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## Effects of monetary and R&D policies on inequality and growth: The case of South Africa

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# Effects of monetary and R&D policies on inequality and growth

The case of South Africa

Yoseph Getachew,<sup>1</sup> Richard Kima,<sup>2</sup> and Nyemwererai Matshaka<sup>1</sup>

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**Abstract:** This paper develops a two-agent worker-capitalist heterogeneous household monetary Schumpeterian growth model to examine the effects of R&D and monetary policies on economic growth and inequality. The model is then calibrated to the South African economy, an upper-middle-income African country infamous for its consistently high level of inequality. A higher nominal interest rate reduces innovation and economic growth but help to mitigate inequality. However, the reduction in consumption inequality comes from a disproportionate decline in the capitalists' condition. In contrast, stronger patent protection fosters innovation and growth but leads to a greater concentration of wealth among capitalists. While broader patents provide long-term gains by boosting productivity and aggregate welfare, higher interest rates consistently decrease societal well-being despite a positive impact on distribution.

**Key words:** economic growth, inequality, patent policy, monetary policy

**JEL classification:** E25, E52, O32, O42

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# 1 Introduction

Over the past four decades, inequality has increased in most countries worldwide, with a significant rise in many. This growing inequality has become a major concern for academics and policymakers as it threatens sustainable growth and poverty reduction strategies. While fiscal policy is often employed to combat high levels of inequality by redistributing resources, it typically comes with unintended consequences. For instance, taxes and social grants aimed at promoting equity often lead to efficiency loss through distorting individual efforts and savings.

Given these challenges, this research explores alternative channels not traditionally used to address inequality. The study investigates in particular the impact of monetary policy and research and development (R&D) policies on growth and inequality. This sharply contrasts with previous studies that focus on fiscal policies when dealing with the growth–inequality nexus (Bénabou 2002; Getachew and Turnovsky 2015). While fiscal interventions are central in redistribution efforts, monetary policy primarily focuses on maintaining price stability and has historically been viewed as equity neutral (da Silva et al. 2022). However, following the global financial crisis, there has been increasing discussion regarding the link between monetary policy and inequality, with growing interest in understanding whether monetary policy influences inequality and vice versa (Borio 2021).

Our analysis extends this discussion by explicitly analysing monetary and patent policies and their implications for growth and inequality in a highly unequal emerging African economy with significant innovation potential. As the world grapples with persistent inequality, technological advancements through innovation have reached new heights, raising important questions about their impact on macroeconomic outcomes, including inequality. While innovation is known to drive growth and expand economic opportunities, its redistributive effects still need to be determined. Monetary and patent policies are traditionally viewed as distinct tools for addressing macroeconomic stability and innovation. However, their linkage arises through mutual influence on investment decisions, innovation incentives, and economic growth. While monetary policy is conventionally used to stabilize business cycles, it also influences drivers of long-run growth as explored in the literature, including Dotsey and Sarte (2000), Gupta and Stander (2018), and Jin (2009). In our study we explore the notion that monetary policy determines the availability and attainability of financing for R&D, while patent policy defines the expected returns from innovation, which determines growth outcomes. Concerning distribution, monetary policy influences inflation, which could impact real income, consumption, and investment decisions. In contrast, patent policy could impact growth and, subsequently, consumption and income distribution by determining who benefits from innovation. This overall effect depends on how the impact of patent policy on innovation-driven growth translates to wage income and capitalists' profit. This interconnection has significant implications for understanding the broader effects of policy decisions on inequality and the need for efficient policy matching.

We develop a monetary quality ladder growth model that accounts for household heterogeneity. Our model builds on the Schumpeterian quality-ladder framework (Aghion and Howitt 1992, Grossman and Helpman 1991, Segerstrom et al. 1990), which posits that innovation and improvements in product quality drive economic growth. Monetary policy is introduced through a cash-in-advance (CIA) constraint (Arawatari et al. 2018), which links monetary policy to individual decisions regarding consumption, investment, and innovation. By incorporating both monetary and R&D policies in a two-agent heterogeneous household model, we can examine the redistributive effects of these policies in the presence of R&D-driven growth.

The model economy consists of two types of households, namely capitalists (capital owners) and workers. Capitalists comprise a small fraction of the population, have full access to financial markets, and trade on assets to smooth consumption. Workers, who constitute the remaining fraction, have limited access to financial markets and are hand-to-mouth consumers. The capitalists own the monopolistic intermediate goods firms that drive innovation, whereas workers rely on labour income. This difference in household characteristics allows us to study how monetary and patent policies affect income distribution and consumption disparities through their influence on factor productivity, innovation, and investment. Perfectly competitive firms in the final goods sector produce the final goods in the economy, which are consumed by households or invested in physical capital to produce differentiated intermediate goods in the intermediate goods sector. Quality-improving innovation is the engine of growth in the model, with capitalists accruing the rents associated with technological advancements. The CIA constraint ties monetary policy to investment decisions, affecting innovation and economic growth.

We calibrate the model to match key parameters of the South African economy. South Africa presents a good scenario for such a study due to its high levels of income inequality and ongoing debates on the role of monetary and innovation policies in addressing the soaring inequality in the country. Therefore, the analysis is based on consumption inequality. Among the key results, a rise in the nominal interest rate increases the cost of borrowing, reducing firms' profitability from innovation, lowering investment in R&D, and stifling economic growth. As a result, monetary tightening dampens growth but reduces inequality as capitalists are disproportionately affected while workers' consumption-to-output ratio remains constant. This is also highlighted in the negative relationship between monetary policy tightening and welfare, as neither household realizes improved outcomes.

Patent policy similarly plays a complex role in the R&D-driven unequal economy. More robust patent protection fosters economic growth by incentivizing firms to engage in R&D. With the assurance of exclusive rights to the profits of their discoveries, firms are more willing to undertake the substantial costs and risks associated with innovation. This protection creates a direct link between intellectual property rights and technological progress, as firms are encouraged to push the boundaries of innovation to maintain a competitive edge. However, the same mech-

anism that drives growth also intensifies inequality. Stronger patent protection often concentrates the returns from innovation among a fraction of firms or individuals who own the intellectual property. These innovators, typically capitalists, enjoy a disproportionate share of the economic gains, resulting in a growing income gap between them and workers who do not directly benefit from these profits. Broader patent breadth, which extends the scope and exclusivity of rights, amplifies this effect by further entrenching the advantages of patent holders. Innovation also benefits workers indirectly by boosting their productivity. The resulting economic landscape is characterized by an unequal distribution of income and wealth, where the gains from growth accrue primarily to those at the top. This dynamic underscores the dual-edged nature of patent policy, highlighting its role in driving economic progress and exacerbating inequality.

In summary, the quantitative analysis confirms that higher interest rates reduce innovation and economic growth while improving consumption and income distribution. However, such improvement comes from a disproportionately negative impact of inflation on the affluent ones, which manifests a novel channel in the complex relationship between monetary policy and the macroeconomy. In contrast, stronger patent protection fosters innovation and growth but leads to a greater concentration of wealth among capitalists. Overall welfare increases with patent breadth due to increased innovation and economic activity, and is largely driven by capitalist gains. Welfare decreases as the nominal interest rate increases, mainly caused by a decline in the economy's long-run growth rate and potentially lower aggregate demand, characterized by a shift in economic activity. These findings highlight the tradeoffs policymakers face when designing interventions to promote growth and reduce inequality.

The remaining sections are organized as follows. Section 2 provides a brief literature review while Section 3 provides a background discussion on inequality and R&D policies in South Africa. Section 4 presents the model and discusses the equilibrium conditions. Section 5 outlines the conditions for a balanced growth path and economic welfare. In Section 6, we build an inequality index and examine the relationship between consumption inequality and monetary and patent policies. In Section 7, we study the model's quantitative properties, while Section 8 concludes.

## **2 Literature review**

This study relates to the literature on innovation and economic growth, which explores how innovation influences growth through various mechanisms. Among these, the Schumpeterian quality-ladder model, developed by Aghion and Howitt (1992), Grossman and Helpman (1991), and Segerstrom et al. (1990), has been instrumental in highlighting how innovation drives economic growth by enhancing product quality and fostering technological progress. This framework has provided a foundation for policy analysis in numerous studies, such as Arawatari et

al. (2018) and Chu and Cozzi (2018), which investigate policy implications in different economic contexts. Building on this established framework, we introduce CIA constraint on R&D investment. This modification captures the role of liquidity and monetary conditions in shaping the dynamics of innovation, offering new insights into the interplay between monetary policy and long-term growth.

Our study also contributes to the literature on inequality and growth. Numerous studies explore this relationship through various channels, including the socio-political economy (Benhabib and Rustichini 1996) and credit market imperfections (Bénabou 1996, 2002) channels. The latter mechanism relates to studies such as Basu and Getachew (2020), Getachew and Turnovsky (2020), and Loury (1981) in which market imperfections relating to credit are modelled to understand the growth–inequality relationship. Credit market imperfections, such as high borrowing costs, collateral constraints, and credit rationing, limit access to finance for poorer individuals and small businesses, which worsens inequality and slows economic growth by reducing investment opportunities and upward mobility. Studies have also considered effects of investment in physical and human capital, and the role of fertility (De La Croix and Doepke 2003). The present study specifically contributes to the literature by considering an innovation channel to explain growth and consumption inequality.

Other related literature considers economic growth and monetary policy. One strand explores the growth effects of monetary policy in the framework of R&D-based endogenous growth. A standard pioneering study by Marquis and Reffett (1994), which investigates the social costs of inflation on growth, introduces money in a Romer (1990) type of model as followed by Arawatari et al. (2018). Arawatari et al. (2018) study the relationship between inflation and growth in a product variety growth model with heterogeneity given by differences in agents based on R&D abilities. Findings show a non-linear relationship between inflation and growth. The main finding is that the heterogeneity in entrepreneurial ability has a key effect on the relationship between growth and inflation, as it mainly generates a non-linear relationship. At low levels, inflation may stimulate economic growth by reducing real wage rigidity and encouraging spending. However, as inflation rises beyond a certain threshold, it creates uncertainty, distorts price signals, and hampers investment, leading to slower growth. Subsequent studies such as Chu and Cozzi (2014), Hu et al. (2021), and Lu (2022) consider a Schumpeterian quality ladder economy. Chu et al. (2019) and Lu (2022) explore the impact of the interaction between patent and monetary policy on growth and welfare. Investigating how intellectual property rights, as the basis of firm market power, influence the effect of monetary policy on growth and social welfare, Chu et al. (2019) consider a growth model in which both R&D and capital accumulation are growth drivers. Monetary expansion increases inflation and the cost of consumption over leisure. This reduces labour supply, subsequently affecting R&D and capital accumulation. The extent of the monetary policy effect on growth and welfare depends on the strength of patent protection such that monetary policy efficiency increases for firms with greater mar-

ket power through an R&D channel. Chu and Lai (2013) carry out a cross-country empirical analysis and explore how inflation could negatively influence the economy due to its negative impact on R&D investment. Lu (2022) particularly investigates the effects of monetary policy, patent breadth, and blocking patents on growth and the interaction between monetary policy and patent policies. The novelty of Lu (2022) is the consideration of the interaction between monetary and patent policies by analysing whether monetary policy plays a role in reducing innovation size. Huang et al. (2017) investigates the effects of monetary policy on growth and social welfare given some level of protection based on intellectual property rights. They also consider the bidirectional relationship and ask how the two policies interact in achieving their mandated goals. We adopt the notion of analysing the two policies—patent and monetary—focusing on income inequality instead of welfare. To achieve this, we follow this stream of discussed literature to study R&D and monetary policies and their effect on economic growth in an economy characterized by heterogeneous agents.

Finally, our study also complements the literature exploring growth, inequality, and policy dynamics. A component of these studies considers the effects of policy on innovation and inequality (Chan et al. 2022; Chu et al. 2021). Chan et al. (2022) study the impact of stimulating technological progress on income inequality through patents and subsidies. The study includes worker heterogeneity along with wealth heterogeneity, in order to capture household asset income inequality. The findings in Chan et al. (2022) show that strengthening patent protection increases the value of financial assets, giving a U-shaped relationship, whereas raising subsidies has the opposite effect. Initially, stronger protection boosts innovation and growth by increasing returns on R&D. However, beyond a certain point, it can stifle competition and innovation diffusion, slowing growth. In a study of the dynamic effects of patent policy on innovation and income inequality, Chu et al. (2021) find either a positive or an inverted-U effect of patent protection on income inequality. This is dependent on the number of differential products in the short run. Their numerical analysis carried out for the United States of America shows that the negative effect of patent strength on income inequality in the long run is greater than the positive short-run effect. In the present study, we extend this to include money and analyse the role of both patent and monetary policies on innovation and inequality. We also set out to capture inequality, given that the concentration of wealth is only in a fraction of the economy. In a similar study, Chu and Cozzi (2018) explore R&D policies of patent protection and R&D subsidies and their effect on growth and inequality in a heterogeneous agent model. The two policies have a positive impact on growth. Increased patent strength increases inequality, while subsidies either decrease or increase inequality depending on the quality step size, which measures the proportion of improvement in technology or product quality with each new successful innovation. Our study contributes to the literature by developing a monetary Schumpeterian growth model with two-agent households to highlight household heterogeneity in studying growth and consumption inequality in relation to monetary and R&D policies.



### 3 Inequality and innovation in South Africa

South Africa's income and wealth inequality is amongst the highest in the world. This is shown in the deep and blatant divide between the rich and poor. The income disparities are rooted in the country's historical background with apartheid, racial segregation characterized by a systematic exclusion and marginalization of the significantly larger Black portion which constitutes the majority of the South African population, concerning economic opportunities and basic rights. Moreover, the country has consistently been ranked globally as the most unequal nation based on the Gini index, a measure of income inequality on which it ranks first among 164 countries (Chancel et al. 2022). According to Chancel et al. (2022), income inequality remains deeply entrenched. Figure 1 highlights this. The World Inequality Database (WID) relies on the best available historical records, which often stem from tax data, surveys, and national accounts sources that likely undercounted large segments of the African population during apartheid. We acknowledge these limitations, but note that the WID dataset offers a consistent long-term perspective.<sup>1</sup> The wealthiest 10% of South Africans control over 85% of the country's wealth, while the bottom 50% holds almost no wealth at all. This stark inequality is reflected in consumption, income, and wealth disparities. The report highlights that South Africa's top 1% benefits disproportionately from wealth accumulation, especially since the mid 1990s. In the context of global wealth inequality, the report indicates that South Africa's situation is among the worst, despite some attempts at redistribution and welfare interventions. Despite historical factors, global phenomena like the COVID-19 pandemic exacerbated the persistence of inequality as it worsened economic conditions for people with low incomes. At the same time, the wealthy remained insulated and in some cases gained further wealth. Other unique elements of the extreme inequality in South Africa include the impact of race, gender, and issues surrounding land ownership. The labour market in South Africa is also characterized by an unemployment crisis, which may also perpetuate stagnant inequality.

Noting the prevalence of inequality in South Africa, it is critical to understand whether existing interventions can address inequality at these extreme levels. Generally, progressive taxation and social transfer programmes are used to counteract inequality. It is also important to consider other non-conventional or indirect interventions. Innovation is one channel that may affect inequality. Innovation potentially plays a dual role in determining inequality, acting as both a driver of opportunity and a source of disparity. Understanding the nuances of this relationship is essential for policy design that balances the benefits of technological progress with its distributional impacts. On the one hand, innovation is noted as a driver of growth in studies such as Aghion and Howitt (1992), Romer (1990), and Segerstrom et al. (1990), and these advancements often lead to higher incomes, improved standard of living, and increased ac-

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<sup>1</sup> The dashed lines in Figure 1 reflect extrapolated data.

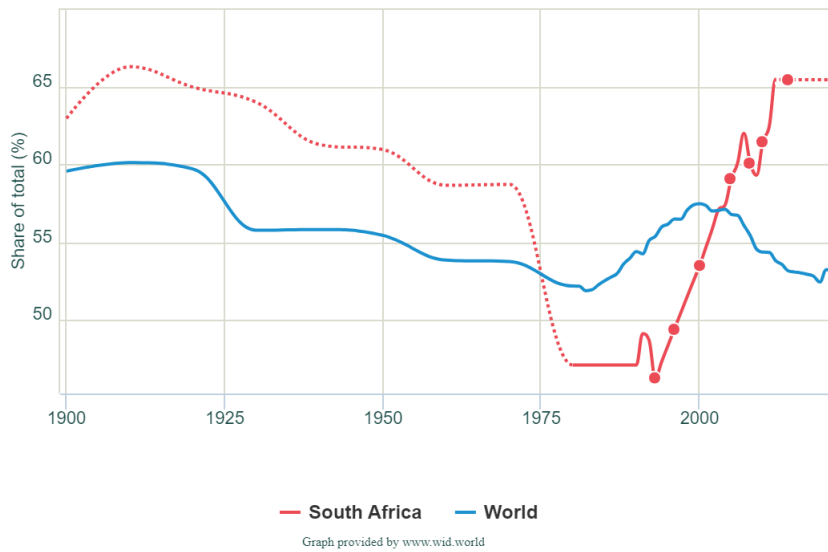
cess to products, particularly for low-income groups. Technological progress can also generate new employment opportunities and create new industries, which may aid redistribution. On the other hand, despite the potential to reduce inequality, innovation often exacerbates disparities when its benefits are unequally distributed. Aghion and Griffith (2024) highlight that the extent and direction of the impact of innovation on inequality depend on ownership and control of rights over innovation. Patent protection is one way to govern that; however, Chien (2022) highlights that majority patents are awarded to the top 1%, further showcasing the linkage between redistribution and innovation. Technological progression may favour a partial group in the economy. South Africa has seen a rise in patent registrations and it is a significant lead for the African continent despite a modest global position (World Intellectual Property Organization 2024). It was ranked 17th in 2022 for patent filings, with non-resident applications being the most dominant (World Intellectual Property Organization 2023b). According to the Global Innovation Index (2023), South Africa ranks 59th (World Intellectual Property Organization 2023a). Generally, the country is noted to be performing well, particularly in terms of innovation outputs. While this innovation may be key for growth, the growth must be inclusive, which may be achieved through innovation policies.

One other policy intervention we consider in this study is monetary policy. Monetary policy has not traditionally been directly associated with inequality. However, this notion has since shifted. Following the 2007–8 global financial crisis and the emergence of new monetary policy tools, the possible bidirectional relationship between inequality and monetary policy has become topical (Borio 2021). This has increased attention on the need to account for the heterogeneity of economic agents in macroeconomic modelling. In South Africa, the monetary policy mandate is to achieve price stability, meant to support balanced and sustainable economic growth. The South African Reserve Bank operates within an inflation-targeting framework primarily, aiming to keep inflation within a target range of 3% to 6%. Although the central bank does not primarily focus on economic growth and redistribution, it is important to consider these in its overall mandate to achieve a conducive economic environment.

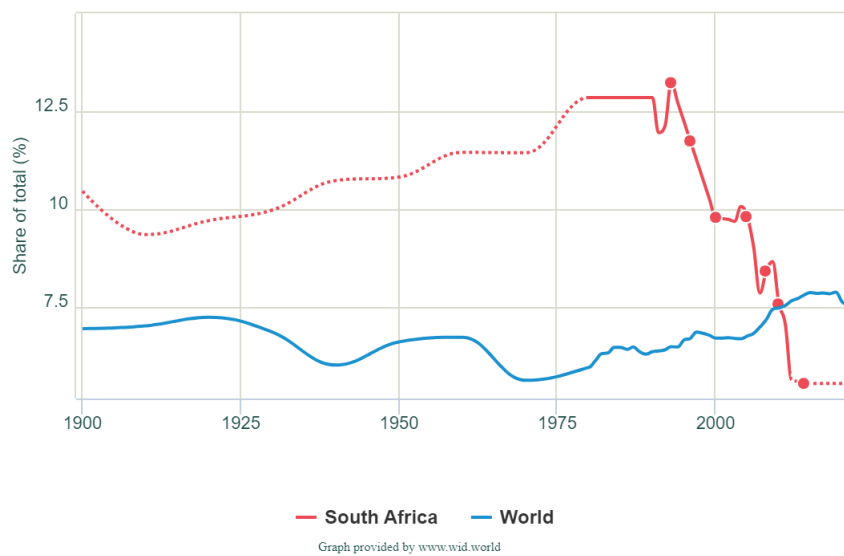
The policy and interventions discussed are primarily efforts towards achieving macroeconomic growth, but their impact on investment and growth may further influence redistribution.

**Figure 1: Income distribution**

**Top 10% national income share**



**Bottom 50% national income share**



Source: World Inequality Database (WID) <https://wid.world/>.

## 4 Model

We adopt a monetary Schumpeterian growth model. We extend the standard model in Aghion and Howitt (2008) and Grossman and Helpman (1991) by introducing agent heterogeneity through two types of households, and including money as in Chu and Cozzi (2014). The economy is characterized by a continuum of households comprised of either capitalists or workers, where the latter have no access to the capital market. Monetary policy is introduced through a CIA constraint on R&D investment and nominal interest as the monetary policy instrument. Patent breadth is also considered an R&D policy instrument that aids innovation by protecting against imitations (Goh and Olivier 2002).

### 4.1 Households

There is a continuum of households represented by a unit interval. There are two types of agents in the economy that we refer to as capitalists and workers (Broer et al. 2020; Debor-toli and Galí 2017). Capitalists have access to capital markets and constitute a time-invariant subset of households. Worker households are comprised of agents that supply labour to earn income but do not participate in the capital market.

Household intertemporal preference is similar between both agents and given by

$$U = \int_0^{\infty} e^{-\rho t} \ln c \, dt, \quad (1)$$

where  $c$  is consumption and  $\rho > 0$  is the subjective discount rate.<sup>2</sup>

#### Capitalist household

A fraction,  $h$ , of households participate in the asset market. They own the intermediate good-producing firms and capital in the economy. The capitalist budget constraint is given as follows:

$$c_c + \dot{a} + \dot{m}_c = ra - \pi m_c + \tau_c + ib, \quad (2)$$

where  $a$  denotes the assets in the form of capital stock and the value of firms owned by the capitalists. The rate of return on assets and the inflation rate, which is the cost of money holding, are denoted by  $r$  and  $\pi = \dot{P}/P$ , respectively, where  $P$  is the price of the final good. Capitalist households receive a lump sum transfer,  $\tau_c$ , from the government.  $m = M/P$  is the real money holdings of the household,  $b$  is the amount of real money lent by households to entrepreneurs to finance R&D investment, and  $i$  is the nominal return on money lending. We sup-

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<sup>2</sup> We suppose that capitalists do not supply labour. An alternative is to attach a fixed cost of labour provision explicitly in their utility function (see Broer et al. 2020).

pose that cash is required to finance R&D and a fraction of consumption, following Chu and Cozzi (2014), such that

$$b + \xi_c c_c \leq m_c. \quad (3)$$

Capitalists maximize their utility in (1), subject to (2) and (3). From standard dynamic optimization we get the Euler equation (see Appendix A),

$$\frac{\dot{c}_c}{c_c} = r - \rho, \quad (4)$$

and the no-arbitrage condition between assets,  $a$ , and money holding,  $m_c$ , which implies the Fisher equation,

$$i = r + \pi. \quad (5)$$

This condition implies that the real return on money must be equal to the real rate of return on assets.

### Worker household

The remaining  $(1 - h)$  fraction of households in the economy are the workers. Workers supply labour to earn a wage and do not participate in the capital market. Workers are hand-to-mouth consumers such that

$$c_w = wl + \tau_w, \quad (6)$$

where  $l$  is labour supply and  $w$  is the real wage rate, which is determined by a labour union. We assume a constant population growth rate and standardize labour to unity. Workers also receive a lump sum transfer,  $\tau_w$ , which finances a fraction of their consumption based on the cash requirement:

$$\xi_w c_w \leq m_w. \quad (7)$$

## 4.2 Monetary authority

The monetary authority exogenously sets the nominal interest rate, denoted as  $i$ , which serves as the policy instrument. The aggregate nominal money balance is  $M \equiv Pm$ . Inflation, denoted as  $\pi \equiv \dot{P}/P$ , is determined by the Fisher equation in (5), given that the monetary authority exogenously sets the nominal interest rate. The growth rate of the aggregate nominal money bal-

ance is given as follows:

$$g_M \equiv \frac{\dot{M}}{M} = \pi + \frac{\dot{m}}{m}. \quad (8)$$

The government earns seigniorage revenue, which finances transfers  $\tau$  to households. The government budget is balanced and given as follows:

$$\tau = \frac{\dot{M}}{P} \frac{M}{M} = m g_M, \quad (9)$$

where  $g_M$  is given in (8). Thus, the government provides the revenue from seigniorage as a lump sum transfer to the capitalist and worker households.

### 4.3 Final goods

Final goods,  $y$ , are produced in a perfectly competitive sector using a continuum of intermediate goods,  $j \in [0, 1]$ . Following Chu and Cozzi (2014), we suppose the following Cobb–Douglas production function:

$$y = \exp \left[ \int_0^1 \ln x_j dj \right], \quad (10)$$

where  $x_j$  denotes the quantity of intermediate good  $j$ . Profit maximization in the final goods sector yields the following condition:

$$x_j = \frac{y}{p_j}, \quad (11)$$

where  $p_j$  denotes the price of the  $j$ th intermediate good. Equation (11) is the inverse demand for the  $j$ th intermediate good.

### 4.4 Intermediate goods

There is a unit of continuum,  $j \in [0, 1]$ , of industries that produce the differentiated intermediate goods. In each industry a temporary monopolistic leader exists until the arrival of the next innovation. The current leader's production function is given as follows:

$$x_j = (q^{\nu_j} l_j)^{1-\alpha} k_j^\alpha, \quad (12)$$

where  $k_j$  is physical capital rented at a price of  $R = r + \delta$  and  $\delta$  is the capital depreciation rate.  $q > 1$  denotes the quality increment of an innovation and  $\nu_j$  is the number of innovations of the  $j$ th variety at time  $t$ . The total cost of producing the  $j$ th intermediate good is  $TC_j = R_t k_j + w_t l_j$

and cost minimization yields

$$\frac{k}{l} = \frac{\alpha}{1-\alpha} \frac{w}{R}, \quad (13)$$

where  $k \equiv \int_0^1 k_j dj$  and  $l \equiv \int_0^1 l_j dj$  are the aggregate capital input and labour supply, respectively. The marginal cost of the monopolistic producer is given by

$$mc_j = \left( \frac{1}{q^{\nu_j}} \right)^{1-\alpha} \left( \frac{R}{\alpha} \right)^{\alpha} \left( \frac{w}{1-\alpha} \right)^{1-\alpha}. \quad (14)$$

Current and previous industry leaders participate in Bertrand competition. Following Goh and Olivier (2002), Iwasako and Futagami (2013), and Li (2001), patent breadth is introduced as a policy instrument determined by a patent authority, which determines the markup added over the marginal cost. The profit-maximizing price of the present leader is thus given by

$$p_j = \mu mc_j, \quad (15)$$

where  $\mu > 1$  is the markup. The existence of monopolistic profits invites possible imitations, which constrain monopolistic markups; therefore, an expanded patent scope effectively increases copycat costs, enabling monopolistic producers to impose a larger markup as outlined by Gilbert and Shapiro (1990), who define breadth as ability to increase price by the patent holder.<sup>3</sup> Using (11) and (15), the cost of producing  $x_j$  is the same across the industry. We obtain the prices of capital and labour respectively from (12), (13), and (14):

$$R = \frac{\alpha y}{\mu k}, \quad (16a)$$

$$w = \frac{(1-\alpha) y}{\mu l}. \quad (16b)$$

It follows that the monopoly profit is given by

$$\Pi = \left( \frac{\mu-1}{\mu} \right) y, \quad (17)$$

which is identical across the intermediate goods sector and the industry, given that all costs are symmetrical.

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<sup>3</sup> The ability of patent holders to restrict competition and preserve their market shares is directly related to the breadth of their patents and affects their profitability. By limiting market access and enabling the holders to charge higher prices inside the protected technology fields, larger patents provide them with more influence over pricing.

## 4.5 Innovation and R&D

The value of an industry's monopolistic firm is denoted by  $v$ , which is symmetrical given identical profit across firms.<sup>4</sup> The no-arbitrage condition for  $v$  is given by

$$r = \frac{\Pi + \dot{v} - \lambda v}{v}, \quad (18)$$

where  $\lambda$  is the aggregate Poisson arrival rate. The no-arbitrage condition shows that the return on each asset value equals the sum of profits,  $\Pi$ , potential capital gain,  $\dot{v}$ , and loss from creative destruction,  $\lambda v$ .

Entrepreneurs employ  $F$  units of final goods to engage in R&D. The arrival rate of innovation is proportional to the resources devoted to R&D such that

$$\lambda = \frac{\phi F}{Q}, \quad (19)$$

where  $\phi > 0$  is R&D productivity and  $Q$  is aggregate technology. Equation (19) shows that  $\lambda$  is decreasing in  $Q$ , highlighting the complex relationship between aggregate technology and the probability of successfully achieving an updated innovation.

To aid payment of a fraction,  $\theta \in (0, 1)$ , of R&D costs, the entrepreneur borrows cash from capitalist households amounting to  $b = \theta F$ .<sup>5</sup> The borrowing cost is  $i$ , such that the total cost of R&D is  $(1 + \theta i)F$ . Free entry into R&D implies that the expected profits from R&D investment are equal to zero such that the marginal cost equals the marginal benefit:

$$\lambda v = (1 + \theta i)F. \quad (20)$$

This highlights how the monetary authority can influence equilibrium outcomes through the CIA constraint on R&D by adjusting the nominal interest rate.

Substituting (19) into (20) yields

$$\phi v = (1 + \theta i)Q, \quad (21)$$

which implies that each innovation's value is proportional to technology,  $Q$ .

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<sup>4</sup> We adopt the standard approach in the literature. See, for instance, Cozzi et al. (2007), which outlines the theoretical justification and extends the discussion on symmetric equilibrium.

<sup>5</sup> See Chu and Cozzi (2014) and Huang et al. (2017) for similar setups.



## 4.6 Decentralized equilibrium

Equilibrium in this economy outlines the time path of allocations  $\{c_w, c_c, c, m_w, m_c, m, l, y, x_j, k_j, F, a\}$ , prices  $\{r, w, p, v, p_j\}$ , and policies  $\{\tau, \mu\}$  that satisfy the following conditions:

- Capitalists maximize utility taking  $\{r\}$  as given, and workers consume the full amount of their income and the government transfer.
- Competitive final good firms produce  $\{y\}$  using  $\{x\}$  to maximize profit, taking  $\{p\}$  as given.
- Monopolistic firms produce differentiated intermediate goods using  $\{k, l\}$  and choose  $\{p_j\}$  contingent on the patent breadth level,  $\mu$ , to maximize profit, taking  $\{R, w\}$  as given.
- Competitive R&D entrepreneurs invest  $\{F\}$  to maximize profit, taking the value of blueprints  $\{v\}$  as given.
- The money market clears such that  $m = m_c + m_w$  given that  $m_c = b + \xi_c c_c$ ,  $b = \theta F$ , and  $m_w = \xi_w c_w$ .
- The labour market clears such that  $\int_0^{1-h} l_i di = l = 1$ .
- The market clearing condition for final goods is given by  $y = c + F + \dot{k} + (\delta + \pi)k$ .
- The value of assets equals the sum of tangible and intangible assets,  $a = k + v$ .
- The central bank, as the monetary authority, balances its budget following  $\tau = g_M m = \tau_w + \tau_c$ .

## 4.7 Aggregate dynamics

Aggregate output is derived by substituting (12) into (10),

$$y = k^\alpha Q^{1-\alpha}, \quad (22)$$

where  $l = 1$  and  $Q$  is aggregate technology given by

$$Q \equiv \exp \left( \int_0^1 \nu_j dj \ln q \right) = \exp \left( \int_0^t \lambda_s ds \ln q \right). \quad (23)$$

We apply the law of large numbers in the second equality. Taking the log of (23) and differentiating with respect to time yields

$$\frac{\dot{Q}}{Q} = \lambda \ln q, \quad (24)$$

which is the growth rate of aggregate technology.

The dynamics for aggregate output are derived from (22):

$$\frac{\dot{y}}{y} = \alpha \frac{\dot{k}}{k} + (1 - \alpha) \frac{\dot{Q}}{Q}. \quad (25)$$

Aggregate consumption is the sum of the total capitalists' and workers' consumption, given by

$$c = c_w + c_c. \quad (26)$$

The evolution of capitalist consumption is derived by substituting (16a) and (22) into (4):

$$\dot{c}_c = \left[ \frac{\alpha}{\mu} \left( \frac{Q}{k} \right)^{1-\alpha} - \delta - \rho \right] c_c. \quad (27)$$

Similarly, one gets the consumption rule of the workers by substituting (7) and (16b) into (6):

$$\dot{c}_w = \frac{(1 - \alpha)}{(1 - \xi_w) \mu} \dot{y}. \quad (28)$$

The dynamics of aggregate consumption are easily derived by taking the time derivative of (26), as follows:

$$\dot{c} = \dot{c}_c + \dot{c}_w.$$

We get capital dynamics from the economy-wide resource constraint, (22), and the money market clearing condition of the capitalist household:

$$\dot{k} = k^\alpha Q^{1-\alpha} - c - \frac{m_c - \xi_c c_c}{\theta} - (\delta + \pi)k \equiv \chi_k. \quad (29)$$

The dynamics for the values of the monopolistic firms are derived from (16a), (17), (18), (19), and the money market clearing condition:

$$\dot{v} = \left( \frac{\psi}{\theta} \frac{(m_c - \xi_c c_c)}{Q} + \frac{\alpha}{\mu} \left( \frac{y}{k} \right) - \delta \right) v - \left( \frac{\mu - 1}{\mu} \right) y \equiv \chi_v. \quad (30)$$

To derive the dynamics of the real money holding of the capitalist, we substitute  $b = m_c - \xi_c c_c$ ,  $\tau_c = m_c$ , and  $a = k + v$  into the capitalist's CIA constraint (2):

$$\dot{m}_c = r(k + v) + (1 + r)m_c - (1 + i\xi_c)c_c - (\chi_k + \chi_v), \quad (31)$$

where  $\chi_k$  and  $\chi_v$  denote the right-hand sides of (29) and (30) respectively. Real money holding dynamics for the worker are derived from (7) and (16b):

$$\dot{m}_w = \frac{\xi_w(1 - \alpha)}{(1 - \xi_w)\mu} \dot{y}. \quad (32)$$

Therefore, the evolution of our economy is determined by the system of equations that consists of the dynamics of  $y$ ,  $k$ ,  $Q$ ,  $v$ ,  $c_c$ ,  $c_w$ ,  $m_w$ , and  $m_c$ . Namely, these are (24), (25), and (27)–(32).

## 5 Balanced growth path and welfare

Given that the nominal interest rate,  $i$ , is constant, the real interest rate is also stationary, and the economy jumps to a balanced growth path where all real aggregate variables  $y$ ,  $k$ ,  $Q$ ,  $\pi$ ,  $w$ ,  $m_c$ ,  $m$ ,  $m_w$ ,  $F$ ,  $c_w$ ,  $c_c$ , and  $c$  grow at the same constant rate:

$$g = r - \rho, \quad (33)$$

where  $g$  is the balanced path growth rate. Substituting (5) and (33) into (8) and using (4), one immediately sees that that nominal money growth ( $g_M$ ) in the balanced growth path is determined by the nominal interest rate:

$$g_M = i - \rho. \quad (34)$$

Equation (34) is the Euler equation version of nominal money growth, which is comparable to (33), the Euler equation for real money growth. Combining (34) with (9), we get the long-run equilibrium government transfer:

$$\tau = (i - \rho)m. \quad (35)$$

From (17), (18), (21), (22), and (33), one derives the steady-state arrival rate of innovation, which drives the long-run growth rate of the economy:

$$\lambda = \left( \frac{\phi}{1 + \theta i} \right) \left( \frac{\mu - 1}{\mu} \right) (\bar{k})^\alpha - \rho, \quad (36)$$

where  $\bar{k} \equiv k/Q$  is the per capita capital in effective labour, and is given by, from (16a), (22), and (33),

$$\bar{k} = \left( \frac{\alpha}{\mu(g + \rho + \delta)} \right)^{1/(1-\alpha)}. \quad (37)$$

From (24), (36), and (37), we get the economy's long-run growth rate, implicitly defined as

$$\Omega \equiv \left[ \left( \frac{\phi}{1+\theta i} \right) \left( \frac{\mu-1}{\mu} \right) \left( \frac{\alpha}{\mu(g+\rho+\delta)} \right)^{\alpha/(1-\alpha)} - \rho \right] \ln q - g. \quad (38)$$

From (36), we note that the arrival rate, which is the main determinant of the economy's long-run growth, is affected by policy. Particularly, patent breadth ( $\mu$ ) and the nominal interest rate ( $i$ ) are among the major determinants of  $\lambda$ . Long-run growth is thus a function of both the nominal interest and the patent breadth.

## 5.1 Welfare

Aggregate welfare is given as

$$W = W_c + W_w, \quad (39)$$

where  $W_c = \int_0^\infty \ln c_c e^{-\rho t} dt$  and  $W_w = \int_0^\infty \ln c_w e^{-\rho t} dt$  are the welfare functions associated with capitalists and workers, respectively, and are derived in Appendix C:

$$W_w = \left( \ln \frac{1-\alpha}{(1-\xi_w)\mu} + (\alpha-1) \ln \bar{k} \right) \frac{1}{\rho} + \frac{\ln k_0}{\rho} + \frac{g}{\rho^2}, \quad (40a)$$

$$W_c = \frac{\ln \bar{c}_c - \ln \bar{k}}{\rho} + \frac{\ln k_0}{\rho} + \frac{g}{\rho^2}, \quad (40b)$$

where  $g$ ,  $\bar{k}$ , and  $\bar{c}_c$  are defined in (38), (37), and (B3);  $k_0$  is the initial capital stock.

## 6 Consumption inequality

Inequality in this economy can be expressed as inequality between the workers' and the capitalists' consumption. We define consumption inequality ( $I$ ) based on the consumption ratio between workers and capitalists:

$$I = 1 - \frac{c_w^p}{c_c^p}, \quad (41)$$

where  $c_c^p \equiv c_c/h$  and  $c_w^p \equiv c_w/(1-h)$  is the per capita consumption associated with the representative capitalist and worker in the economy, respectively. We derive the worker's consumption from (22) and (28) such that

$$c_w = \frac{1-\alpha}{(1-\xi_w)\mu} \bar{k}^\alpha Q. \quad (42a)$$

With respect to capitalist consumption, we have (see Appendix B)

$$c_c = [\rho(k + v) + (1 + \rho)b] (1 + \xi_c(i - (1 + \rho)))^{-1}. \quad (42b)$$

Substituting (42a) and (42b) into (41), we obtain the inequality index:

$$I = 1 - \frac{h(1 - \alpha)(1 + (i - (1 + \rho))\xi_c)\bar{k}^\alpha}{\mu(1 - \xi_w)(\rho(\bar{k} + \bar{v}) + (1 + \rho)\bar{b})(1 - h)}, \quad (43)$$

where  $\bar{k}$  is given in (37),  $\bar{v} \equiv v/Q$ , and  $\bar{b} \equiv b/Q$  (see Appendix B). Thus, the nominal interest rate and the patent breadth are important determinants of consumption inequality in the economy, which we will look into in more detail in the next section.

## 7 Quantitative analysis

In this section we quantitatively examine the effects of patent protection policy and monetary policy on growth and inequality. We start by calibrating the parameters for the South African economy, which are summarized in Table 1.

**Table 1: Parameter values and targeted moments**

| Parameters  |        | Targeted moments                   |        |
|---|--------|------------------------------------|--------|
| Subjective discount rate, $\rho$                  | 0.05   | Innovation arrival rate, $\lambda$ | 5.19%  |
| Share of capital, $\alpha$                        | 0.33   | Economic growth rate, $g$          | 1.45%  |
| Depreciation rate, $\delta$                       | 0.04   | Average inflation, $\pi$           | 6.728% |
| Fraction of capitalists, $h$                      | 0.10   |                                    |        |
| CIA constraint on R&D, $\theta$                   | 1.00   |                                    |        |
| Markup, $\mu$                                     | 1.2740 |                                    |        |
| Nominal interest rate, $i$                        | 0.1318 |                                    |        |
| Quality step size, $q$                            | 1.3223 |                                    |        |
| R&D productivity, $\psi$                          | 0.3429 |                                    |        |
| Cash requirement for consumption, $\xi_c = \xi_w$ | 0.35   |                                    |        |

Source: References as detailed in Section 7.

### 7.1 Calibration

We set the discount rate,  $\rho$ , to 0.05 and the capital depreciation rate,  $\delta$ , to 0.04, following Rattsø and Stokke (2009). The share of capital is set at its standard value 0.33. As for the CIA constraint parameter,  $\theta$ , we follow Arawatari et al. (2018) and set it to unity. There is no direct estimate for  $h$ , the size of the capitalists. We set it at 0.1, which implies that only 10% of the population are entrepreneurs, for the benchmark value. In the current model workers are hand-to-mouth, which implies they have no wealth. But capitalists have wealth, which could be ac-

cumulated through capital stock holdings and firm value appreciation.<sup>6</sup> Therefore, the analysis is based on consumption inequality, which can be further extended to income inequality. However, given the possibility of wealth being concentrated among a small fraction of the population in our economy, our benchmark value aligns with how wealth is highly concentrated in South Africa. For instance, merely 10% of the population owns more than 80% of the national wealth (SA-TIED 2020).

We set the benchmark arrival rate at  $1/\lambda = 19.27$  years. Chu and Cozzi (2018) consider a value of 12.5% for the US from a wide range of values, 4%–33%, estimated by Acemoglu and Akcigit (2012) and Caballero and Jaffe (1993). We rather consider the much lower value of 5.19%, which implies a longer arrival rate. The long-run growth rate in South Africa over 1994–2018 is approximately 1.45% (Feenstra et al. 2021). Considering this, and from (24), we can calibrate the quality step size parameter,  $q = 1.3223$ . The average inflation rate ( $\pi$ ) in South Africa for the period 1994–2018 is 6.728% (World Bank 2024). This implies, together with the Euler and Fisher equations, (4) and (5), a nominal interest rate of 13.18%.

**Figure 2: Patent strength index for South Africa**



Source: Based on data from Ginarte and Park (1997) and Park (2008).

Ginarte and Park (1997) and Park (2008) established the Ginarte–Park Index (GPI) ranging between 0 and 5, which measures the strength of patent protection. Figure 2 outlines this index for South Africa from 1960 to 2005, when the last data was available. We calibrate the level of patent protection,  $\mu$ , at an average of 1.274, which is the log of the average of the GPI.

<sup>6</sup> Capital is not fully depreciated in the current setup.

We then calibrate the R&D productivity parameter at  $\psi = 0.3429$  using (36) and (37). According to the South African Reserve Bank (2023), cash usage constitutes 56% of transaction volume and 21% of transaction value. We thus set the fraction of consumption purchased using cash as  $\xi_c = \xi_w = 35\%$ .

## 7.2 Effects of monetary and patent policy on the macroeconomy

Here, we conduct a policy experiment by varying the nominal interest rate and patent breadth from their baseline values as reported in Table 1.<sup>7</sup> Table 2 provides the impact on growth, consumption inequality, innovation arrival rate, consumption–income ratio, capital–output ratio, firm value, and welfare. A one percentage point (ppt) increase in patent breadth increases growth and consumption inequality by about 4.22% and 0.45% respectively, while it decreases the aggregate consumption–income ratio by about 0.03%. The consumption-to-income ratio of the workers decreases as income increases by a larger proportion following the productivity boost. However, for the capitalists, consumption-to-income ratio increases by 1.22%, which means capitalists’ consumption grows more than aggregate income, following an increase in patent breadth. The resultant effect is to decrease the aggregate consumption-to-income ratio.

**Table 2: Macroeconomic impact of policy changes**

|           | Baseline | Effect of<br>$\Delta\mu = 1 \text{ ppt}$ | Effect of<br>$\Delta i = 1\%$ |
|-----------|----------|--|-------------------------------|
| $g$       | 0.0145   | 4.2241                                   | −14.1673                      |
| $I$       | 0.8157   | 0.4462                                   | −1.4962                       |
| $\lambda$ | 0.0519   | 4.2267                                   | −14.1673                      |
| $c_w/y$   | 0.8091   | −0.7788                                  | 0                             |
| $c_c/y$   | 0.4879   | 1.2205                                   | −6.2125                       |
| $c/y$     | 1.2970   | −0.0267                                  | −2.3370                       |
| $k/y$     | 2.4788   | −1.3569                                  | 2.0050                        |
| $v/y$     | 3.3006   | 0  | 7.7766                        |
| $W_w$     | −16.5928 | 2.1808                                   | −7.3445                       |
| $W_c$     | −26.7090 | 2.8487                                   | −9.3655                       |
| $W$       | −43.3018 | 2.5927                                   | −8.5911                       |

Source: Authors’ results.

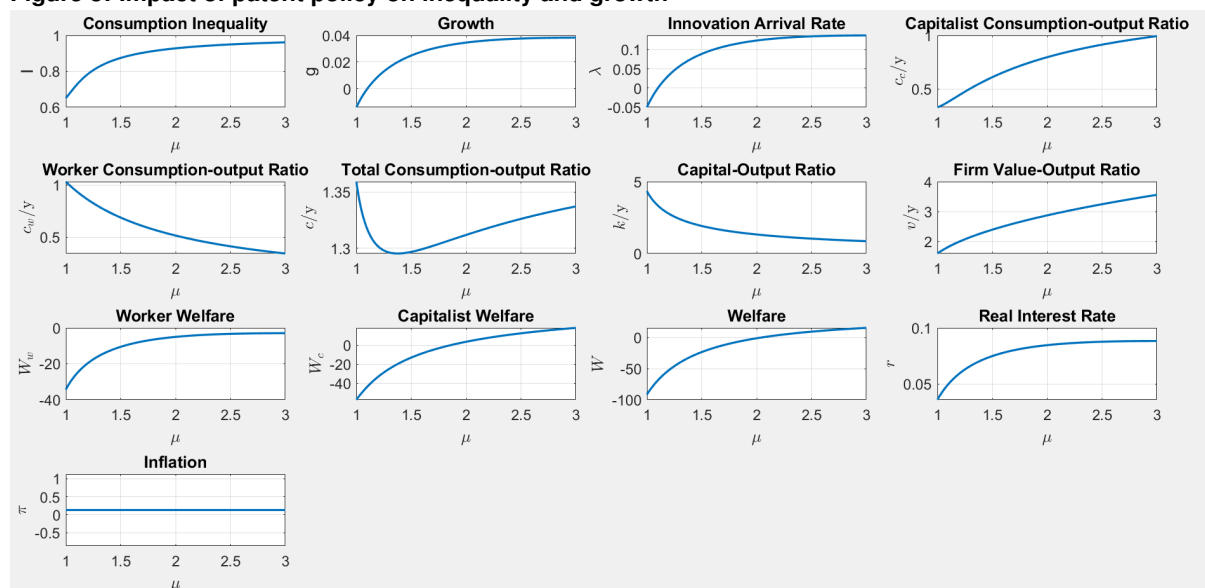
In contrast, a one percentage point increase in the nominal interest rate decreases growth by about 14.17% while it reduces consumption inequality by almost 1.5%. It has no impact on the consumption–income ratio of the workers, but it significantly decreases the consumption–income ratio of the capitalists by about 6.21%. Because workers do not participate in the asset market, their consumption and income composition is little affected. Any effect the policy

<sup>7</sup> Naturally, the South African Reserve Bank uses nominal interest rates as a tool to stabilize inflation and keep it within the inflation target; that is, changes to the inflation rate trigger changes in the nominal interest rate. In the current model, this mechanism is not in play; the only source of inflation is money growth. We thus treat the nominal interest rate as an exogenous policy variable and conduct policy experiments on how changes in this variable affect other macro variables.

change has on the wage rate will have the same effect on the national income. For capitalists, the change in the nominal interest rate leads to a change in the borrowing cost of R&D investment, further impacting profit and the value of intangible assets. Aggregate welfare improves by about 2.6% when patent breadth increases by one percentage point, whereas it decreases by about 8.59% following a percentage point increase in the nominal interest rate.

Figure 3 shows the impact of expanding patent breadth on the economy. The long-run growth rate of the economy increases in patent breadth. Stronger patent protection increases growth by encouraging agents to engage in R&D investment and innovation activities. We also see that strengthening patent policy increases consumption inequality. Increasing patent breadth leads to more exclusive rights for inventors for the stipulated period, which may lead to the concentration of wealth among the patent holders. Higher patent restrictions could decrease the opportunities for new entrants, limiting their benefits and access, and widening the income gap. The relationship between patent breadth and the aggregate consumption–output ratio is shown to be non-linear in Figure 3, which is the result of the contrasting effects of patent breadth in the capitalists’ and workers’ consumption-to-income ratios.

**Figure 3: Impact of patent policy on inequality and growth**



Source: Authors’ results.

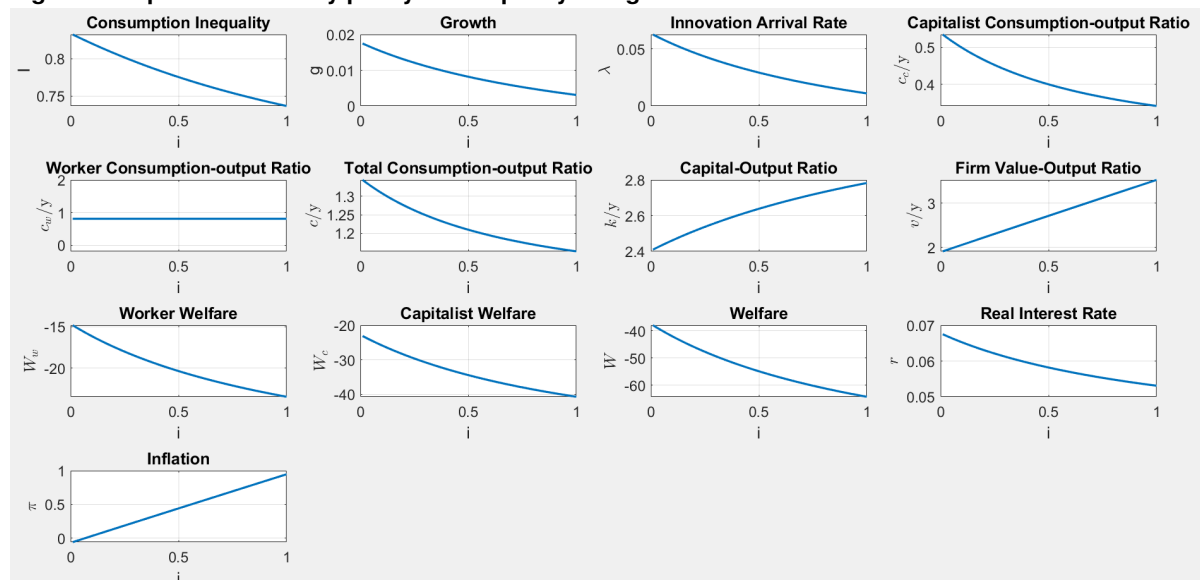
Furthermore, as patent breadth widens, the real interest rate rises, leading to an increase in growth (Eq. (33)). In endogenous growth models, the real interest rate is an endogenous variable, often reflecting capital or investment productivity. Therefore, a greater patent breadth may translate to higher productivity in R&D investment that helps to boost the innovation arrival rate and growth. The capital–output ratio decreases in patent breadth, which indicates a shift in the composition of investment. Aggregate welfare improves following an increase in patent protection. The increase in growth and output (benefits that arise from increased innovation) allows workers to have higher wages, leading to an increase in welfare for both the worker and capi-



talist households. However, capitalist households benefit disproportionately, as reflected in the increase in consumption inequality and the capitalist consumption–output ratio.

Figure 4 depicts the macroeconomic effects of increasing the nominal interest rate. An increase in the nominal interest rate implies an increase in the cost of borrowing, which constrains R&D funding and leads to a lower R&D investment.

**Figure 4: Impact of monetary policy on inequality and growth**



Source: Authors' results.

We also see in Figure 4 that consumption inequality decreases in the nominal interest rate,  $i$ . As only the capitalists have access to the financial market, the change in the nominal interest rate may disproportionately affect the capitalist households. A higher nominal interest rate increases the cost of R&D investment, reducing profits for the capitalists. This also means lower growth and, hence, lower workers' productivity, undermining the trickle-down effects of growth. Therefore, the net impact of increasing the nominal interest rate in our economy is to decrease both growth and inequality. This is intuitive as workers do not participate in the financial markets, where their cash-in-advance constraint is related to their hand-to-mouth consumption. Therefore, the only way inflation affects the poor is indirectly, through a negative impact on their productivity (growth); however, it directly impacts the capitalists who actively participate in the financial market. This leads to a disproportionate negative impact of inflation on the affluent ones. This result reveals a novel channel in the complex relationship between monetary policy and inequality. Inflation could reduce inequality not by making the poor better off (rather the opposite) but by making the rich worse off.

Following the increase in the nominal interest rate, the capitalists' consumption–output ratio declines while the workers' consumption–output ratio is constant, reflecting the disproportionate effects of the monetary policy on workers' and capitalists' consumption and income. The real interest rate changes marginally, though. The nominal interest rate increase mainly trans-

lates to a higher inflation rate (through the Fisher equation). Inflation increases almost on a one-to-one basis with an increase in nominal interest rate. The increase in the nominal interest rate also leads to a decrease in both the capitalists' and workers' welfare and, subsequently, to a decrease in aggregate welfare. This is mainly attributed to a decline in the economy's growth rate, negatively impacting workers' productivity and capitalists' profit.

## 8 Conclusion

This study examines the relationship between monetary and R&D policies, economic growth, and consumption inequality using the case of an emerging African economy. To do so, we develop a heterogeneous agent Schumpeterian growth model, with money introduced as cash-in-advance constraints required to finance R&D investment. There are two agents in the economy—capitalists and workers. Workers supply labour, have no access to the capital markets, are hand to mouth, and consume their entire income. Capitalists own the intermediate firms that innovate and produce the intermediate goods. The government uses seigniorage revenue to finance the R&D investment and consumption through cash transfers. The model is then calibrated to the South African economy—an upper middle-income African country—known for its consistently high level of inequality.

The study has multiple novel features. First, it expands on R&D-driven endogenous growth models by incorporating household heterogeneity and monetary policy, providing a richer understanding of how these policies affect growth and income distribution. Second, it addresses the relatively less-explored relationship between monetary policy and inequality, offering new insights into the redistributive effects of interest rates. Finally, by calibrating the model to the South African economy, the study offers policy-relevant insights for emerging markets grappling with persistent inequality and slow innovation-driven growth processes.

Among the findings, increasing patent breadth, such as strengthening patent protection, encourages innovation, which drives economic growth and welfare. Broader patent protection creates incentives to firms to engage in R&D activities, fostering technical progress. However, broader patent protection aggravates inequality and leads to a greater wealth concentration among a few entrepreneurs. We also note that growth decreases in nominal interest rates, as higher borrowing costs discourage investment and innovation, whereas the relationship between nominal interest rate and inequality is negative. The results also highlight a non-linear relationship between patent breadth and the consumption–output ratio. Higher nominal interest is found to have a distributional effect as it reduces consumption inequality. This finding highlights a new channel in the complex relationship between monetary policy and inequality. However, tightened monetary policy also leads to a decline in aggregate welfare since the shrinking

of the consumption gap results from the worsening of the capitalists' consumption rather than the improvement of the workers' consumption.

The work can be extended to include unemployment. South Africa is known for its high unemployment rate, which could be one important determining factor of its high level of income and wealth inequality. In particular, youth unemployment is alarmingly high in the country, reaching approximately 45% in 2024. There is some evidence that the country's high level of unemployment contributes to its soaring earnings inequality (Tregenna 2009). Traditionally, the macroeconomics literature treats unemployment as part of the business cycle problem, while inequality is often a persistent variable. However, given the high unemployment rate in the country, modelling unemployment in the South African context and studying its impact on the country's persistent income and wealth inequality could present a compelling area for further research.

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## Appendix

### A Household dynamic optimization

In this section we derive the first-order conditions for the capitalist household problem. The associated Hamiltonian is given by

$$H = U(c) + \lambda(ra + ib + \tau - \pi m_c - c_c) + \eta(m - b - \xi c_c).$$

The first-order conditions are given as follows:

$$\frac{1}{c_c} = \lambda + \eta\xi, \quad (\text{A1})$$

$$\lambda i = \eta, \quad (\text{A2})$$

$$\lambda r = \rho\lambda - \dot{\lambda}, \quad (\text{A3})$$

$$-\pi\lambda + \eta = \rho\lambda - \dot{\lambda}. \quad (\text{A4})$$

Combining (A2), (A3), and (A4) gives the Fisher equation. From (A1), (A2), and (A3), we get the Euler equation.

### B Capitalist consumption

We compute  $\bar{c}_c$  as follows. Firstly, from (31) and the balanced growth conditions we get

$$(1 + i\xi_c)c_c = (g + \rho)(k + v) + (1 + g + \rho)m_c - \dot{m}_c - (\dot{k} + \dot{v}), \quad (\text{B1})$$

which we divide by  $Q$  to get

$$(1 + i\xi_c)\bar{c}_c = \rho(\bar{k} + \bar{v}) + (1 + \rho)\bar{m}_c. \quad (\text{B2})$$

Given that  $\bar{m}_c = \bar{b} + \xi_c\bar{c}_c$ , we substitute into the above to obtain

$$\bar{c}_c = [\rho(\bar{k} + \bar{v}) + (1 + \rho)\bar{b}] (1 + \xi_c(i - (1 + \rho)))^{-1}, \quad (\text{B3})$$

where  $\bar{k}$  is given in (37). Then, using (19) and (21) respectively, we obtain

$$\begin{aligned} \bar{b} &= \frac{b}{Q} \equiv \frac{\lambda\theta}{\psi}, \\ \bar{v} &= \frac{v}{Q} \equiv \frac{(1 + \theta i)}{\psi}. \end{aligned}$$



## C Welfare

In this section we derive the welfare functions for the capitalists and workers in the balanced growth path. Aggregate welfare is the sum of the two, and is given by

$$W = W_{c_c} + W_{c_w} = \int_0^\infty e^{-\rho t} \ln c_c dt + \int_0^\infty e^{-\rho t} \ln c_w dt. \quad (C1)$$

From (22) and (28), we get the welfare function for the workers:

$$W_w = \int_0^\infty e^{-\rho t} \ln \left( \frac{(1-\alpha)\bar{k}^\alpha Q}{\mu(1-\xi_w)} \right) dt.$$

Substituting  $Q = \bar{k}^{-1}k = \bar{k}^{-1}k_0 e^{gt}$  into the above, and noting that  $\bar{k}$  is constant in the balanced growth path, we get

$$W_w = \ln \left( \frac{1-\alpha}{(1-\xi_w)\mu} + (\alpha-1) \ln \bar{k} \right) \frac{1}{\rho} + \frac{\ln k_0}{\rho} + \frac{g}{\rho^2}. \quad (C2)$$

With respect to the capitalists' welfare we have  $W_c = \int_0^\infty e^{-\rho t} \ln c_c dt$ , which we can rewrite as

$$W_c = \int_0^\infty e^{-\rho t} \ln (\bar{c}_c \bar{k}^{-1} k_0 e^{gt}) dt,$$

considering that  $c_c = \bar{c}_c \bar{k}^{-1} k = \bar{c}_c \bar{k}^{-1} k_0 e^{gt}$ . But  $\bar{c}_c$  and  $\bar{k}$  are constant in the balanced growth path and defined in (B3) and (37), whereas  $k_0$  is given. This implies that

$$W_c = \frac{\ln \bar{c}_c - \ln \bar{k}}{\rho} + \frac{\ln k_0}{\rho} + \frac{g}{\rho^2}. \quad (C3)$$