate},t}$ erodes productivity over time.

The climate stress variable itself evolves as an autoregressive process of order 1(AR(1)) given by the following.

$$C_{\text{climate},t+1} = \rho_c C_{\text{climate},t} + \sigma_c \varepsilon_{c,t} \tag{13}$$

where ρ_c governs persistence, while $\sigma_c \varepsilon_{c,t}$ captures random climate shocks. This stochastic climate system interacts recursively with the economy via $\Gamma_{j,t}$, making firms' price and profit expectations increasingly dependent on environmental volatility.

Together, these structural elements offer a robust framework to study how climate-induced shocks transmit through the price-setting behaviour of firms, affect inflation dynamics and necessitate adaptive monetary responses.

5. Results and analysis

This study provides a comprehensive analysis of the impact of climate shocks on South Africa's macroeconomic stability, emphasising the need for adaptive monetary policy frameworks. The simulation-based approach reveals that climate variability significantly influences inflation expectations and real economic output in South Africa. Specifically, increased climate stress – such as droughts, floods and altered rainfall patterns – disrupts supply, particularly in vital sectors like agriculture, culminating in higher production costs and cost-push inflation. These supply shocks tend to elevate inflationary pressures, compelling the SARB to respond with interest rate adjustments to anchor inflation within its target range of 3% to 6%. However, the simulations indicate a delicate trade-off: raising interest rates to combat inflation may inadvertently dampen economic growth and elevate unemployment, especially if the climate shocks are persistent or severe.

Furthermore, the results illustrate that climate variability exacerbates volatility in exchange rates and employment levels, creating additional challenges for policy stability. The dynamics suggest that traditional monetary policy tools might be insufficient or less effective if climate risks are not integrated into the decision-making process. The simulations also underscore the uncertainties surrounding these outcomes, emphasising that climate-induced shocks can lead to complex, non-linear economic responses. Such fluctuations necessitate a responsive and flexible policy approach that not only targets price stability but also enhances resilience against climate variability.

Given these findings, there is an urgent need for the SARB to incorporate climate risk considerations into its monetary policy framework. Specifically, the central bank should develop climate-informed interest rate policies that proactively address expected and unexpected climate shocks. This entails integrating climate forecasts and stress-testing scenarios into policy models, enabling the SARB to better anticipate inflationary or deflationary pressures driven by environmental factors. In addition, monetary policy should be complemented by targeted fiscal and agricultural policies – such as investing in climate-resilient infrastructure and promoting sustainable agricultural practices – to mitigate the adverse effects of climate variability on the economy.

Crucially, the SARB needs to establish a climate risk monitoring system, coupled with a flexible inflation-targeting framework that can accommodate temporary shocks without overreacting. It should also foster closer collaboration with environmental agencies and policymakers to ensure that climate data inform monetary decisions. Moreover, the SARB could consider operational tools like climate risk buffers or green financing initiatives to support sectors vulnerable to climate impacts and facilitate a smoother transition towards a climate-resilient economy.

The simulation results presented here provide a comprehensive view of the potential macroeconomic impacts of climate shocks on South Africa's economy through the projected trajectories of variables over a 50-year period. The total output, for instance, declines under the climate shock scenario relative to the baseline, indicating that climate-induced disruptions adversely affect economic growth. This finding aligns with the broader literature, including Zhao, Gerety and Kuminoff (2018), who document that weather shocks, such as droughts and erratic rainfall patterns, have long-term negative effects on agricultural productivity and industrial output, which in turn depress overall economic activity. Similarly, the decline in consumption observed in the model's simulations reflects the diminished household income and increased economic uncertainty attributed to climate stress – a pattern consistent with empirical findings by Dube, Nhamo and Chikodzi (2022), who show that water crises and extreme weather events during South Africa's Western Cape drought led to reduced household consumption and economic slowdown.

Investment levels similarly decline more markedly than in the baseline scenario, illustrating that heightened climate uncertainty discourages capital formation. This pattern resonates with the work of Gaies (2024), who found that uncertainty stemming from climate risks significantly hampers investment decisions, especially in climate-vulnerable economies. However, in some studies, such as those by Nakov and Thomas (2023), the results suggest that with well-calibrated climate policy interventions, the negative effects on investment could be mitigated or even reversed, highlighting the role of policy as a buffer against climate shocks. The labour market outcomes further reinforce these findings – employment tends to decrease, while unemployment rises under climate stress, showing how an economic contraction affects job creation. This outcome is in line with findings by Ojha, Pattnaik and Rout (2018), who report that weather shocks contribute to job losses, particularly in sectors like agriculture and forestry that depend directly on climate-sensitive resources.

Inflation behaviour exhibits some interesting patterns. While inflation remains relatively stable or slightly declines in the baseline scenario, it rises during climate shocks, possibly driven by the increased cost of essential inputs or energy. This is consistent with the hypothesis presented by Höök and Tang (2013), who explain that climate disruptions can lead to supply-side constraints that elevate prices. Notably, the simulations portray increased uncertainty in inflation expectations during climate shocks, with confidence intervals widening considerably. This mirrors empirical observations by Boneva, Ferrucci and Mongelli (2022), who argue that climate variability can create inflation volatility and challenge monetary policy stability. The potential for increased inflation volatility complicates the task faced by central banks, especially when trying to maintain stable inflation targets, as highlighted by Annicchiarico and Diluiso (2019).

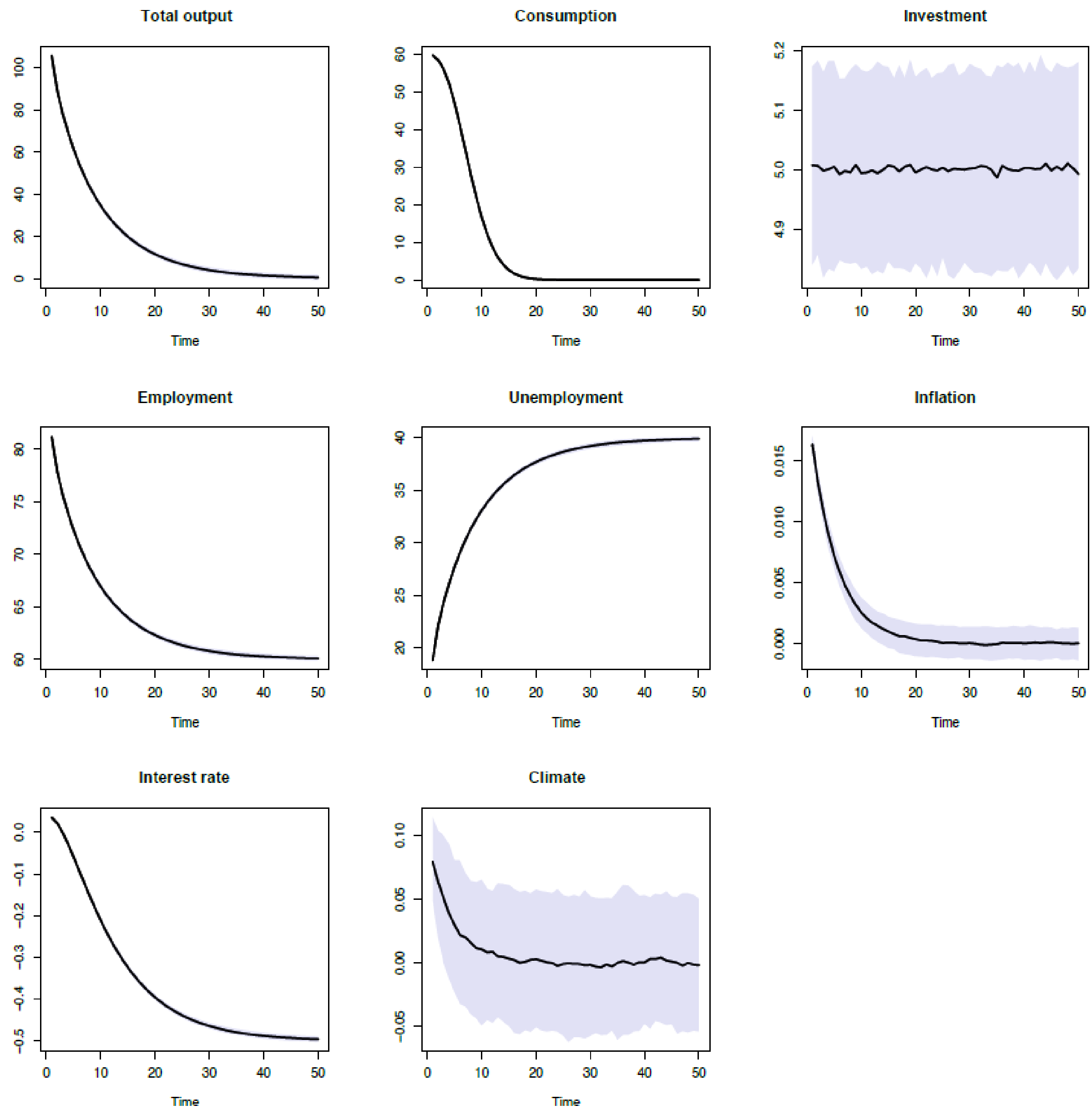
The plots collectively underscore the importance of proactive policy responses. The non-negligible decline in output and employment highlights the risk that climate shocks pose to economic stability, confirming the findings of Zhao, Gerety and Kuminoff (2018), who emphasise that climate variability can trigger persistent economic downturns if not adequately addressed. Furthermore, the increased uncertainty indicated by wider confidence intervals in inflation and other variables suggests that adaptive and flexible policy frameworks, such as those employing dynamic interest rate responses, are essential for mitigating these risks. This aligns with the rationale adopted in the model's modified Taylor rule, which accounts for climate and economic uncertainties.

Interestingly, some studies, such as those by Nakov and Thomas (2023), suggest that climate policies like carbon taxes, when optimally implemented, do not conflict with monetary objectives and may even complement stabilisation efforts. This contrasts with the more pessimistic outlook implied by the simulations. The discrepancy may be due to differences in model assumptions, such as policy scope or the inclusion of adaptive measures. Nonetheless, the evidence from the simulation results in this study shows that climate shocks pose immediate and persistent threats to macroeconomic stability, especially in emerging economies like South Africa, which are highly susceptible to climate variability. Consequently, integrating climate risks into macroeconomic planning and adopting resilient policy measures are pivotal for safeguarding economic stability in the face of escalating climate challenges.

6. Simulation under baseline, climate shocks and fiscal shocks

The analysis presented in this section offers valuable insights into how climate and fiscal shocks influence key macroeconomic indicators over time, particularly within the South African context. The plots, covering total output, consumption, investment, employment, inflation, interest rates and climate stress, exhibit nuanced responses that underline both the immediate and persistent effects of climate-related disruptions (see Figure 2).

Figure 2: Comprehensive view of the potential macroeconomic impacts of climate shocks on South Africa's economy



Beginning with the total output trajectories, the plots demonstrate a notable decline in output following climate shocks compared to the baseline scenario. This pattern aligns with the empirical findings of Zhao, Gerety and Kuminoff (2018), who document that climate variability, especially droughts and extreme weather events, has a direct negative impact on economic growth, primarily through agrarian productivity and supply chain disruptions. The sharp dip in total output during initial periods reflects the immediate adverse effects, with a gradual recovery that hinges on policy responses and adaptation measures. Nevertheless, the recovery is incomplete and slower under more severe climate stress, reinforcing the vulnerability of South Africa’s economy to persistent climatic volatility.

Consumption exhibits a similar downward trend amid climate shocks, indicating reduced household income and increased uncertainty. As households anticipate potential income losses and higher prices, particularly in food and energy, consumption declines. This outcome corroborates the findings of Dube, Nhamo and Chikodzi (2022), who highlight that climate-induced supply chain disruptions and water shortages curb household consumption, exacerbating economic hardship. However, some studies, such as Nakov and Thomas (2023), report contrasting evidence where proactive fiscal policies, like targeted transfers and interest rate adjustments, can buffer consumption declines. This emphasises the importance of responsive policy tools in mitigating impacts on welfare.

The investment sector contracts during periods of climate stress, reflecting the heightened uncertainty faced by investors in climate-vulnerable sectors such as agriculture and energy. This aligns with Dafermos, Nikolaidi and Galanis (2018), who assert that increased climate risk discourages capital expenditure, leading to slower economic growth and declining employment. Conversely, Nakov and Thomas (2023) argue that green investment initiatives and climate-resilient infrastructure can offset these reductions, suggesting that policy environments geared towards sustainable development can transform climate risk into opportunities for economic transformation.

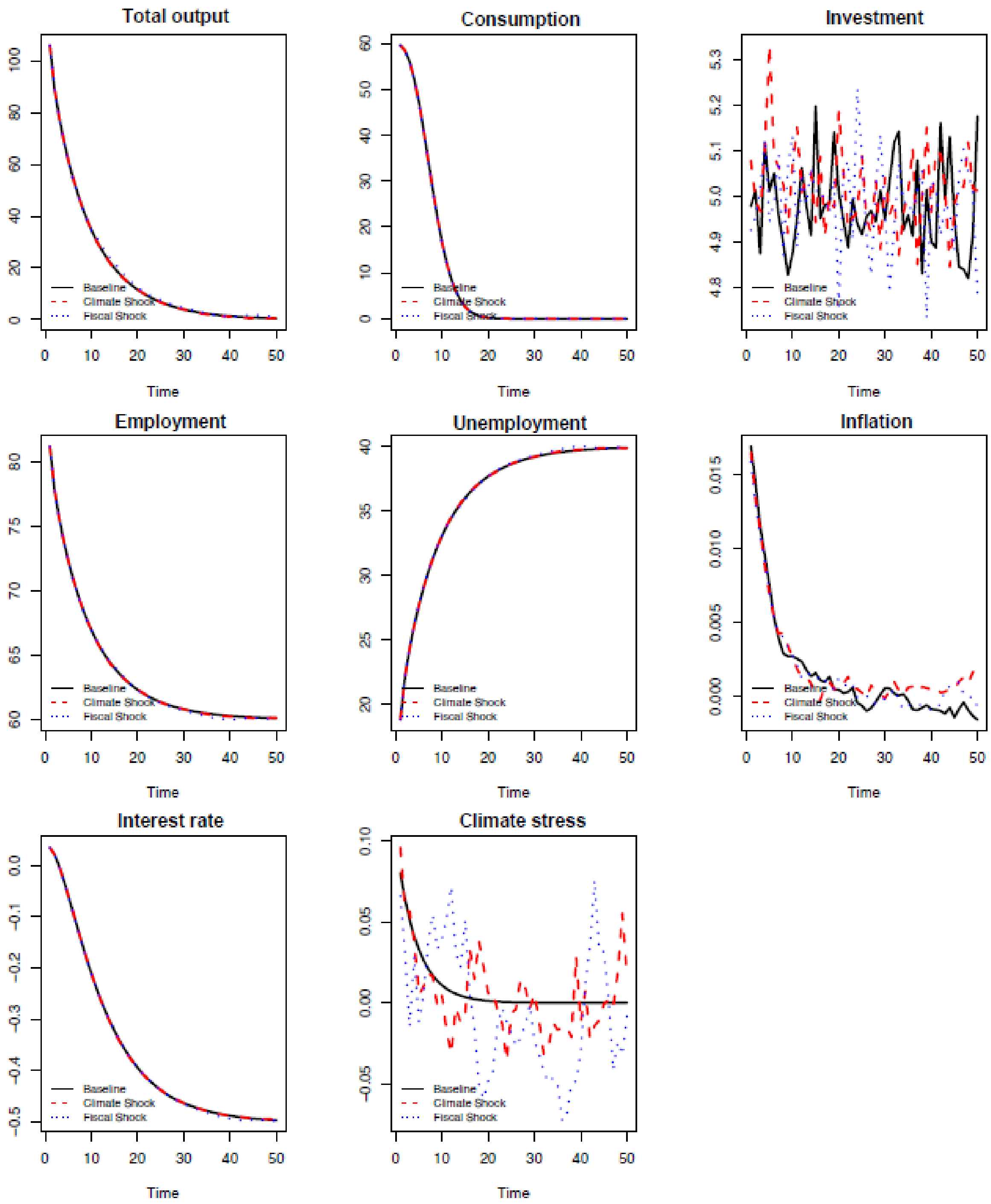
In terms of employment, the plots depict a decline during periods of climate shock, with unemployment rising significantly, particularly in sectors closely tied to climate-sensitive resources. This is consistent with Ojha, Pattnaik and Rout (2018), who document that weather shocks disproportionately affect employment in agricultural and resource-dependent sectors, often exacerbating social inequalities. The recovery of employment levels varies across scenarios. During policy intervention phases, employment stabilises more rapidly, indicating that active monetary and fiscal measures can help ameliorate job losses. This result is supported by studies emphasising the importance of policy flexibility, for example Boneva, Ferrucci and Mongelli (2022).

Inflation dynamics reveal complex, often volatile patterns in response to climate shocks. During initial shock periods, inflation tends to stabilise or decline slightly, potentially reflecting supply-side disruptions that reduce demand or delay price adjustments. However, as climate impacts persist, inflation tends to rise, driven by cost-push pressures such as increased food and energy prices. This is consistent with Höök and Tang (2013), who contend that climate-induced disruptions lead to higher production costs and inflationary spirals. The wider confidence bands underscore the inherent uncertainty in inflation forecasts amid climate variability, challenging traditional inflation-targeting regimes.

The interest rate responses depicted in the plots illustrate proactive monetary policy adjustments, with interest rates generally increasing in response to rising inflation and economic uncertainty. These shifts align with the modified Taylor rule used in the model, supporting findings by Annicchiarico and Diluiso (2019), who advocate for flexible, climate-aware monetary policy frameworks. Nonetheless, some studies warn that aggressive interest rate hikes may deepen recessionary pressures (Nakov and Thomas 2023). This underscores the delicate balance policymakers must maintain between containing inflation and supporting growth, especially in climate-affected economies.

Finally, the climate stress plots reveal a persistent increase in climate-related disruptions over time, reflecting ongoing and escalating climate risks. The rising levels of climate stress highlight the importance of incorporating climate resilience into economic planning. Empirical studies, such as Dube, Nhamo and Chikodzi (2022), demonstrate that recurrent climate shocks can have long-term economic impacts, including infrastructure damage, water crises and productivity losses. Conversely, the simulations suggest that policies integrating green finance, adaptive infrastructure and robust monetary responses can dampen the adverse effects, emphasising the significance of proactive and targeted policy measures.

Figure 3: Responses of various macroeconomic variables under specific shock scenarios



7. Conclusion

This study highlights the significant impact of climate shocks on South Africa's macroeconomic stability, affecting output, consumption, investment, employment, inflation and the effectiveness of monetary policy. Through a robust simulation-based DSGE framework, it underscores the vital need for adaptive policy strategies that integrate climate risks. Findings suggest that proactive monetary, fiscal and structural policies – such as green investments and climate-responsive interest rate adjustments – are crucial in mitigating climate-induced economic disruptions. The paper underscores the importance of embedding climate considerations into macroeconomic planning to enhance resilience and ensure sustainable growth in climate-vulnerable economies like South Africa.

References

Ahmed, M, Hayat, R, Ahmad, M, Ul-Hassan, M, Kheir, A M, Ul-Hassan, F, Ur-Rehman, M H, Shaheen, F A, Raza, M A and Ahmad, S. 2022. 'Impact of climate change on dryland agricultural systems: a review of current status, potentials, and further work need'. *International Journal of Plant Production* 16(3): 341–363.

Akinbami, O, Oke, S and Bodunrin, M. 2021. 'The state of renewable energy development in South Africa: an overview'. *Alexandria Engineering Journal* 60(6): 5077–5093.

Al-Humaiqani, M M and Al-Ghamdi, S G. 2022. 'The built environment resilience qualities to climate change impact: concepts, frameworks, and directions for future research'. *Sustainable Cities and Society* 80: 103797.

Annicchiarico, B and Diluiso, F. 2019. 'International transmission of the business cycle and environmental policy'. *Resource and Energy Economics* 58: 101112.

Baarsch, F, Granadillos, J R, Hare, W, Knaus, M, Krapp, M, Schaeffer, M and Lotze-Campen, H. 2020. 'The impact of climate change on incomes and convergence in Africa'. *World Development* 126: 104699.

Baptista, D M S, Farid, M, Fayad, D, Kemoe, L, Lanci, L S, Mitra, P, Muehlschlegel, T S, Okou, C I, Spray, J A, Tuitoek, K and Unsal, F D. 2022. 'Climate change and chronic food insecurity in sub-Saharan Africa'. International Monetary Fund, Departmental paper 016.

Boneva, L, Ferrucci, G and Mongelli, F. 2022. 'Climate change and central banks: what role for monetary policy?' *Climate Policy* 22(6): 770–787.

Cevik, S and Jalles, J T. 2022. 'This changes everything: climate shocks and sovereign bonds'. *Energy Economics* 107: 105856.

Chan, Y T. 2020. 'Are macroeconomic policies better in curbing air pollution than environmental policies? A DSGE approach with carbon-dependent fiscal and monetary policies'. *Energy Policy* 141: 111454.

Chen, C, Pan, D, Huang, Z and Bleischwitz, R. 2021. 'Engaging central banks in climate change? The mix of monetary and climate policy'. *Energy Economics* 103: 105531.

Chen, X and Yang, L. 2019. 'Temperature and industrial output: firm-level evidence from China'. *Journal of Environmental Economics and Management* 95: 257–274.

Dafermos, Y, Nikolaidi, M and Galanis, G. 2018. 'Climate change, financial stability and monetary policy'. *Ecological Economics* 152: 219–234.

Dell, M, Jones, B F and Olken, B A. 2014. 'What do we learn from the weather? The new climate-economy literature'. *Journal of Economic Literature* 52(3): 740–798.

Diluiso, F, Annicchiarico, B, Kalkuhl, M and Minx, J. 2021. 'Climate actions and macro-financial stability: the role of central banks'. *Journal of Environmental Economics and Management* 110: 102548.

Dube, K, Nhamo, G and Chikodzi, D. 2022. 'Climate change-induced droughts and tourism: impacts and responses of Western Cape province, South Africa'. *Journal of Outdoor Recreation and Tourism* 39: 100319.

Economides, G and Xepapadeas, A. 2018. 'Monetary policy under climate change'. Bank of Greece Working Paper No. 254.

Falchetta, G, Gernaat, D E, Hunt, J and Sterl, S. 2019. 'Hydropower dependency and climate change in sub-Saharan Africa: a nexus framework and evidence-based review'. *Journal of Cleaner Production* 231: 1399–1417.

Ferrari, A and Nispi Landi, V. 2024. 'Will the green transition be inflationary? Expectations matter'. *IMF Economic Review*: 1–64.

Frame, D, Wehner, M, Rosier, S and Noy, I. 2020. ‘Climate change attribution and the economic costs of extreme weather events: a study on damages from extreme rainfall and drought’. *Climatic Change* 162: 781–797.

Gaies, B. 2024. ‘Exploring the time-varying predictability of global financial instability over the last two decades: the influence of climate change news’. *Journal of Economic Studies* 52(5): 904–918.

Gemeda, D and Sima, A. 2015. ‘The impacts of climate change on African continent and the way forward’. *Journal of Ecology and the Natural Environment* 7(10): 256–262.

Gupta, R, Kabundi, A and Modise, M. 2010. ‘Has the SARB become more effective post inflation targeting?’ *Economic Change and Restructuring* 43: 187–204.

Hendrixson, A and Hartmann, B. 2019. ‘Threats and burdens: challenging scarcity-driven narratives of “overpopulation”’. *Geoforum* 101: 250–259.

Hollander, H and van Lill, D. 2019. ‘A review of the South African Reserve Bank’s financial stability policies’. Stellenbosch Economic Working Papers, WP11/2019. Department of Economics, Stellenbosch University.

Höök, M and Tang, X. 2013. ‘Depletion of fossil fuels and anthropogenic climate change – a review’. *Energy Policy* 52: 797–809.

Ibarrarán, M E, Ruth, M, Ahmad, S and London, M. 2009. ‘Climate change and natural disasters: macroeconomic performance and distributional impacts’. *Environment, Development and Sustainability* 11: 549–569.

Jabeen, M, Gabriel, H F, Ahmed, M, Mahboob, M A and Iqbal, J. 2017. ‘Studying impact of climate change on wheat yield by using DSSAT and GIS: a case study of Pothwar region’. In *Quantification of climate variability, adaptation and mitigation for agricultural sustainability*, edited by M Ahmad and C Stockle. Switzerland: Springer. 387–411.

Javadinejad, S, Hannah, D H, Krause, S K, Dara, R, Jafary, F and Naseri, M. 2020. 'The impacts of climate change on energy-water systems and economic analysis'. *Iraqi Geological Journal* 53(2F): 1–17.

Kahn, M E, Mohaddes, K, Ng, R N, Pesaran, M H, Raissi, M and Yang, J-C. 2021. 'Long-term macroeconomic effects of climate change: a cross-country analysis'. *Energy Economics* 104: 105624.

Kipngeno, S. 2020. 'Drought prevalence in the Horn of Africa and its implications on forest cover: a case study of Somalia'. Doctoral dissertation, University of Embu, Kenya.

Kusangaya, S, Warburton, M, van Garderen, E and Jewitt, G. 2014. 'Impacts of climate change on water resources in southern Africa: a review'. *Physics and Chemistry of the Earth,* parts A/B/C 67: 47–54.

Lamperti, F, Bosetti, V, Roventini, A, Tavoni, M and Treibich, T. 2021. 'Three green financial policies to address climate risks'. *Journal of Financial Stability* 54: 100875.

Lemoine, D. 2016. 'Environmental risk and growth'. *Journal of Economic Dynamics and Control* 67: 35–50.

Lottering, S, Mafongoya, P and Lottering, R. 2021. 'Drought and its impacts on small-scale farmers in sub-Saharan Africa: a review'. *South African Geographical Journal* 103(3): 319–341.

Mahlalela, P, Blamey, R, Hart, N and Reason, C. 2020. 'Drought in the Eastern Cape region of South Africa and trends in rainfall characteristics'. *Climate Dynamics* 55: 2743–2759.

McKibbin, W, Konradt, M and Weder di Mauro, B. 2021. 'Climate policies and monetary policies in the euro area'. Paper for ECB Forum on Central Banking.

McKibbin, W, Morris, A, Panton, A J and Wilcoxen, P J. 2017. 'Climate change and monetary policy: dealing with disruption'. CAMA Working Paper 77/2017. Centre for Applied Macroeconomic Analysis, Australian National University.

Munyai, R B, Chikoore, H, Musyoki, A, Chakwizira, J, Muofhe, T P, Xulu, N G and Manyanya, T C. 2021. 'Vulnerability and adaptation to flood hazards in rural settlements of Limpopo province, South Africa'. *Water* 13(24): 3490.

Nakov, A and Thomas, C. 2023. 'Climate-conscious monetary policy'. European Central Bank Working Paper No. 2845.

Ng, T and Motlanthe, K. 2020. 'Climate change and macroeconomic policy in South Africa: a DSGE approach'. *South African Journal of Economics* 88(3): 271–298.

Ngwira, A, Aune, J B and Thierfelder, C. 2014. 'DSSAT modelling of conservation agriculture maize response to climate change in Malawi'. *Soil and Tillage Research* 143: 85–94.

Nhamo, L, Matchaya, G, Mabhaudhi, T, Nhlengethwa, S, Nhemachena, C and Mpandeli, S. 2019. 'Cereal production trends under climate change: impacts and adaptation strategies in Southern Africa'. *Agriculture* 9(2): 30.

Nordhaus, W D. 2008. *A question of balance: weighing the options on global warming policies*. Yale University Press.

Odongo, M, Misati, R, Kamau, A and Kisingu, K. 2022. 'Climate change and inflation in Eastern and Southern Africa'. *Sustainability* 14(22): 4764.

Ojha, A, Pattnaik, A K and Rout, J. 2018. 'Climate change impacts on natural resources and communities: a geospatial approach for management'. *Lakes & Reservoirs: Research & Management* 23(1): 34–42.

Parker, L, Bourgoin, C, Martinez-Valle, A and Läderach, P. 2019. 'Vulnerability of the agricultural sector to climate change: the development of a pan-tropical Climate Risk

Vulnerability Assessment to inform sub-national decision making'. *PLoS ONE* 14(3): e0213641.

Pielke Jr, R, Burgess, M and Ritchie, J. 2022. 'Plausible 2005-2050 emissions scenarios project between 2 and 3 degrees C of warming by 2100'. *Environmental Research Letters* 17(2).

Reid, H, Sahlén, L, Stage, J and MacGregor, J. 2008. 'Climate change impacts on Namibia's natural resources and economy'. *Climate Policy* 8(5): 452–466.

Salahuddin, M, Gow, J, Ali, M I, Hossain, M R, Al-Azami, K S, Akbar, D and Gedikli, A. 2019. 'Urbanization-globalization-CO2 emissions nexus revisited: empirical evidence from South Africa'. *Heliyon* 5(6): e01974.

Santabárbara, D and Suárez-Varela, M. 2022. 'Carbon pricing and inflation volatility'. Banco de España Working Paper No. 2231.

Seneviratne, S I, Zhang, X, Adnan, M, Badi, W, Dereczynski, C, Di Luca, A, Ghosh, S, Iskandar, I, Kossin, J, Lewis, S, Otto, F, Pinto, I, Satoh, M, Vicente-Serrano, S M, Wehner, M, Zhou, B and Allan, R P. 2021. 'Weather and climate extreme events in a changing climate'. In *Climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by V Masson-Delmotte, P Zhai, A Pirani, S L Connors, C Péan, S Berger, N Caud, Y Chen, L Goldfarb, M I Gomis, M Huang, K Leitzell, E Lonnoy, J B R Matthews, T K Maycock, T Waterfield, O Yelekçi, R Yu, and B Zhou. Cambridge: Cambridge University Press. 1513–1766

Shackleton, C M, Blair, A, De Lacy, P, Kaoma, H, Mugwagwa, N, Dalu, M T and Walton, W. 2018. 'How important is green infrastructure in small and medium-sized towns? Lessons from South Africa'. *Landscape and Urban Planning* 180: 273–281.

Shikwambana, L, Mhangara, P and Kganyago, M. 2021. 'Assessing the relationship between economic growth and emissions levels in South Africa between 1994 and 2019'. *Sustainability* 13(5): 2645.

Thakoor, M V V and Kara, E. 2023. ‘Monetary policy design with recurrent climate shocks’. International Monetary Fund Working Paper No. 2023/243.

Wang, S L, Ball, E, Nehring, R, Williams, R and Chau, T. 2019. ‘Impacts of climate change and extreme weather on US agricultural productivity: evidence and projection’. In *Agricultural productivity and producer behavior*, edited by W Schlenkler. Chicago and London: University of Chicago Press. 41–76.

Zhao, X, Gerety, M and Kuminoff, N V. 2018. ‘Revisiting the temperature-economic growth relationship using global subnational data’. *Journal of Environmental Management* 223: 537–544.