Slow Recoveries, Endogenous Growth and Macro-prudential Policy*†

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June 2023

Abstract

Financial crises have severe short and long-term consequences. We develop a general equilibrium model with financial frictions and endogenous growth in which macro-prudential policy supports economic activity and productivity growth by strengthening the resilience of financial intermediaries to adverse shocks. The improved intermediation capacity of a safer financial system leads to a higher steady-state growth rate. The optimal capital ratio increases welfare by 8%, one order of magnitude more than in the case without endogenous growth.

JEL Codes: E32, E44, E52, G01, G18

Keywords: Slow Recoveries, Endogenous Growth, Financial Stability, Macro-prudential Policy

*We would like to thank Andrea Tambalotti, two anonymous referees, Ambrogio Cesa-Bianchi, Mark Gertler, Oliver de Groot, Richard Harrison, Daisuke Ikeda, Michel Juillard, Gabor Pinter, Lukasz Rachel, and Maarten de Ridder for detailed comments, Albert Queralto for sharing his data set and codes, as well as seminar participants at the Bank of England for invaluable comments and suggestions. We would also like to thank an anonymous referee of the Bank of England SWP series for their helpful comments.

†The views expressed in this paper are those of the authors and not necessarily those of the Bank of England or its committees.

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1 Introduction

This paper investigates the role of macro-prudential policy in mitigating the short- and long-term effects of adverse financial shocks. Following the 2007/08 Global Financial Crisis, many advanced economies experienced slow recoveries, failing to revert to pre-crisis growth trends. These sustained output losses have been attributed to a decline in productivity-enhancing investments and slower adoption of new technologies (e.g. Anzoategui et al. (2019)). These findings underscore the significance of considering innovation and productivity growth as endogenous outcomes. Recent studies have examined the implications of monetary policy in an environment with endogenous growth, integrating short-term business cycle dynamics with medium-term growth dynamics (see, e.g., Moran and Queralto (2018) and Ikeda and Kurozumi (2019)). However, the potential long-term benefits of macro-prudential policy within a Dynamic Stochastic General Equilibrium (DSGE) framework have not yet been explored in the literature. This paper aims to fill this gap by being the first to study macro-prudential policy in a medium-scale model incorporating financial frictions and endogenous growth. The prevailing theoretical literature suggests that the welfare gains from macro-prudential policy are relatively modest, as most models struggle to generate slow recoveries and permanent effects following financial disruptions. However, our paper shows that the welfare gains from macro-prudential policy can be significantly larger when considering not only the stabilisation of output fluctuations but also the stabilisation of the overall growth path.

To provide a foundation for the theoretical investigation, we carry out a Structural Vector Autoregressive analysis for the US, which reveals that financial shocks lead to a lasting decline in macroeconomic activity, innovation, and productivity. The paper's theoretical model incorporates a financial sector based on Gertler et al. (2012), where financial intermediaries (FIs) rely on non-state-contingent short-term debt and outside equity for funding. The cost of outside equity is contingent upon the state of the world and moves in line with the return on assets. Consequently, the risk exposure of FIs is determined by their financing choices. FIs take asset prices as given, and their reliance on outside equity is inefficiently low. Within this framework, macro-prudential policy is modelled as a subsidy on outside equity, enhancing the resilience of FIs to asset price changes and mitigating the propagation of shocks through the financial accelerator mechanism. This approach captures two important real-world aspects: discouraging excessive debt accumulation by intermediaries, especially during economic downturns, and countercyclical intervention, aligning with the regulatory frameworks of many countries. The paper highlights that macro-prudential policy's effectiveness is not solely dependent on stabilising output fluctuations but also on stabilising the long-term growth path itself.

Another crucial feature of the model is an endogenous growth mechanism à la Grossman and Helpman (1991) and Aghion and Howitt (1992). Productivity is influenced by the aggregate level of R&D services, allowing business cycle shocks to affect long-run growth. Financial shocks in this framework lead to significant declines in output and investment in both physical capital and R&D, resulting in a temporary reduction in productivity growth and an output decline without full recovery. By facilitating credit flows towards physical capital and R&D investment, macro-prudential policy positively impacts productivity growth and the long-term level of real economic activity. Consequently, compared to the previous literature, which mainly focused on the short-term benefits of macro-prudential policy, our analysis suggests that a more aggressive policy stance may be justified.

The key findings of the paper are as follows: First, macro-prudential policy can alleviate permanent output losses resulting from financial shocks. Second, the optimal simple macro-prudential policy rule suggests a capital ratio of 20%, 4 percentage points higher than in a version of the model with exogenous growth. Finally, the paper establishes significant welfare gains from macro-prudential policy, with consumption-equivalent welfare gains estimated at approximately 8%, which is considerably larger than in previous studies. This result is explained by the fact that an optimal simple macro-prudential policy rule enhances the economy's steady-state growth rate, significantly impacting household lifetime utility, which serves as a measure of welfare. These findings emphasise the importance of considering medium and long-term economic prospects when designing appropriate macro-prudential policies. Such policies can play a crucial role in promoting financial stability and productivity growth. However, it is essential to avoid excessive regulation of financial intermediaries, as it can lead to inefficiency and hinder potential productivity growth.

1.1 Related Literature

Our paper contributes to three distinct strands of literature, namely: (i) the literature on endogenous growth and slow recoveries, (ii) the literature on the relationship between financial conditions and research and development (R&D), and (iii) the literature on financial frictions, specifically focusing on endogenous bank balance sheet determination with debt and equity as forms of bank finance.

Endogenous Growth In the field of endogenous growth, two main approaches have been developed. The first approach, known as the expanding variety approach or "horizontal innovation," was pioneered by Romer (1986) and Romer (1990). Comin and Gertler (2006) incorporate this mechanism of endogenous growth into a standard business cycle macro model. Building upon this work, Anzoategui et al. (2019) find that a significant portion of the decline in productivity after the Great Recession was endogenous, indicating the role of demand factors in the post-crisis slowdown. Benigno and Fornaro (2018) analyse how animal spirits can create a long-lasting liquidity trap in a New Keynesian growth model with multiple equilibria. Queralto (2020) includes endogenous growth in a model with financial frictions and demonstrates that such frictions amplify medium-run total factor productivity (TFP) and output losses following a crisis. Moran and Queralto (2018) incorporate endogenous growth into a New Keynesian model and find substantial TFP losses due to the constraints on monetary policy imposed by the zero lower bound. Ikeda and Kurozumi (2019) develop a model with endogenous TFP growth, where adverse financial shocks lead to slow recoveries. Their welfare-maximising monetary policy rule places a strong emphasis on output stabilisation, with larger welfare gains compared to an exogenous TFP trend. Ma (2020) investigates the impact of macro-prudential policy in a small open economy model with endogenous growth and occasionally binding collateral constraints. His findings highlight the substantial welfare implications of changes in the growth rate.[1]

The second approach to endogenous growth, referred to as "vertical innovation" or Schumpeterian creative destruction, was introduced by Aghion and Howitt (1992). Kung (2015) incorporates this endogenous growth mechanism into a basic New Keynesian model with recursive preferences to explain key stylised facts in bond markets. Bianchi et al. (2019) build upon this work and analyse the effects of financial shocks, demonstrating their potential to significantly slow down productivity growth. Our

[1]While closely related to our paper, Ma (2020) implements macro-prudential policy as a tax on capital inflows, which leads to a *quantity* restriction on credit, reducing financial intermediation and lowering the available amount of resources that can be dedicated to enhancing productivity and growth. In our model, on the other hand, macro-prudential policy is modelled as a subsidy affecting the liability composition of banks and hence the safety and *quality* of financial intermediation. For this reason, unlike Ma (2020), we find that optimal macro-prudential policy leads to increased financial intermediation in steady state.

analysis considers a similar endogenous growth mechanism of vertical innovation because of its higher tractability compared to the horizontal innovation approach. Despite the differences in the two approaches to modelling endogenous growth (i.e., horizontal and vertical innovation), these differences would not affect our main result: financial shocks and demand shocks in general cause a decline in R&D, its utilisation or adoption, and a permanent fall in the level of macroeconomic activity.

Financial Conditions and R&D A growing literature provides evidence of the negative impact of tighter financial conditions on innovation and productivity. Among others, Aghion et al. (2010) shows that liquidity shocks lead firms to reduce long-term productivity-enhancing investments if credit constraints are tight. de Ridder (2019) uses a dataset on 522 US companies responsible for a significant portion of industrial R&D and finds that tight credit conditions resulted in reduced intangible investment between 2010 and 2015. Huber (2018) estimates a decline in innovation, firm size, and productivity following a reduction in lending by a large German bank. Li (2011) shows that financially constrained R&D-intensive firms are more likely to suspend R&D projects. Schmitz (2021) shows that credit tightness significantly affects small and young innovative firms, amplifying the adverse effects of financial crises on innovation.

Financial Frictions and Macro-prudential Policy Concerning the modelling of the financial sector, our paper builds on Gertler et al. (2012) (henceforth GKQ) by accounting for the long-term benefits of macro-prudential policy. Other papers that have used the GKQ setup are de Groot (2014), which examines how monetary policy affects the riskiness of banks' balance sheets, and Liu (2016), which investigates the welfare gains of various macro-prudential policy rules. Alternative approaches to modelling macro-prudential policy regulation are proposed in Gertler et al. (2020b), Ma (2020) and Begenau and Landvoigt (2022). These three papers present different models of macro-prudential policy, but they all share the common feature of a competitive equilibrium characterised by excessive risk (an inefficiently high crisis frequency). In such a context, macro-prudential policy can reduce risk and increase welfare, but it can also become excessively tight and diminish welfare. Our choice of following the approach in GKQ is primarily motivated by its transparency and tractability. Although our model is not solved with global solution methods, it can still capture the policy trade-off mentioned above with a second-order approximation around the risk-adjusted steady state. To sum up, our result that macro-prudential policy leads to significant welfare gains by stabilising economic activity in both the short and long term does not depend on the specific financial friction or solution method considered in this paper.[2]

Roadmap The remainder of the paper is organised as follows. Section 2 provides empirical evidence that financial shocks cause sharp and long-lasting declines in output, R&D investment, and TFP. Section 3 presents the model. In Section 4, we describe the solution method, calibration, and impulse response function. In Section 5, we discuss the impact of macro-prudential policy. Section 6 discusses how the model compares to the data and the empirical results. Finally, Section 7 presents some concluding remarks.

[2]An in-depth discussion of alternative approaches to modelling financial frictions and endogenous growth is provided in the online appendix, Section 3.7.

2 Empirical Evidence

To motivate our theoretical investigation, we conduct an SVAR analysis for the US economy to estimate the impact of financial shocks on the main macroeconomic aggregates, R&D investment, and total factor productivity.[3]

Our impulse response function (IRF) analysis extends beyond the typical horizon considered in the standard business cycle literature, encompassing 40 quarters. We specifically examine the impact of financial shocks on R&D investment, total factor productivity (TFP), and other key macroeconomic aggregates. Following Gilchrist and Zakrajsek (2012), we identify the shocks with a recursive scheme (i.e., Cholesky identification). Our VAR comprises 7 variables in the following order: (i) Excess Bond Premium; (ii) GDP, (iii) personal consumption in non-durables and services (Consumption); (iv) Durable Consumption and Private Fixed Investment excluding R&D Investment (Investment); (v) Private Fixed Investment in R&D; (vi) Total Factor Productivity (TFP) as measured by Fernald (2014); (vii) the GDP Implicit Price deflator, as a measure of the price level; (viii) the federal funds rate (FFR).

The excess bond premium (EBP) developed in Gilchrist and Zakrajsek (2012) captures investor attitudes toward corporate credit risk, reflecting credit market sentiment. GDP, consumption, investment, and R&D investment are expressed in logs, real per-capita terms. Further details on our data can be found in the online appendix, Section 2.1. To account for the monetary policy stance when the FFR reached the ZLB, our VAR includes the shadow rate developed by Wu and Xia (2016). The ordering described above implies that the EBP is not contemporaneously affected by the other macroeconomic variables, facilitating the comparability of results between the VAR and DSGE models. As a robustness check (see online appendix, Section 2.3), we also consider the same identification scheme as Gilchrist and Zakrajsek (2012), assuming the EBP to be contemporaneously impacted by all the variables in the VAR. We find the results to be only marginally affected. Data are at a quarterly frequency, spanning the period 1985Q1-2019Q4, and all variables that are available at a higher frequency are averaged over the quarter. We include four lags in our VAR. All variables, except the policy rate and the EBP, enter the VAR in log differences.

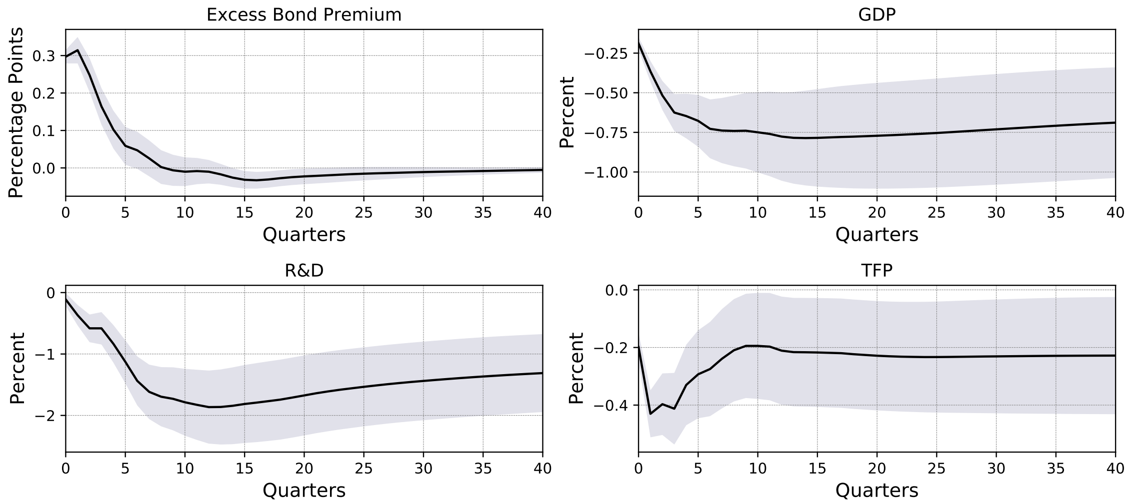
Evidence based on SVAR Figure 1 displays how the levels of EBP, GDP, R&D, and TFP respond to a one-standard-deviation financial shock. The IRFs of the other variables included in the VAR are left to the online appendix, Section 2.2. The solid lines represent the IRFs, while the shaded areas are 68% bootstrapped confidence intervals. An increase in the EBP reflects a reduction in the risk-bearing capacity of the financial sector, leading to a contraction in credit supply and a deterioration in macroeconomic conditions. Real GDP and R&D investment decline permanently by about 0.7% and 1.5%. Furthermore, the IRFs show a significant reduction in TFP, which falls by 1.5% on impact and 0.8% in the long term.

3 The Model

In this section, we discuss the main components of our model. The financial sector and the macroprudential policy are introduced in the spirit of GKQ. We extend their framework by including an endogenous growth mechanism of vertical innovation along the lines of Kung (2015) and Bianchi et al. (2019).

[3] In the online appendix, Section 1, we also present international empirical evidence on the negative relationship between banking crises, innovation, and productivity.

FIGURE 1: THE EFFECTS OF FINANCIAL SHOCKS IN THE US



Note: Black lines are the Impulse Responses to a Financial Shock. The IRFs of GDP, R&D, and TFP are cumulated. Grey-shaded areas are 68% confidence bands.

3.1 Households

There is a continuum of identical households defined on the unit interval. Within each household, there are $1-f$ workers and f financial intermediaries. Workers supply labour and return their wages to the household. Financial intermediaries channel funds to non-financial firms and transfer the associated profit back to the household. Within each household, there is perfect consumption insurance. Households can only save by supplying funds to financial intermediaries. In addition to non-state-contingent deposits D_t the household can also save by purchasing state-contingent outside equity E_t from financial intermediaries. The household lifetime utility $\mathcal{W}_t$ is given by the expected, discounted sum of period utilities $\mathcal{U}$ following the specification by Greenwood et al. (1988)

$$\mathcal{W}_t = \mathbf{E}_t \sum_{k=0}^{\infty} \beta^{t+k} \mathcal{U}_{t+k}, \quad \mathcal{U}_t = \frac{1}{1-\gamma}\left(C_t - h\Gamma_t C_{t-1} - \vartheta_t \frac{L_t^{1+\varphi}}{1+\varphi}\right)^{1-\gamma}, \quad \vartheta_t = \chi N_t.$$

The source of growth in our model is the accumulation of R&D, N_t. Its gross growth rate is defined as $\Gamma_t \equiv N_t/N_{t-1}$. We assume that the weight associated with the dis-utility of providing labour, ϑ_t, grows at the same rate as the economy itself.

C_t denotes the household's consumption basket, L_t denotes labour supply. β denotes the household discount factor, $\gamma > 1$ denotes the degree of risk-aversion, φ denotes the inverse Frisch elasticity, χ is the weight parameter associated with the dis-utility of labour supply and h is the parameter characterising internal habit formation.[4] Households choose C_t, L_t, nominal risk-free deposits D_t and outside equity E_t issued by the financial intermediary to maximise their lifetime utility subject to the sequence of budget constraints

$$P_t C_t + Q_t^E E_t + D_t \quad = \quad W_t L_t + \Xi_t - T_t + Q_{t-1}^E R_t^E E_{t-1} + R_{t-1}^D D_{t-1}.$$

W_t is the nominal wage, Ξ_t is a real transfer of net profits from the financial intermediaries and monop-

[4]This specification of habit formation allows us to detrend the period utility function.

olistically competitive firms to the household,[5] and T_t is a real lump-sum tax transfer. $\mathcal{R}_t^E$ denotes the flow returns at time t from one unit of equity and will be defined when discussing financial intermediaries. Q_t^E is the associated price of outside equity. Each unit of outside equity E_t is a claim to the future return on the portfolio of assets that the financial intermediary holds. R_t^D is the nominal gross deposit rate, while $\Pi_t \equiv P_t / P_{t-1}$ represents the gross inflation rate. Combining the household's inter-temporal optimality conditions gives rise to a standard no-arbitrage condition between investing in D_t and E_t

$$0 \quad = \quad \mathbf{E}_t \left[\Lambda_{t,t+1} \Pi_{t+1}^{-1} \left(R_t^D - R_{t+1}^E \right) \right] \tag{3.1}$$

where we defined the stochastic discount factor $\Lambda_{t,t+1} \equiv \beta \mathcal{U}_{C,t+1} / \mathcal{U}_{C,t}$, with $\mathcal{U}_{C,t}$ being the marginal utility of consumption at time t. A detailed derivation and full statement of the household optimality conditions can be found in the online appendix, Section 3.2.

3.2 Non-financial Firms

The three non-financial firms in this model are final output producers, intermediate output producers, and capital producers.

Final Output Producers Perfectly competitive final output producers purchase varieties of intermediate outputs $Y_{m,t}$, $m \in [0,1]$ at price $P_{m,t}$ and aggregate them into a final output Y_t. The demand schedule for intermediate output varieties is given by

$$Y_{m,t} = \left(\frac{P_{m,t}}{P_t} \right)^{-\frac{\mathcal{M}}{\mathcal{M}-1}} Y_t, \quad \text{where} \quad P_t \equiv \left(\int_0^1 (P_{m,t})^{\frac{1}{1-\mathcal{M}}} dm \right)^{1-\mathcal{M}},$$

where $\mathcal{M} \equiv \epsilon(\epsilon-1)^{-1}$ is the markup that intermediate output producers charge on top of their marginal costs, while ϵ is the elasticity of substitution between intermediate goods.

Intermediate Output Producers Intermediate output producers operate in a monopolitiscally competitive market. Each variety $Y_{m,t}$ is produced according to the production function

$$Y_{m,t} = \left(\varepsilon_t^K U_{m,t}^K K_{m,t} \right)^{\alpha} \left(\mathcal{X}_{m,t}^{LAP} L_{m,t} \right)^{1-\alpha}. \tag{3.2}$$

where ε_t^K denotes a physical capital quality shock. The production inputs are physical capital $K_{m,t}$, R&D $N_{m,t}$ and labour $L_{m,t}$. The parameter α denotes the share of physical capital, $U_{m,t}^i$, $i \in [N,K]$ represents the degree of capital utilisation and $\mathcal{X}_{m,t}^{LAP}$ is labour-augmenting productivity at the firm level

$$\mathcal{X}_{m,t}^{LAP} = \left(U_{m,t}^N N_{m,t} \right)^{\eta} \left(U_t^N N_t \right)^{1-\eta}. \tag{3.3}$$

Firm m's labour-augmenting productivity depends, therefore, both on its chosen amount of utilised R&D, $U_{m,t}^N N_{m,t}$, as well as on the aggregate level $U_t^N N_t$. The parameter $\eta \in (0,1)$ drives the degree of knowledge spillovers affecting the individual firm's productivity. If we set η to be a small number (implying large spillovers), productivity would be almost exogenous from the firm's perspective. In equilibrium, this would imply a smaller endogenous response of productivity to the shocks affecting

[5] These transfers matter since intermediaries enter and exit in this economy. Exiting intermediaries transfer a dividend payment to the household, while newly entering intermediaries receive a start-up endowment.

our economy. It also bears noting that the endogenous growth in this model stems from the production function (3.2) featuring increasing returns to scale.

At the end of period $t-1$, firms order capital $\{K_{m,t}, N_{m,t}\}$ for use in production in the subsequent period t. To purchase this capital they need funding from a financial intermediary. There is frictionless intermediation between the intermediate output producer and the financial intermediary since the former is able to issue state-contingent claims on its capital. The price of such a claim is equal to the price of the underlying capital so that $K_{m,t} = B^K_{m,t-1}$ and $N_{m,t} = B^N_{m,t-1}$. These claims on capital, $B^K_{m,t}$, and $B^N_{m,t}$ can be interpreted as corporate bonds or commercial paper. After aggregate shocks have materialised at the beginning of period t and production has taken place, intermediate output firms sell the remaining (non-depreciated) capital on the open market to capital goods producers at price Q^i_t, $i \in [K, N]$ who then conduct capital refurbishment and investment. The firm's optimality conditions are standard and give rise to demand schedules for labour and capital

$$W_t = \frac{MC_{m,t}}{\tau^{\mathcal{M}}_t}(1-\alpha)\frac{Y_{m,t}}{L_{m,t}} \tag{3.4}$$

$$R^N_t = \frac{\mathcal{R}^N_{m,t} + (1-\delta^N_t)Q^N_t}{Q^N_{t-1}}, \quad R^K_t = \frac{\mathcal{R}^K_{m,t} + (1-\delta^K_t)Q^K_t\varepsilon^K_t}{Q^K_{t-1}} \tag{3.5}$$

$$\mathcal{R}^N_{m,t} \equiv \frac{MC_{m,t}}{\tau^{\mathcal{M}}_t}(1-\alpha)\eta\frac{Y_{m,t}}{N_{m,t}}, \quad \mathcal{R}^K_{m,t} \equiv \frac{MC_{m,t}}{\tau^{\mathcal{M}}_t}\alpha\frac{Y_{m,t}}{K_{m,t}}. \tag{3.6}$$

$MC_{m,t}$ denotes the nominal marginal cost of producing one more unit of final output and $\tau^{\mathcal{M}}_t = \tau^{\mathcal{M}}\varepsilon^{\mathcal{M}}_t$ is a subsidy to correct for the distortions associated with monopolistic competition. We allow for a shock $\varepsilon^{\mathcal{M}}_t$ to marginal costs that is isomorphic to a price markup shock. The labour demand schedule (3.4) equates the wage paid by the firm to the marginal product of labour multiplied by the tax-adjusted marginal cost factor. We introduce the auxiliary variables $\mathcal{R}^K_{m,t}$ and $\mathcal{R}^N_{m,t}$, which can be interpreted as the net returns on physical capital and R&D and are given by the respective marginal products of capital. The gross returns on capital, R^K_t, and R^N_t, are given by the sum of the net return and the re-selling value, relative to the purchasing value of capital in the previous period.

Intermediate output producers maximise profits by choosing their prices. Each period, with probability ϕ_P, a firm may not be able to reset its price. In this case, prices are indexed to the steady-state inflation target. We state the remaining optimality conditions in the online appendix, Section 3.2.

Capital Producers There are two types of perfectly competitive capital producers $i \in [K, N]$, refurbishing physical capital and R&D, respectively, subject to convex investment adjustment costs ψ_{I^i}

$$\max_{I^i_t} \mathbf{E}_t \left[\sum_{k=0}^{\infty} \beta^{t+k} \frac{\mathcal{U}_{C,t+k}}{\mathcal{U}_{C,t}} \frac{P_t}{P_{t+k}} \left\{ Q^i_{t+k} I^i_{t+k} - \left[1 + \frac{\psi_{I^i}}{2} \left(\frac{I^i_{t+k}}{I^i_{t+k-1}} - \bar{\Gamma} \right)^2 \right] P_{t+k} I^i_{t+k} \right\} \right],$$

where $\bar{\Gamma}$ is the gross growth rate of investment on the balanced growth path (BGP) of the economy,[6] and where physical capital and R&D investment, I^K_t and I^N_t respectively, are given by

$$I^K_t = K_{t+1} - \left[1-\delta^K_t\right] K_t \varepsilon^K_t, \quad I^N_t = N_{t+1} - \left[1-\delta^N_t\right] N_t. \tag{3.7}$$

[6] We abstract from sector-specific trends and assume that all expenditure components in this economy grow at the same rate.

For both types of investment, we obtain the following optimality condition

$$Q_t^i = 1 + \frac{\psi_{I^i}}{2}\left(\frac{I_t^i}{I_{t-1}^i} - \bar{\Gamma}\right)^2 + \left(\frac{I_t^i}{I_{t-1}^i}\right)\psi_{I^i}\left(\frac{I_t^i}{I_{t-1}^i} - \bar{\Gamma}\right) - \mathbf{E}_t\Lambda_{t,t+1}\left(\frac{I_{t+1}^i}{I_t^i}\right)^2\psi_{I^i}\left(\frac{I_{t+1}^i}{I_t^i} - \bar{\Gamma}\right). \quad (3.8)$$

3.3 Financial Intermediaries

Financial intermediaries collect funds from households and lend to firms to finance their investment in physical capital and R&D. The portfolio of assets of a financial intermediary j consists of (i) reserve holdings $RE_{j,t}$, (ii) claims on physical capital $B_{j,t}^K$, and (iii) claims on R&D $B_{j,t}^N$. The portfolio is either funded by net worth $NW_{j,t}$, by outside equity $Q_t^E E_{j,t}$, or by non-state-contingent deposits $D_{j,t}$

$$RE_{j,t} + \left(1+\tau_t^N\right)Q_t^N B_{j,t}^N + \left(1+\tau_t^K\right)Q_t^K B_{j,t}^K = NW_{j,t} + \left(1+\tau_t^E\right)Q_t^E E_{j,t} + D_{j,t}.$$

We will describe the macro-prudential taxation scheme $\{\tau_t^K, \tau_t^N, \tau_t^E\}$ on the intermediary's assets and outside equity issuance in detail in Section 3.5. In contrast to $E_{j,t}$ and $D_{j,t}$, net worth $NW_{j,t}$ is raised internally via the accumulation of retained earnings

$$NW_{j,t} = R_{t-1}^D RE_{t-1} + R_t^N Q_{t-1}^N B_{j,t-1}^N + R_t^K Q_{t-1}^K B_{j,t-1}^K - R_t^E Q_{t-1}^E E_{j,t-1} - R_{t-1}^D D_{j,t-1}.$$

The nominal franchise value, $V_{j,t}$, is the expected payout from the terminal nominal net worth $NW_{j,t}$

$$V_{j,t} = \mathbf{E}_t\left[\sum_{k=t+1}^{\infty}(1-\sigma)\sigma^{k-t-1}\Lambda_{t,k}\Pi_{t,k}^{-1}NW_{j,k}\right],$$

where σ denotes the survival rate of the intermediary. Following GKQ we introduce a moral hazard problem to limit the ability of intermediaries to expand their balance sheet and maximise their terminal dividend value. It is assumed that intermediaries can abscond with a fraction Θ_t of their assets. Households, therefore, incentivise intermediaries not to divert assets by limiting the funding of intermediaries such that their franchise value $V_{j,t}$ is at least as large as the asset stock that can be diverted

$$V_{j,t} \geq \Theta_t\left(\Delta^K Q_t^K B_{j,t}^K + Q_t^N B_{j,t}^{R\&D}\right), \quad 0 < \Delta^K < 1.$$

Note that we allow for different liquidation values of physical capital and R&D claims via the risk-weight $\Delta^K < 1$. We assume that physical capital claims are less risky than R&D capital claims. We furthermore assume that the fraction of assets that the financial intermediary can steal depends on the liability composition. Following Calomiris and Kahn (1991) and GKQ, we assume that the more (outside) equity an intermediary uses to finance itself, the more difficult it is to monitor its balance sheet. In terms of repayments and returns, debt is assumed to be more transparent and can, therefore, serve as a disciplining device. Therefore, the diversion rate Θ is an increasing function of equity and decreasing in debt

$$\Theta_t = \theta\left(1 + \omega_1 X_{j,t} + \frac{\omega_2}{2}X_{j,t}^2\right) \quad (3.9)$$

where the intermediary's risk-weighted equity-to-asset ratio $X_{j,t}$ is given by

$$X_{j,t} \equiv \frac{Q_t^E E_{j,t}}{\Delta^K Q_t^K B_{j,t}^K + Q_t^N B_{j,t}^N}, \quad X_{j,t} \in (0,1)$$

and where $\omega_1 < 0$ and $\omega_2 > 0$. The calibration of the parameters ω_1, ω_2 will be such that the marginal diversion rate is positive $\Theta'(X_{j,t}) = (\omega_1 + \omega_2 X_{j,t}) > 0$ in the risk-adjusted BGP (steady state with balanced growth).[7] We define the intermediary's risk-weighted leverage ratio as follows

$$\phi_{j,t} \equiv \frac{\Delta^K Q_t^K B_{j,t}^K + Q_t^N B_{j,t}^N}{NW_{j,t}}. \tag{3.10}$$

The intertemporal optimality conditions of the intermediary and the associated auxiliary definitions are

$$\Delta^K \mu_{j,t}^{B^N} \equiv \mathbf{E}_t\left[\Omega_{j,t+1}\Lambda_{t,t+1}\Pi_{t+1}^{-1}\left(R_{t+1}^K - R_t^D\right)\right] \tag{3.11}$$

$$\mu_{j,t}^{B^N} \equiv \mathbf{E}_t\left[\Omega_{j,t+1}\Lambda_{t,t+1}\Pi_{t+1}^{-1}\left(R_{t+1}^N - R_t^D\right)\right] \tag{3.12}$$

$$\mu_{j,t}^{E} \equiv \mathbf{E}_t\left[\Omega_{j,t+1}\Lambda_{t,t+1}\Pi_{t+1}^{-1}\left(R_t^D - R_{t+1}^E\right)\right] \tag{3.13}$$

$$\nu_{j,t} \equiv \mathbf{E}_t\left[\Omega_{j,t+1}\Lambda_{t,t+1}\Pi_{t+1}^{-1} R_t^D\right], \tag{3.14}$$

where $\mu_{j,t}^{B^N}$ denotes the excess returns from investing in R&D claims over the cost of issuing deposits. $\mu_{j,t}^{E}$ denotes the excess funding cost from issuing deposits over issuing equity and $\nu_{j,t}$ represents the cost of issuing deposits. $\Omega_{j,t}$ can be interpreted as the shadow price of net worth

$$\Omega_{j,t} = (1-\sigma) + \sigma\left[\nu_{j,t} + \phi_{j,t}\left(\mu_{j,t}^{B^N} + \phi_{j,t} X_{j,t} \mu_{j,t}^{E}\right)\right]. \tag{3.15}$$

Given its net worth, the intermediary has to decide on the volume of its assets and the share of its portfolio of assets that is funded by equity. Combining the first-order conditions of the intermediary delivers

$$\frac{\mu_{j,t}^{B^N} + \mu_{j,t}^{E} X_{j,t}}{\Theta(X_{j,t})} = \frac{\mu_{j,t}^{E} + \nu_{j,t}\tau_t^E}{\Theta'(X_{j,t})}. \tag{3.16}$$

Expression (3.16) equates the benefit-cost ratio of having more assets (LHS) to that of increasing outside equity issuance (RHS) to finance the portfolio increase. Note that the intermediary faces a trade-off when using outside equity. On the one hand, outside equity provides a hedging value for the intermediary since it is state-contingent and, therefore, tied to the return on assets. On the other hand, issuing outside equity is assumed to increase Θ and will therefore tighten the overall borrowing capacity of the financial intermediary.[8] Assuming that the incentive constraint is always binding, we derive the intermediary's

[7] The reason for allowing for a negative ω_1 is to calibrate a sufficiently high level of equity financing to match the data. Crucially, at the margin, $\Theta'(X_{j,t}) > 0$.

[8] Note that if one assumes that Θ is a constant, unresponsive to equity $E_{j,t}$, then intermediaries would prefer to exclusively fund themselves with state-contingent outside equity and their net worth would not at all respond to asset returns.

optimal leverage ratio

$$\phi_{j,t} = \frac{\nu_{j,t}}{\Theta_t - \left(\mu^{BN}_{j,t} + X_{j,t}\mu^{E}_{j,t}\right)} \tag{3.17}$$

which is increasing in those elements that raise the franchise value of the intermediary. We normalise the intermediary's return on outside equity such that it entitles the household to the return on one unit of the intermediary's portfolio of assets. The gross return on equity is thus given by

$$R^E_t = \frac{\mathcal{R}^E_t + Q^E_t \varepsilon^E_t}{Q^E_{t-1}} \tag{3.18}$$

where the flow return on equity $\mathcal{R}^E_t$ is equal to the flow return on total capital, which, in turn, is a weighted average of the flow return on physical capital and R&D

$$\mathcal{R}^E_t = R^K_t \frac{K_t}{\mathcal{K}_t} + R^N_t \frac{N_t}{\mathcal{K}_t}, \quad \mathcal{K}_t \equiv \left((K_t)^{\alpha} (N_t)^{\eta(1-\alpha)} \right)^{1/(\alpha+\eta(1-\alpha))}, \quad \varepsilon^E_t \equiv \left(\varepsilon^K_t\right)^{\alpha/(\alpha+\eta(1-\alpha))} \tag{3.19}$$

Total capital $\mathcal{K}_t$ is defined as a composite between physical capital and R&D and the shock to equity returns ε^E_t is a scaling of the shock to physical capital quality. A detailed derivation can be found in the online appendix, Section 3.2.

3.4 Monetary Policy

The central bank sets the short-term nominal gross interest rate on deposits R^D_t according to a simple Taylor-type rule

$$\frac{R^D_t}{\bar{R}^D} = \left(\frac{R^D_{t-1}}{\bar{R}^D}\right)^{\rho_R} \left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\kappa_\Pi} \left(\frac{MC_t}{\overline{MC}}\right)^{\kappa_Y} \right]^{1-\rho_R} \varepsilon^{MP}_t . \tag{3.20}$$

The central bank responds to deviations of inflation from its target and to a proxy of the output gap, given by the marginal cost relative to the flexible price marginal cost. κ_Π and κ_Y are the respective reaction coefficients. The parameter ρ_R captures the gradual adjustment of the policy instrument. Finally, ε^{MP}_t represents a monetary policy shock.

3.5 Macro-prudential Policy

Since asset prices enter the intermediary's incentive compatibility constraint, a pecuniary externality arises. The use of state-contingent outside equity dampens fluctuations that transmit via shocks on asset returns through the intermediary's net worth (or shocks to net worth) to lending to firms and investment. Financial intermediaries take asset prices as given and, as a result, they ignore the stabilisation benefits that outside equity finance would have on asset prices. The failure to recognise the external benefits of outside equity issuance constitutes an inefficiency that warrants a macro-prudential policy intervention.

Macro-prudential policy is implemented via a subsidy, τ^E_t, on outside equity. This subsidy is financed by taxing the intermediary's asset holdings, such that: $\tau^N_t Q^N_t B^N_{j,t} + \tau^K_t Q^K_t B^K_{j,t} = \tau^E_t Q^E_t E_{j,t}$. Additionally, we assume that τ^K and τ^N are set according to their relative asset risk profiles: $\tau^K_t = \Delta^K \tau^N_t$.[9] Subsidising

[9] Refer to the online appendix, Section 3.2, for details and implications.

equity issuance increases its relative attractiveness over deposit finance. In line with GKQ, we assume that τ_t^E follows a simple rule and responds to the inverse of the shadow cost of deposits[10]

$$\tau_t^E = \kappa_\nu \nu_t^{-1}. \tag{3.21}$$

The reaction coefficient κ_ν governs the responsiveness of macro-prudential policy. If the shadow cost of deposits ν_t is low, the macro-prudential subsidy τ_t^E will be high, and vice versa. By increasing τ_t^E, the regulator provides an incentive for intermediaries to issue more outside equity even though the shadow cost of deposits is low.

The introduction of macro-prudential policy gives rise to a higher risk-adjusted steady state outside-equity-to-assets ratio (our model's theoretical counterpart to the 'capital adequacy ratio'). Moreover, Equation (3.21) implies countercyclical movements in the desired level of the equity-to-asset ratio. While in reality, these fluctuations in the capital ratio of financial intermediaries are the consequence of regulatory requirements, in our model they are the result of a taxation/subsidy scheme. The macro-prudential policy specification in our model thus captures important elements of real-world macro-prudential policy, albeit in a stylised manner.

3.6 Market Clearing, Aggregation, and Equilibrium Definition

The model is closed with market clearing conditions for securities, capital, and labour. In equilibrium, all financial intermediaries have the same risk-weighted equity-to-asset and leverage ratios. Aggregate net worth is the sum of the net worth of old intermediaries, NW_t^o, and new intermediaries, $NW_t^y = \xi$, $NW_t = \sigma NW_t^o + \xi$. NW_t^o, is the given by the earnings on assets net of the cost of funding. Combining this with the balance sheet identity, one can derive the law of motion of aggregate net worth

$$\begin{aligned} NW_t \quad = \quad & \sigma \Big[Q_{t-1}^K B_{t-1}^K \left(R_t^K - R_{t-1}^D \right) + Q_{t-1}^N B_{t-1}^N \left(R_t^N - R_{t-1}^D \right) \\ & + X_{t-1} \phi_{t-1} \left(R_{t-1}^D - R_{t-1}^E \right) NW_{t-1} + R_{t-1}^D NW_{t-1} \Big] + \xi. \end{aligned} \tag{3.22}$$

To induce stationarity, we divide all real quantities by the aggregate stock of N_t capital, all nominal quantities by $P_t N_t$, and nominal prices by P_t. For example, detrended output $\hat{Y}_t$, real detrended net worth $\widehat{NW}_t$ and the real price of capital $\hat{Q}_t^K$ are given by $\hat{Y}_t \equiv Y_t/N_t$, $\widehat{NW}_t \equiv NW_t/(P_t N_t)$, and $\hat{Q}_t^K \equiv Q_t^K/P_t$. Consider the detrended version of the R&D accumulation equation and note that growth Γ_t is endogenous in this model[11]

$$\Gamma_{t+1} = \hat{I}_t^N + \left[1 - \delta_t^N\right], \quad \text{where} \quad \Gamma_t \equiv \frac{N_t}{N_{t-1}}.$$

The exogenous processes for markups ($\log \varepsilon_t^{\mathcal{M}}$), monetary policy ($\log \varepsilon_t^{MP}$) and capital quality ($\log \varepsilon_t^K$)

[10] In the online appendix, Section 8, we show that our main results also hold under alternative macro-prudential policy rules. Specifically, we consider a subsidy responding to the aggregate equity-to-asset ratio, as proposed by Liu (2016), and a constant subsidy rule.

[11] In the online appendix, Section 3.3, there is a detailed derivation of how all the above-derived equations were detrended.

follow standard AR(1) processes

$$\log \varepsilon_t^{\mathcal{M}} = \rho_{\mathcal{M}} \log \varepsilon_{t-1}^{\mathcal{M}} + \varsigma_{\mathcal{M}} \eta_t^{\mathcal{M}} \tag{3.23}$$
$$\log \varepsilon_t^{MP} = \rho_{MP} \log \varepsilon_{t-1}^{MP} + \varsigma_{MP} \eta_t^{MP} \tag{3.24}$$
$$\log \varepsilon_t^{K} = \rho_{K} \log \varepsilon_{t-1}^{K} + \varsigma_{K} \eta_t^{K} \tag{3.25}$$

with persistence ρ_j and standard deviation ς_j for shock η^j, respectively. In the online appendix, Section 3.4, we state the complete set of stationary equilibrium conditions.

In the analysis that follows below, we compare our baseline model to an exogenous growth counterpart and a model with endogenous growth but without financial frictions. In the case of exogenous growth, it holds that $\Gamma_t = \bar{\Gamma}$, which can be thought of as a limiting case in which the adjustment cost for R&D investment is infinitely high $\psi_{I^N} \to \infty$. All variables associated with R&D become constants. In the model without financial frictions, we can disregard Equations (3.9)-(3.19), associated with the financial block, and all spreads become zero.

4 Model Solution, Parametrisation and Numerical Example

4.1 Model Solution and Parametrisation

Model Solution One key feature of our model is that the bank's balance sheet structure depends on risk perceptions. Therefore, it is crucial to take risk into account when solving the model. To address this, we consider a second-order approximation of the equations that account for risk perceptions (refer to the online appendix, Section 4, for details). Following Coeurdacier et al. (2011) and de Groot (2014), we construct a risk-adjusted balanced-growth path, where variables remain unchanged when a shock has a zero realisation, given agents' perceptions of second moments. The risk-adjusted BGP only differs from the non-stochastic state by second-order terms that determine the bank's balance sheet. To analyse the model dynamics, we conduct a first-order log-linear approximation around the risk-adjusted steady state.[12] To sum up, accounting for future risk in the computation of the BGP enables us to express the level of risk as a function of banks' liabilities and allows us to capture the benefits of macro-prudential policy in terms of reduced volatility.

Calibration The upper part of Table 1 presents the calibration of our baseline model. The five parameters related to the household preferences $\{\gamma, \beta, h, \chi, \varphi\}$ take values that are standard in the literature. We calibrate χ such that the balanced-growth-path (BGP) value of employment implies a steady-state share of *R&D* investment to GDP of roughly 3%. This in turn implies a value for the knowledge spillover parameter of $\eta = 0.0619$. We calibrate the annual net growth rate of the economy to be 1.6% in the risk-adjusted steady state. This implies a quarterly gross growth rate of $\bar{\Gamma} = 1.004$, roughly in line with the average real per-capita GDP growth rate of the US economy since the early 1980s.[13] The capital share α, the elasticity of substitution ϵ and the physical capital depreciation rate δ_{bgp}^K are all calibrated to standard values. The depreciation rate of R&D is set to $\delta_{bgp}^N = 0.0375$, consistent with the value used by the US Bureau of Labour Statistics in the R&D stock calculations.

[12] Due to certainty equivalence, if the model was solved around the deterministic BGP, banks would have no advantage to fund with equity rather than debt. Consequently, they would rather use cheap debt than expensive state-contingent equity.

[13] Note that the deterministic steady state values may deviate from the risk-adjusted steady state. Due to the presence of risk, investment and hence growth would be lower. This implies that in our model the deterministic steady state value of the growth rate is above 1.004.

Regarding the parameters related to the financial sector, we target a leverage ratio of roughly 6 and average spreads for physical capital and R&D that correspond to investment-grade and high-yield corporate bond spreads. For physical capital, we target the average spread between Moody's Seasoned Aaa corporate bond yield and the federal funds rate, while for R&D we target the average spread between the 'ICE BofA BB US High Yield Index Effective' yield and the federal funds rate. The latter is a high-yield corporate bond spread, available since 1997. The ratio between these average spreads is $\Delta^K \approx 0.63$, and it indicates the relative risk between these two types of bonds. We also target a 6% capital adequacy ratio (CAR) in the unregulated risk-adjusted BGP equilibrium.[14] These targets imply an absconding rate $\theta = 0.7413$, consistent with the calibration in Queralto (2020), and $\xi = 0.0124$, $\sigma = 0.93$, consistent with the calibration in Gertler et al. (2020a). To implement a similar sensitivity of Θ_t to changes in the equity-to-asset ratio X_t as in GKQ, we set $\omega_2 \approx 13.5$.[15] Since we want an unregulated equity-to-asset ratio of $X_{bgp,r} \approx 0.06$, we set $\omega_1 = -0.75$.[16]
We assume that there is no inflation along the BGP so that $\bar{\Pi} = 1$. This assumption, together with our assumptions on β and $\bar{\Gamma}$, implies an annual nominal net interest rate of $r_{bgp} \approx 3.7\%$.

Estimation We target moments for output, consumption, physical capital, and R&D investment, employment, inflation, and the two spreads to estimate the remaining parameters associated with investment adjustment costs, variable utilisation, price stickiness, the Taylor rule sensitivities, and the shock processes: $\bar{\varepsilon} = \{\psi_{I^K}, \psi_{I^N}, \zeta_{U,K}, \zeta_{U,N}, \psi_P, \kappa_\Pi, \kappa_Y, \rho_{R^{TR}}, \rho_{\mathcal{M}}, \varsigma_{\mathcal{M}}, \varsigma_{MP}, \varsigma_{CQ}\}$. Parameter estimates are presented in the lower part of Table 1. In our estimation, we search for the parameter vector $\bar{\varepsilon}^*$ minimising the distance between the moments observed in the data and their model counterparts. The objective function is given by

$$\bar{\varepsilon}^* = \underset{\bar{\varepsilon}}{argmin} \left[\Xi - \tilde{\Xi}(\bar{\varepsilon})\right]' \left[\Xi - \tilde{\Xi}(\bar{\varepsilon})\right]. \tag{4.1}$$

Here, Ξ denotes the moments observed in the data, and $\tilde{\Xi}(\bar{\varepsilon})$ denotes the model counterpart that depends on the parameter vector $\bar{\varepsilon}$. In Section 5.2 we discuss how the model, with and without macro-prudential policy, compares to the data and to the empirical evidence presented in Section 2.

4.2 Impulse Responses: Disentangling the Different Channels

Figure 2 presents the impulse-response functions (IRFs) for key variables following a markup shock, a monetary policy shock, and a capital quality shock (financial shock). To highlight how endogenous growth and financial frictions affect the transmission of the shocks, we compare the IRFs across different models. We consider three alternative specifications: the baseline model with endogenous growth and financial frictions (blue-solid line), a version of the model with exogenous growth and financial frictions (green-circled line), and a model with endogenous growth but without financial frictions (purple-dotted line).

[14] Considering that even early macro-prudential regulations, such as the first Basel accord in 1988, required banks with an international presence to hold capital equivalent to 8% of their risk-weighted assets, it is not unreasonable to assume a capital ratio of 6% in our unregulated economy.

[15] In GKQ the parameter is labelled κ and set to $\kappa = 13.4$, targeting a fall in the aggregate leverage ratio of one-third as they move their model economy from low risk to high risk. They find optimal values of macro-prudential policy between 18% and 22%.

[16] Due to the presence of risk in the risk-adjusted steady state, a risky-ss value of $X_{bgp,r} = 0.06$ requires a lower deterministic target value $X_{bgp,d} < X_{bgp,r}$. Also note that $\Theta'_{bgp,d} = 0$, so that $\omega_1 = -\omega_2 * X_{bgp,d}$.

TABLE 1: PARAMETER VALUES

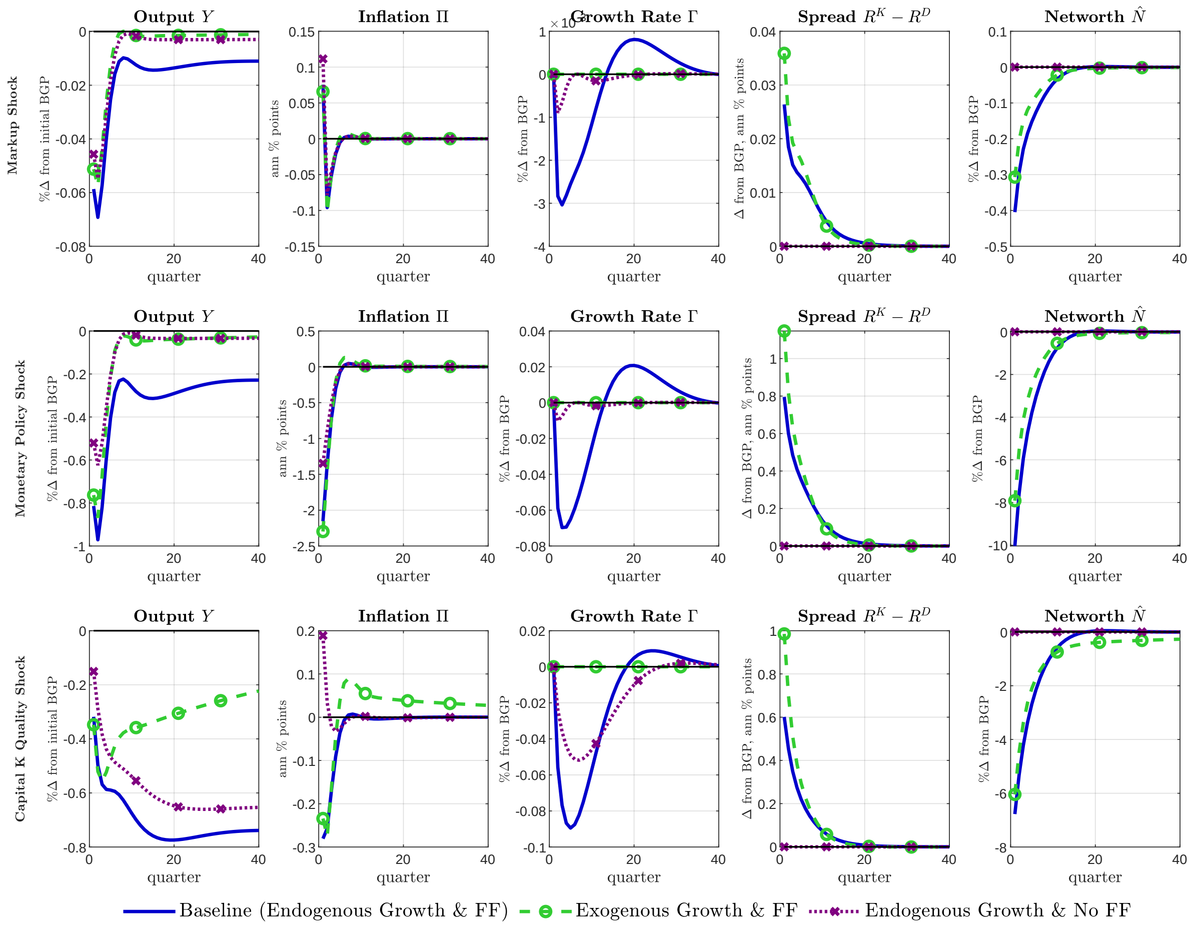
Calibrated Parameters	Definition	Value	Source/Target
Households			
γ	Household Risk Aversion	2.000	Literature
β	Household Discount Factor	0.999	Literature; annual net nominal rate $r_{bgp} \approx 3.7\%$
h	Habit formation parameter	0.600	Literature; Volatility of C
χ	Utility Weight of Labour	1.943	Implies $L_{bgp,r} \approx 0.5$ so that $I^N_{bgp,r}/Y_{bgp,r} \approx 3\%$
φ	Inverse Frisch Elasticity	1.000	Literature
Endogenous Growth			
η	Knowledge Spillover parameter	0.062	Implied by target-ratio $I^N_{bgp,r}/Y_{bgp,r} \approx 3\%$
$\bar{\Gamma}$	BGP Gross Growth Rate	1.004	1.6 % BGP annual net growth
Non-financial Firms			
α	Capital share	0.330	Literature; Capital/Labour Shares
ϵ	Substitution Elasticity	11.000	Markup of 10%
$\bar{\delta}^K$	Constant K Depreciation parameter	0.018	Target $\delta^K_{bgp,r} = 0.0250$
$\bar{\delta}^N$	Constant N Depreciation parameter	0.031	Target $\delta^N_{bgp,r} = 0.0375$
$b_{U,K}$	K Depreciation Sensitivity	0.039	Implied by MPK, $b_{U,K} = \alpha Y_{bgp,d}/K_{bgp,d}$
$b_{U,N}$	N Depreciation Sensitivity	0.060	Implied by MPN, $b_{U,N} = (1-\alpha)\eta Y_{bgp,d}/K_{bgp,d}$
Financial Intermediaries			
σ	Survival Rate	0.930	Gertler et al. (2020a), target $\phi_{bgp,d} = 6$
ξ	Transfer to entering FI	0.012	Implied by target-$SpreadK_{bgp,d} = 0.008$
θ	Absconding coefficient for N capital	0.741	Implied by target-$SpreadRnD_{bgp,d} = 0.012$
Δ^K	Risk-weight on K capital claims	0.630	Avg Spread Ratio: (AAA-FFR)/(BofABB-FFR)
ω_1	Asset Diversion Parameter 1	-0.750	$\Theta'_{bgp,d} = 0$, $\omega_1 = -\omega_2 * X_{bgp,d}$, target risk-adj $X_{bgp,r} \approx 6\%$
ω_2	Asset Diversion Parameter 2	13.5	Gertler et al. (2012)
Macro-prudential Policy			
$\kappa_\nu (\kappa^*_\nu)$	Equity Subsidy Sensitivity to ν^{-1}	0.0000 (0.0700)	Find welfare-maximising value
Monetary Policy			
Π^*	Inflation Target	1.0000	Similar to Sims and Wu (2021)

Estimated Parameters	Definition	Value
Non-financial Firms		
ψ_{I^K}	K Investment Adjustment Cost	0.475
ψ_{I^N}	N Investment Adjustment Cost	1.462
$\zeta_{U,K}$	K Depreciation Elasticity	7.926
$\zeta_{U,N}$	N Depreciation Elasticity	8.070
ψ_P	Calvo Price Stickiness	0.728
Monetary Policy		
κ_Π	Interest Rate Sensitivity to Inflation	1.841
κ_Y	Interest Rate Sensitivity to Output	0.165
ρ_{RTR}	Interest Rate Smoothing	0.756
Shock Processes		
$\rho_{\mathcal{M}}$	Persistence of Markup Shock	0.001
$\varsigma_{\mathcal{M}}$	St Dev of Markup Shock	0.004
ς_{MP}	St Dev of MP Shock	0.005
ς_{CQ}	St Dev of K Capital Quality Shock	0.008

Markup Shock A markup shock induces output and inflation to move in opposite directions. In response to the increase in inflation induced by the markup shock, the central bank raises the policy rate, which leads to a contraction in output, investment and the growth rate Γ. The contraction in real activity corresponds to a decline in asset returns, the net worth of financial intermediaries falls and the spread increases. The combined presence of financial frictions and endogenous growth implies that a markup shock in our baseline model induces a substantial contraction of output on impact and also leads to permanent losses and scarring effects due to the reduction in utilised R&D and, hence, productivity. When financial frictions are switched off, the permanent losses in output are substantially smaller, as can be seen by comparing the purple line to the blue line in the top left panel of Figure 2.

Monetary Policy Shock Next, we consider a contraction in demand caused by an unexpected tightening in monetary policy. As a result, we observe a decline in output, inflation, the growth rate, and the net

FIGURE 2: IMPULSE RESPONSES TO MARKUP, MONETARY POLICY, AND CAPITAL QUALITY SHOCK



Note: FF stands for financial frictions.

worth of financial intermediaries, accompanied by an increase in the spread. In the baseline model, the economic contraction leads to a decrease in investment in both physical capital and R&D. Specifically, the decline in R&D investment subsequently triggers a reduction in productivity growth Γ. For this reason, in the baseline model, the level of output does not return to its initial BGP in the absence of the shock. The fall in demand also leads to a decrease in asset prices and a rise in the spreads, leading to a decline in banks' net worth. This, in turn, tightens credit conditions, further amplifying the contraction in demand and the permanent losses in macroeconomic activity.

To highlight how endogenous growth affects the transmission of the monetary policy shock, compare the baseline results to those from the exogenous-growth specification. In the baseline model, the level of output experiences a permanent decline relative to the initial BGP. However, this is not the case under exogenous growth. In the exogenous growth model, the growth rate Γ remains unaffected, resulting in the convergence of output back to its initial BGP. Comparing the baseline model to the specification without financial frictions allows us to underscore the amplification provided by the financial sector. In particular, we note how financial frictions strongly amplify the response of the growth rate. The reason is that, in the baseline model, a contractionary monetary policy shock causes a fall in asset prices and a rise in the spread, leading to a credit tightening. This has severe consequences for both forms of investment. Since the endogenous growth mechanism is closely tied to the dynamics of R&D investment, financial frictions imply that even non-financial adverse shocks have more pronounced effects on the productivity growth rate, ultimately resulting in mild yet persistent output losses.

Capital Quality Shock The capital K quality shock induces a significant reduction in output, investment, and productivity growth rate. While the initial impact on output is comparable to that of the markup shock and the monetary policy shock, a financial shock has a more substantial effect on investment (not shown), leading to a more pronounced contraction in the productivity growth rate. Consequently, the long-term decline in the level of output is more severe following a capital quality shock compared to a markup shock or a monetary policy shock. When we compare the baseline model (blue line) to the version with exogenous growth (green line), the difference in the output responses is quite striking. In the absence of financial frictions (purple line), the medium-term loss in output is around 0.1pp (15%) less severe.

5 Macro-prudential Policy Analysis

In this section, we provide some intuition on how our assumption regarding endogenous growth affects welfare-based policy analysis. Subsequently, we discuss the optimal macro-prudential policy and its static and dynamic implications.

5.1 Welfare under Endogenous Growth

Throughout this paper, we use the household's lifetime value $\mathcal{W}$ as the relevant welfare metric. Under the assumption of GHH-type preferences we can derive an expression of the stationary lifetime value $\hat{\mathcal{W}}_t$ as a function of the stationary period utility $\hat{\mathcal{U}}_t$ and the gross growth rate of the economy Γ_t[17]

$$\mathcal{W}_t \quad = \quad \mathcal{U}_t + \beta \mathbf{E}_t \mathcal{W}_{t+1} \quad \Leftrightarrow \quad \hat{\mathcal{W}}_t \equiv \mathcal{W}_t / N_t^{1-\gamma} = \left\{ \hat{\mathcal{U}}_t + \beta \mathbf{E}_t \Gamma_{t+1}^{1-\gamma} \hat{\mathcal{W}}_{t+1} \right\}.$$

It bears noting that under our assumption of GHH-type preferences, the period utility and the lifetime utility will actually take negative values. Hence, the policymaker's objective is to minimise the losses in households' lifetime utility. The risk-adjusted BGP value of the household's lifetime utility $\hat{\mathcal{W}}_{bgp,r}$ is given by

$$\hat{\mathcal{W}}_{bgp,r} \quad = \quad \hat{\mathcal{U}}_{bgp,r} \left(1 - \tilde{\beta}_{bgp,r}\right)^{-1}, \; \tilde{\beta}_{bgp,r} \equiv \beta \Gamma_{bgp,r}^{1-\gamma}, \; \gamma > 1.$$

Since we assume $\gamma > 1$, an increase in the gross growth rate $\Gamma_{bgp,r}$ decreases the effective discount factor $\tilde{\beta}_{bgp,r}$. As we show in detail in Section 5.2, a change in the policy sensitivity parameters can affect the risk-adjusted BGP, including $\hat{\mathcal{U}}_{bgp,r}$ and $\tilde{\beta}_{bgp,r}$. Importantly, a policy-induced change in $\tilde{\beta}_{bgp,r}$ has a much stronger impact on welfare than a change in $\hat{\mathcal{U}}_{bgp,r}$, which can be seen by comparing the elasticities of welfare with respect to the period utility and the effective discount factor, respectively

$$\mathcal{E}_{\hat{\mathcal{W}}_{bgp,r},\hat{\mathcal{U}}_{bgp,r}} \equiv \left| \frac{\partial \hat{\mathcal{W}}_{bgp,r}}{\partial \hat{\mathcal{U}}_{bgp,r}} \frac{\hat{\mathcal{U}}_{bgp,r}}{\hat{\mathcal{W}}_{bgp,r}} \right| = |1| \; < \; \mathcal{E}_{\hat{\mathcal{W}}_{bgp,r},\tilde{\beta}_{bgp,r}} \equiv \left| \frac{\partial \hat{\mathcal{W}}_{bgp,r}}{\partial \tilde{\beta}_{bgp,r}} \frac{\tilde{\beta}_{bgp,r}}{\hat{\mathcal{W}}_{bgp,r}} \right| = \left| -\frac{\tilde{\beta}_{bgp,r}}{1 - \tilde{\beta}_{bgp,r}} \right|, \text{ if } \tilde{\beta}_{bgp,r} > 0.5.$$

Even a mild increase in the BGP value of the gross growth rate $\Gamma_{bgp,r}$ could have a substantial positive impact on welfare. Intuitively, a rise in $\Gamma_{bgp,r}$ lowers the effective discount factor $\tilde{\beta}_{bgp,r}$, the stream of

[17] See Section 3.3, in the online appendix, for details.

future period dis-utilities is discounted stronger, giving rise to a higher lifetime utility value. In fact, the role of discounting in determining welfare is so strong that even an increase in the period disutility (equivalent to a decrease in the period utility) could still be associated with an overall improvement in welfare. Indeed, in our numerical analysis, we find that the optimal simple macro-prudential policy rule is associated with a lower period utility but a higher gross growth rate (increasing discounting) which leads to significant welfare gains. These gains are not accounted for in standard models with exogenous productivity.

As is standard in the literature, we measure and compare welfare by expressing it in consumption-equivalent terms. In particular, we denote $\mathcal{C}^{equiv}$ as the percentage increase in consumption that would be required for the unregulated baseline model to reach the same level of welfare as the one with the optimal simple macro-prudential policy rule

$$\hat{\mathcal{W}}^*_{bgp,r} = \left(1 - \tilde{\beta}_{bgp,r}\right)^{-1} \left(\frac{1}{1-\gamma} \left((1 + \mathcal{C}^{equiv})(1-h)\hat{C}_{bgp,r} - \hat{\vartheta}_{bgp,r} \frac{L^{1+\varphi}_{bgp,r}}{1+\varphi} \right)^{1-\gamma} \right).$$

5.2 Optimal Macro-prudential Policy

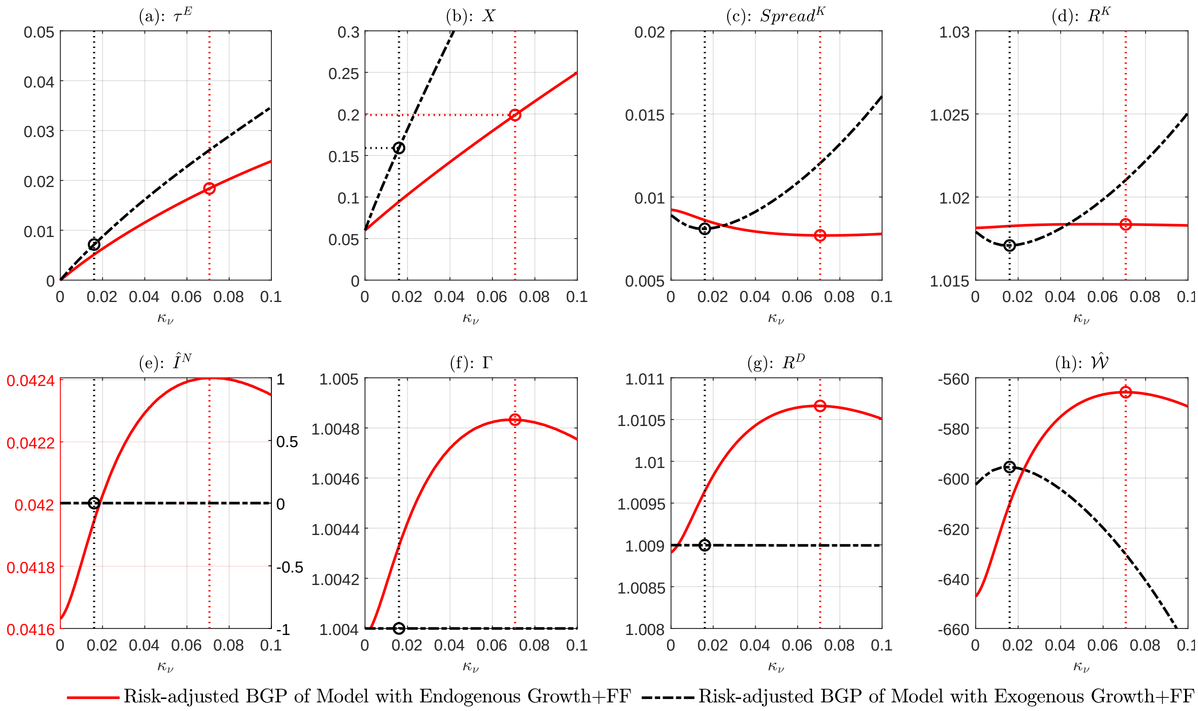
We will now look at optimal macro-prudential policy in the form of an optimal simple rule. First, in a static context, we discuss the choice of the macro-prudential policy sensitivity κ_ν that maximises welfare in the risk-adjusted balanced growth path (BGP). We then discuss the dynamic consequences of shocks under optimal macro-prudential policy.

Risk-adjusted BGP Values The role of macro-prudential policy is to incentivise financial intermediaries to finance a larger share of their portfolio with outside equity rather than with short-term non-state-contingent deposits. The policy instrument of macro-prudential policy is a subsidy on outside equity τ^E_t. As shown in equation (3.21), the subsidy on outside equity reacts to the intermediary's shadow cost of deposits with sensitivity κ_ν. We derive the optimal simple macro-prudential policy rule by picking the value κ^*_ν that maximises the household's lifetime utility $\hat{\mathcal{W}}^*_{bgp,r}$ in the risk-adjusted BGP. In Figure 3, we illustrate the optimisation of welfare by varying the sensitivity parameter of macro-prudential policy, κ_ν. As can be seen in Panel (h), the optimal level of κ_ν is around 0.07 in the endogenous growth case (red line).

Panel (a) and (b) highlight that increasing κ_ν leads to an increase in the equity-to-asset ratio $X_{bgp,r}$. A higher value of κ_ν implies a more aggressive and responsive conduct of macro-prudential policy. Starting at the unregulated level of roughly $X_{bgp,r} = 6\%$, the increase in $X_{bgp,r}$ via the increase in κ_ν is initially welfare improving ($\hat{\mathcal{W}}_{bgp,r}$ in Panel (h) increases, then decreases) because the increased reliance on outside equity financing strengthens the financial system's resilience and its shock absorption capacity. The reduction in volatility mitigates the incentive compatibility problem between the household and the financial intermediary, spreads decline (Panel (c)), and the capacity of the financial system to channel funds to firms increases, which has a positive effect on investment in physical capital and R&D. However, as stated above in equation (3.9), the increase in outside equity finance also aggravates the incentive compatibility problem between the household and the financial intermediary since the absconding rate Θ increases in $X_{bgp,r}$. Thus, once the latter effect starts dominating the former, an increase in κ_ν will lower welfare $\hat{\mathcal{W}}_{bgp,r}$.[18] For this reason, an increase in the responsiveness of macro-prudential policy

[18] Refer to Liu (2016) for a detailed discussion of these two opposing effects in the model by GKQ.

FIGURE 3: RISK-ADJUSTED BGP VALUES AS A FUNCTION OF κ_ν



Note: κ_ν denotes the macro-prudential sensitivity parameter. The vertical-dotted lines indicate at which level of κ_ν welfare would be optimal.

will always lower welfare in a deterministic BGP since only the cost (increase in Θ and hence increase in spreads) is captured, while the benefit (reduction in volatility) is ignored.

Increasing κ_ν also leads to a reduction in spreads. The increase in the BGP value of R&D investment leads to an increase in the BGP value of the productivity growth rate from 1.004 to roughly 1.0048. The increase in the growth rate is associated with a rise in interest rates, as implied by the Euler equation and the definition of the stochastic discount factor. The increase in the deposit rate causes a rise in the rate of return on capital, R^K, which, in turn, reduces detrended capital, output, consumption, employment and hence, the detrended household *period* utility. Despite the reduction in the detrended period utility, the household's *lifetime* utility $\hat{\mathcal{W}}$ still increases (Panel (h)) due to the rise in the growth rate Γ, as explained in Section 5.1.

We repeat the same exercise in the context of an exogenous growth model. As shown in the black line in Panel (h), the optimal level of κ_ν is around 0.018. Under exogenous growth, an increase in κ_ν leads to a reduction in spreads. However, in contrast to our baseline model, an increase in κ_ν leads to a reduction in the return on capital R^K.[19] Under exogenous growth, the reduction in R^K leads to an increase in the BGP value of capital, output, consumption, and hours worked. The increase in consumption more than offsets the rise in hours worked, which improves the household's period and lifetime utility. Unlike the endogenous growth case, under exogenous growth, macro-prudential policy can only increase the households' lifetime utility by affecting the period utility.

[19] The level of R&D investment and consequently the growth rate Γ is fixed in the risk-adjusted BGP in the exogenous growth case. In the case of endogenous growth, the SDF declines as the subsidy increases. A lower SDF implies a higher BGP deposit rate R^D. Under exogenous growth, a lower spread $Spread^K \equiv R^K - R^D$ and a fixed deposit rate R^D imply a lower return on capital R^K. Under endogenous growth, a compression of the spread to a comparable level as under exogenous growth is consistent with a small increase in R^K, since R^D itself is higher.

In Panel (h), it can be seen that relative to the level associated with $\kappa_\nu = 0$, the optimal level of welfare increases a lot more in the case of endogenous growth. The beneficial effects of macro-prudential regulation are larger under endogenous growth (from -647 to -566) than under exogenous growth (from -603 to -596).[20] Note that our parametrisation is such that the effects of a higher X on the agency problem Θ are very similar in the endogenous and in the exogenous growth model. Thus, while the cost of macro-prudential regulation is similar across both models, the benefits are larger under endogenous growth. Under endogenous growth, it is optimal for the policy-maker to implement a subsidy on equity that gives rise to a capital ratio of roughly 20%. Under exogenous growth, instead, the capital ratio implied by the optimal macro-prudential subsidy is significantly lower (approximately 16%). In other words, the cost-benefit analysis shows that the presence of endogenous growth amplifies the beneficial effects of macro-prudential policy and, therefore, warrants a tighter stance in the risk-adjusted BGP. Only after a capital ratio of roughly 20% is reached, the adverse effects of the increased agency cost start to dominate.[21]

IRFs under the optimal macro-prudential policy In Figure 4, we show the IRFs to a markup shock, a monetary policy shock and a capital quality shock for output, inflation, productivity growth, spreads, and net worth in the baseline model with endogenous growth and financial frictions. We compare the case without macro-prudential policy (blue-solid line) and the case with the optimal simple macro-prudential rule (red-dashed line).[22] Macro-prudential policy mitigates the initial drop in output for all four shocks. The permanent loss in output is also much smaller. As described above, macro-prudential policy increases the resilience of the financial system and thus facilitates the intermediation of credit even when the economy is hit by adverse financial shocks. Since macro-prudential policy mitigates the decline in investment, also the growth rate of the economy will fall less. The milder drop in the growth rate means that the post-shock BGP will deviate less from the initial pre-shock path. Output, expressed in terms of its deviation from the initial BGP, will thus decline less under optimal macro-prudential policy. For the capital quality shock, output deviates from the initial BGP after 40 quarters by around -0.75% in the absence of macro-prudential policy and by around -0.65% under the optimal macro-prudential rule. Note that under the optimal macro-prudential rule, the capital quality shock induces responses for output and inflation that closely resemble the IRFs from Figure 2 for the case without financial frictions but with endogenous growth. In other words, optimal macro-prudential policy successfully mitigates the adverse effects of financial frictions.

6 Empirical Fit of the Model

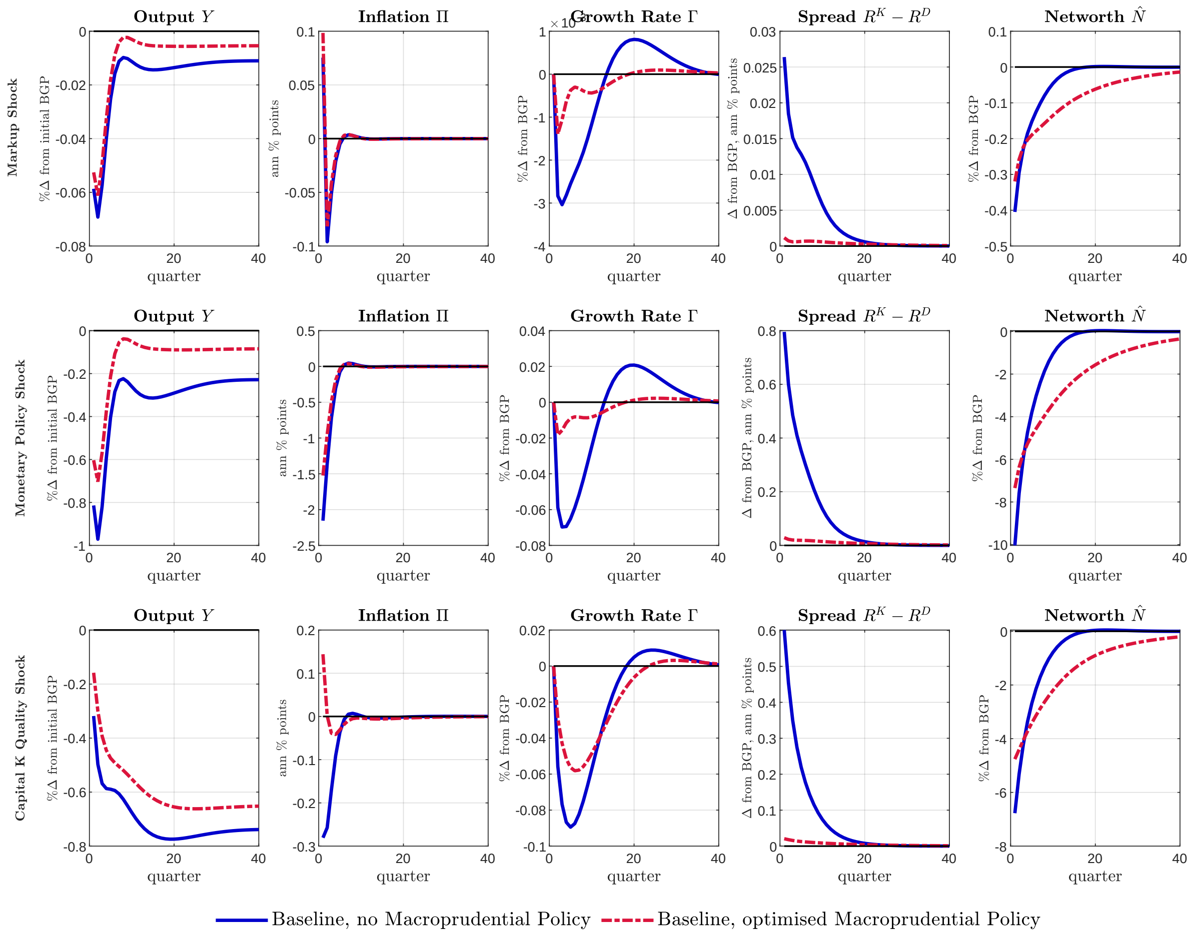
Our model with endogenous growth and financial frictions is able to match key moments of the data. Table 2 reports the standard deviations of some key variables. We compare the model standard deviations to their empirical counterparts for two sample periods: the US postwar period and the period 1984Q1-2019Q4. The baseline model in the absence of macro-prudential policy is parametrised to match these empirical moments. Implementing an optimised macro-prudential policy significantly reduces the volatility of the variables. For instance, while the unregulated model economy with endogenous

[20]The different start values of welfare at κ_ν across the two models are a consequence of slightly different values for consumption and employment in the risk-adjusted BGP's of the model.

[21]Table 7 in the online appendix reports the exact balanced-growth path value of the key model variables.

[22]In the online appendix, Section 5, we discuss how the IRFs change as we consider alternative values of the macro-prudential policy coefficient κ_ν.

Figure 4: Impulse Responses to Markup, Monetary Policy, and Capital Quality Shock



Note: The upper row depicts the IRFs for a (+1stdev) markup shock, the middle row depicts the IRFs for a (+1stdev) monetary policy shock and the lower row for a (-1stdev) capital K quality shock. The blue-straight line depicts the responses of the baseline model, with endogenous growth and financial frictions, in the absence of macro-prudential policy. The red dashed line depicts the responses for the baseline model with the optimal simple macro-prudential policy rule.

growth suggests a 0.94% volatility in output growth rate, the optimised macro-prudential policy reduces it to 0.68%. Notably, the spreads become much less volatile, indicating the stabilisation benefits of macro-prudential policy in mitigating shocks transmitted through the financial system.

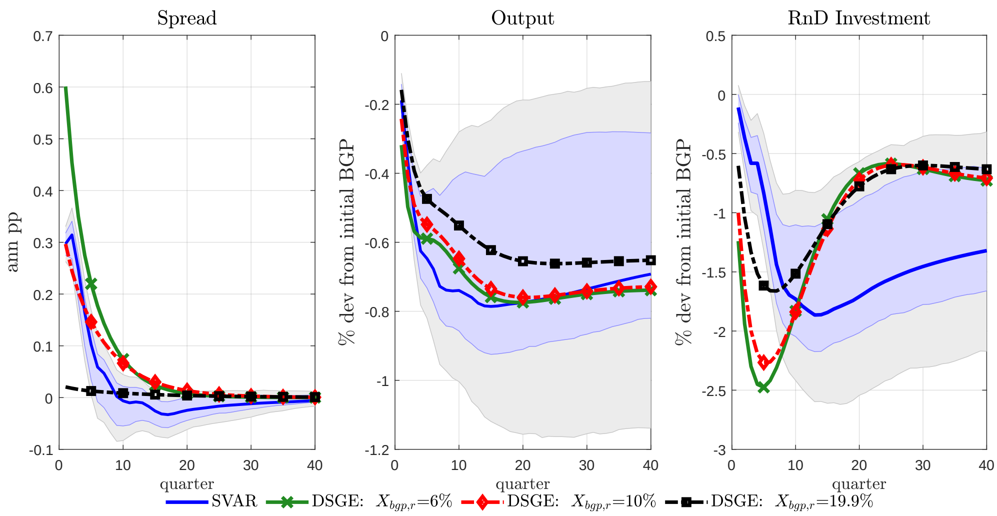
Table 2: Volatilities without and with Macro-prudential Policy

		Endogenous Growth Model		Exogenous Growth Model	
		No MacroPru	With MacroPru	No MacroPru	With MacroPru
Moments	**Data, full sample (post 1984Q1)**				
StDev(Y)	0.99 (0.58)	0.94	0.68	1.15	0.82
StDev(C)	0.84 (0.55)	0.62	0.51	0.72	0.56
StDev(IK)	2.30 (1.77)	2.37	1.56	3.28	2.10
StDev(IRnD)	2.12 (1.45)	2.32	1.07	0.00	0.00
StDev(L)	0.89 (0.66)	1.15	0.81	1.54	1.12
StDev(Pi)	0.66 (0.37)	0.63	0.39	0.81	0.61
StDev(SpreadK)	0.47 (0.36)	0.39	0.02	0.61	0.17
StDev(SpreadRnD)	0.57 (0.57)	0.67	0.05	0.00	0.00

Moreover, the IRFs generated by the capital quality shock η_t^K for Spreads, Output, and R&D investment are consistent with the empirical evidence shown in Sections 2 and 2.2.

IRF Comparison under Endogenous Growth More specifically, Figure 5 displays a comparison between the IRFs from our SVAR model for a financial shock and the IRFs from our DSGE model for a capital quality shock. While the DSGE model without macro-prudential policy produces a response for the spread that is excessively large, compared to the SVAR-IRFs, the IRFs can be well-aligned by introducing a modest degree of macro-prudential policy, characterised by a risk-adjusted steady state capital ratio $X_{bgp,r}$ of 10%. Under the optimal macro-prudential policy, the model indicates a nearly negligible spread response and a more muted decline in output and R&D investment. The DSGE-IRFs for output lie well within the 68% confidence bands implied by the empirical analysis. Regarding R&D investment, the DSGE-IRFs are a bit too volatile, with a sharp initial decline that subsequently rebounds, and eventually settling at a permanently lower level due to the endogenous growth mechanism. After 5 quarters, our R&D DSGE-IRFs lie within the 90% confidence band. Overall, given that we only targeted the moments in Table 2 and not the SVAR-IRFs, our model captures well the dynamics of a financial shock.

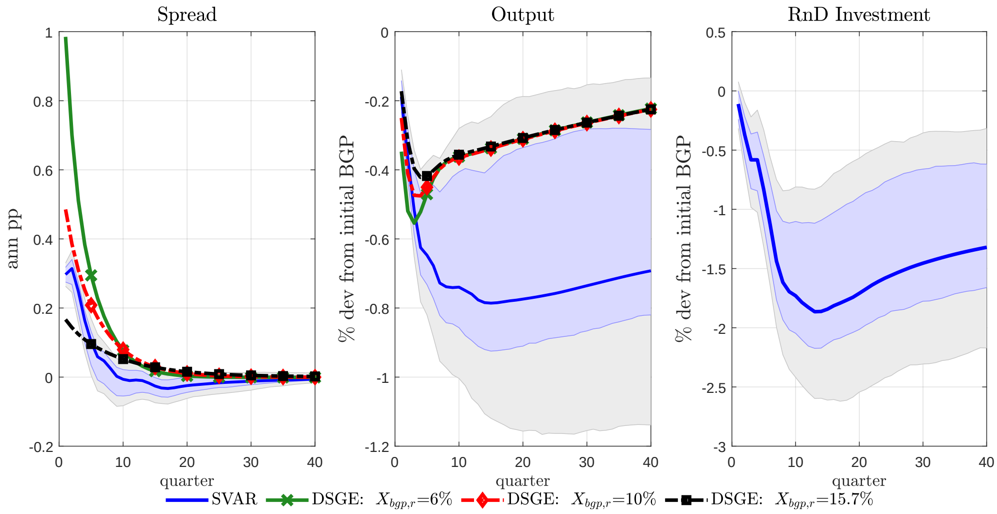
FIGURE 5: COMPARISON OF SVAR AND DSGE MODEL UNDER DIFFERENT CAPITAL RATIOS



Note: The blue straight line depicts the median, and the purple (grey) bands correspond to the 68% (90%) confidence bands of the SVAR-IRFs for a 1 std financial shock. The green line denotes the IRFs for a 1 stdev capital quality shock from the DSGE model (under endogenous growth) with a capital ratio of 6%. The red (black) line denotes the DSGE-IRFs in the presence of modest (optimal) macro-prudential policy associated with a 10% (19.9%) capital ratio.

IRF Comparison under Exogenous Growth In Figure 6 we repeat the same experiment for the model with exogenous growth. In this case, the output response implied by the model is substantially milder than the empirical counterpart. The DSGE-IRFs for output still lie within the 90% confidence band. However, in the case of endogenous growth, the DSGE-IRFs are substantially closer to the SVAR-IRFs. This highlights that our model with endogenous growth outperforms its exogenous growth counterpart in capturing the slow recovery and scarring effects of output following a financial shock.

FIGURE 6: COMPARISON OF SVAR AND DSGE MODEL UNDER EXOGENOUS GROWTH



Note: The blue straight line depicts the median, and the purple (grey) bands correspond to the 68% (90%) confidence bands of the SVAR-IRFs for a 1 std financial shock. The green line denotes the IRFs for a 1 std capital quality shock from the DSGE model (under exogenous growth) with a capital ratio of 6%. The red (black) line denotes the DSGE-IRFs in the presence of modest (optimal) macro-prudential policy associated with a 10% (15.7%) capital ratio.

7 Concluding Remarks

In this paper, we study how macro-prudential policy can mitigate the adverse short-run and long-run consequences of financial shocks, thereby significantly improving aggregate welfare. To motivate our theoretical analysis, we conduct an SVAR analysis for the US and show that financial shocks cause declines in economic activity, R&D investment, and productivity that last significantly over 40 quarters. Next, we build a medium-scale DSGE model with financial frictions and endogenous growth that can explain the long-term effects of financial shocks. Within such a framework, we study the welfare implications of macro-prudential policy. Because productivity growth and the balanced growth path of the economy are endogenous and subject to financial shocks, this justifies a more robust macro-prudential response. Our baseline model implies an optimal capital ratio of 20%, about four percentage points higher than in a specification with exogenous growth. We find that the optimal macro-prudential policy reduces the slowdown in productivity growth and avoids permanent losses in output. Our main result is that macro-prudential policy leads to substantial welfare improvements when we account for its potential long-term benefits. In particular, compared to the unregulated scenario, macro-prudential policy increases welfare, translated into consumption terms, by around 8% against the 0.7% implied by a model with exogenous growth. Our work highlights the importance of taking the long-term costs of financial crises into account when assessing the benefits of macro-prudential policy. The surprisingly small welfare gains from macro-prudential policy commonly found in the theoretical literature are a consequence of ignoring long-term effects and endogenous growth elements.

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