Persistent Slumps: Innovation and the Credit Channel of Monetary Policy

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Abstract

Monetary policy is increasingly found to exert long-run effects on the aggregate economy. We investigate the long-term effects of monetary policy through the credit channel. We develop a dynamic general equilibrium model with financial intermediaries and endogenous innovation in which credit frictions constrain firms' investment and R&D expenses. Following an adverse monetary shock, the tightening in lending conditions for the innovation sector generates sizeable long-term effects, turning the shock into a persistent stagnation. We quantify the contribution of this transmission channel to productivity and output hysteresis. We then characterize the monetary policy trade-offs between short- and long-term targets, showing that the control of inflation can entail a growth slowdown. The results are consistent with Bayesian VAR estimates of the responses of credit and innovation aggregates to monetary shocks.

Keywords: Monetary Policy; Business Cycles; R&D; Stagnation; Credit.

JEL Classification: E22, E32, E44, E52, G20.

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1 Introduction

The medium- and long-run effects of aggregate shocks have attracted growing attention in recent decades. Recessionary shocks are increasingly found to exert a persistent impact on the macroeconomy, especially when they propagate through the financial sector and when they entail disruptions in the dynamics of productivity and knowledge capital accumulation (e.g., R&D and innovation processes). Cerra et al. (2023) and Cerra and Saxena (2008) study a large set of recessions and document that, ten years after the initial impact of the shock, the output drop still exceeded 6% on average. And Reinhart and Rogoff (2014) find that in 23 out of 30 crises after 1990 the average length of recessions was no lower than 5 years. In recent years, for example, the scars of the Global Financial Crisis were visible up to the edge of the Covid-19 upheaval, with output and productivity growth remaining below pre-crisis trends throughout the 2010s. More broadly, the persistent stagnations following recessionary shocks (*"L-shaped"* recoveries) have led scholars and policy makers to reconsider the traditional gap between the analysis of short-run (business cycle) dynamics and that of long-run outcomes (trends) (Cerra et al., 2023).

Recent evidence suggests that, on the demand side, monetary policy shocks can have long-lasting effects on the macroeconomy. Investigating 122 recessions in 23 advanced countries, Blanchard et al. (2015), for instance, find that between 70 and 80 percent of these recessions exhibited persistent deviations from pre-crises trends and that demand shocks (including monetary disturbances) induced departures from pre-recession trends ("hysteresis") as much as other shocks. A relevant channel of transmission of monetary policy that has been widely studied in recent decades consists of the impact of monetary shocks on credit markets (the "credit channel of monetary policy"; Bernanke et al., 1999). Given the perceived importance of credit and financial factors in determining the long-run persistence of recessions, it is then natural to wonder whether monetary policy can exert medium- and long-run effects through the credit channel.

The objective of this paper is to address this question, studying the possible long-term aggregate consequences of the interplay between monetary policy and the credit sector. In particular, we aim to understand the impact of monetary policy in economies with financial (credit) frictions and endogenous growth driven by innovation. The fundamental importance of external financing for R&D and innovation activities is widely acknowleged. Figure 1 offers a glimpse of the strong link between R&D expenditures and credit flows in the United States: the pairwise correlation between the two time series equalled 0.91 between 1995 and 2019. The figure also shows the correlation between the dynamics of these two variables and those of total factor productivity (TFP) and real GDP.[1]

We conduct our analysis in two steps. We first provide motivating evidence on the rele-

[1]Given the non-stationary behaviour of R&D and loans, we have performed a cointegration test after investigating the integrated order of the two variables. The test, based on the two I(1) variables, suggests a cointegration relationship between them (results available upon request), offering further evidence on the correlation analysis.

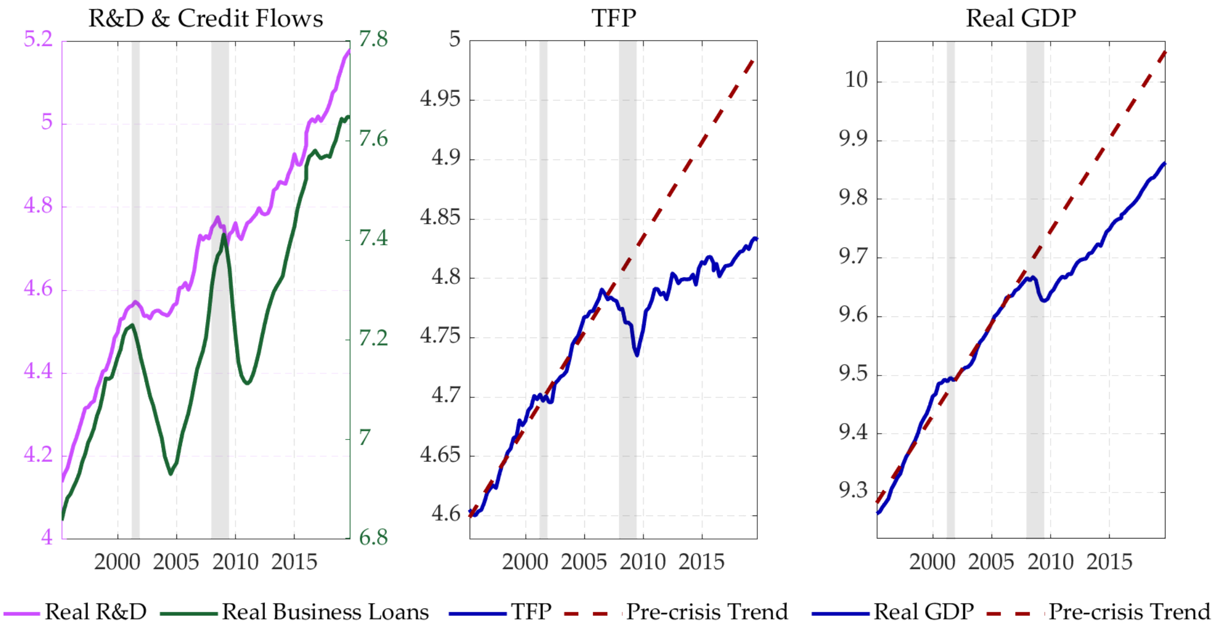


Figure 1: Output, TFP, R&D & Credit Flows

Data from 1995:Q1 to 2019:Q4, in log levels of: Real GDP, billions of 2012 US $; TFP levels, 1995:Q1 = 100; Private R&D expenditure index, 2012:Q1 = 100; Commercial and industrial loans from all banks, billions of 2012 US $. R&D and credit series are in real terms, deflated by GDP deflator.

vance of the credit channel in shaping the aggregate transmission of monetary impulses at different time horizons, highlighting the effects associated with R&D and innovation activities. Then, we interpret this evidence through the lens of a New Keynesian DSGE model incorporating nominal rigidities, endogenous innovation and financial frictions.

Building on Miranda-Agrippino and Ricco (2021), our motivating empirical framework investigates the transmission of a monetary shock to macroeconomic variables by means of a Bayesian VAR. In particular, we shed light on the effects through aggregates which can affect the long-term dynamics of the economy, including credit levels, R&D expenditures and TFP. While the role of the financial accelerator in the propagation of shocks has been acknowledged since at least Bernanke et al. (1999), despite some evidence on the topic, the literature is substantially silent about the influence of the credit channel of monetary policy through innovation-related variables.

We then build a dynamic general equilibrium model with financial intermediation, nominal rigidity, and endogenous TFP growth linking cyclical fluctuations to long-term growth dynamics. In the model economy, both the investments in physical capital and in innovation are financed by financial intermediaries, with the financial intermediation sector, and its frictions, modelled along the lines of Gertler and Karadi (2011). In line with Anzoategui et al. (2019), innovation is modelled as a two-step process: creation and adoption of new technologies. R&D drives potential technology, creating "blueprints" needed for the creation of new intermediate product varieties; adoption, in turn, converts potential into effective technology, expanding the number of product varieties. The monetary authority follows a Taylor rule.

We calibrate the model to the moments of an advanced economy. We then study the dynamic properties of the model and evaluate the capability of monetary shocks to generate persistent stagnations. We also compare the effects of monetary shocks with those of financial shocks hitting the financial intermediation sector. The key results can be summarized as follows. First, the analysis provides support to the notion of long-run monetary non-neutrality. We assess the long-lasting slump induced by a contractionary monetary shock and document its possible contribution to rationalizing sluggish recoveries. The model simulations reveal that a negative monetary shock can significantly raise financial spreads, and hence shrink credit flows to innovative investments, determining hysteresis in productivity and output levels even at low frequencies. The quantitative analysis also reveals that such long-term effects of monetary shocks are especially pronounced when the innovation sector is relatively more sophisticated and profitable, as captured by the factors that govern the profitability of newly created product varieties and the probability of success of R&D and adoption processes.[2] Further, when we turn to dissect the relative influence of the creation (R&D) and adoption phases, we obtain that it is especially the phase of creation of innovations that contributes to the long-run relevance of the credit channel of monetary transmission.

Overall, these findings elicit natural questions about the conduct of monetary policy and the policy trade-offs between short-run stabilization and long-run outcomes. In the last part of the paper, we then perform a comparison of different monetary policy rules, contrasting a conventional Taylor rule with a rule targeting the economy's growth gap (besides the inflation gap). Interestingly, we find that the alternative rule underperforms relative to the conventional one, in the sense of weakening the stabilization effects of monetary policy without achieving clear-cut benefits in terms of lower hysteresis of the

[2] Intuitively, an economy with an unsophisticated innovation sector is less sensitive to possible damages to the innovation financing process induced by shocks.

effects of shocks.

Related Literature The paper relates to various strands of literature. First, the analysis speaks to the literature that investigates the persistent effects of recessions. A class of recent medium-scale DSGE models incorporate growth to analyze the factors that lie behind the productivity drop observed following financial crises (Anzoategui et al., 2019; Bianchi et al., 2019; Ikeda and Kurozumi, 2019; Moran and Queralto, 2018; Queralto, 2020; Elfsbacka Schmoller and Spitzer, 2021; Schmitz, 2021). Studies based on the Schumpeterian innovation framework consider, for example, the role of expectation formation in trapping economies in regimes of persistent stagnation through contractions in R&D expenditures (Benigno and Fornaro, 2018) or the consequences of shocks to fundamentals (Garga and Singh, 2021; Fornaro and Wolf, 2023). Demand-driven output hysteresis due to slowdowns in capital investment is instead modelled in Cerra et al. (2021) and Vinci and Licandro (2021).

The analysis also relates to the literature that studies the transmission channels of monetary policy. The analyses of Aikman et al. (2022), Furlanetto et al. (2023) and Jordà et al. (2023) offer proof of the long-run non-neutrality of monetary actions. Moran and Queralto (2018) document the persistent aggregate effects of expansionary monetary shocks. Relative to these studies, on the empirical side our analysis focuses on how these effects of monetary policy unfold through the interplay between financial frictions and R&D (a long-run credit channel of monetary policy). The estimates in De Ridder (2019), Duval et al. (2020) and Huber (2018) provide broad support for this interplay, identifying credit frictions and weak aggregate demand as complementary causes of the reduction in investments and the persistent fall of TFP and output after crises.[3] And the impact of credit constraints on innovation is also documented in Aghion et al. (2008), Aghion et al. (2010) and Ma and Zimmermann (2023).

From a methodological point of view, on the empirical front the analysis especially relates to Miranda-Agrippino and Ricco (2021) which develop the methodology we apply in this paper to study the aggregate effects of shocks in a large BVAR. On the theoretical side, our model builds on the credit sector framework pioneered by Gertler and Karadi (2011). In particular, we embed a rich endogenous innovation and growth engine in a

[3] The authors provide evidence of an increasing tendency to finance innovative investments through the banking sector.

dynamic general equilibrium framework with financial intermediaries. Bonciani et al. (2023) perform macroprudential policy analyses in a framework with intangible capital and vertical innovation. Cloyne et al. (2022) and Elfsbacka Schmoller (2022), in turn, study the long-term effects of fiscal policy in a model a là Anzoategui et al. (2019), while abstracting from the financing of technical improvements.

The paper unfolds as follows: section 2 provides motivating evidence on the transmission of monetary shocks. Section 3 presents the theoretical model, while section 4 simulates the effects of shocks. Section 5 further dissects the channels of monetary transmission. Section 6 highlights the role of creation and adoption of new technologies. Section 7 examines the stabilization properties of alternative monetary rules. Finally, section 8 concludes. More details on the data and additional theoretical and empirical results are in appendix A, while we relegate further details on the model derivations to the online technical appendix B.

2 Empirical Evidence

To motivate our analysis, we begin by providing an empirical assessment of the transmission of monetary shocks to macroeconomic aggregates. In particular, our interest focuses on: i) the impact of monetary shocks on innovation and growth, ii) the relevance of credit frictions in the shock transmission, i.e. disentangling a credit channel of monetary policy.

Following the strategy of Miranda-Agrippino and Ricco (2021), we estimate a Bayesian Proxy SVAR using quarterly data for the United States. We depart from previous works by focusing on the response of variables at the core of the credit channel and on the link between short-term effects of monetary policy and aggregates relevant to the long-run dynamics of the economy. As noted by Gertler and Karadi (2015) and Miranda-Agrippino and Ricco (2021), there is widespread evidence of a financial accelerator mechanism which can amplify downturns through the response of credit markets. We supplement previous analyses on the financial accelerator and, besides financial variables (credit flows and spreads), we introduce innovation variables (namely R&D expenditures, patents, and TFP) in order to examine the transmission of a monetary shock through growth-driving factors.

Model Specification The vector of endogenous variables comprises: the real GDP; the real private expenditure in R&D; an index for total factor productivity, as in Fernald (2014); the number of granted patents; the Consumer Price Index; a measure of commercial and industrial loans extended by the banking sector; the policy rate, represented by the 1-year Treasury rate; the credit spread, as measured by Gilchrist and Zakrajšek (2012).[4]

The identification strategy consists of the use of an external instrument to evaluate structural policy innovations, as proposed by Caldara and Herbst (2019) and Gertler and Karadi (2015). Here, in particular, we follow the approach put forward by Miranda-Agrippino and Ricco (2021) and use their *"Monetary Policy Instrument"* (MPI) as our proxy variable. This instrument is robust to the presence of information frictions, allowing to distinguish a proper monetary policy shock, i.e. an unforecastable and non-systematic exogenous shift of the policy instrument which impacts agents, from the "information channel" of monetary policy actions.

Based on the outcome of AIC, SBC and HQ information criteria, we estimate the following model over 2 lags and compute the impulse response functions over a 40-quarter horizon to analyze the effects beyond the business cycle frequency:

$$Y_t = \sum_{j=1}^{p} B_j Y_{t-j} + u_t. \tag{1}$$

We move from monthly to quarterly frequency to be consistent with our data availability (see appendix A for all technical information and data description).

Results Figure 2 reports the impulse responses to our identified monetary shock obtained from the the BVAR. The increase in the policy rate, the 1-year Treasury rate, amounts to 1% by construction. Light shaded areas represent 68% confidence bands. The responses reveal a clear recessionary effect of the shock with a significant aftermath lasting up to 10 years after the impact.

Regarding the transmission channel, the monetary shock appears to transmit to the financial side of the economy through an immediate spike in the credit spread. Credit flows are unaffected on impact but exhibit a declining pattern thereafter, with a slow but

[4] All variables are included in log-levels, except for the interest rate and the credit spread. We rely on the 1-year rate in order to perform our estimation beyond 2007, after which the Federal Funds Rate (FFR) was tied at the ZLB.

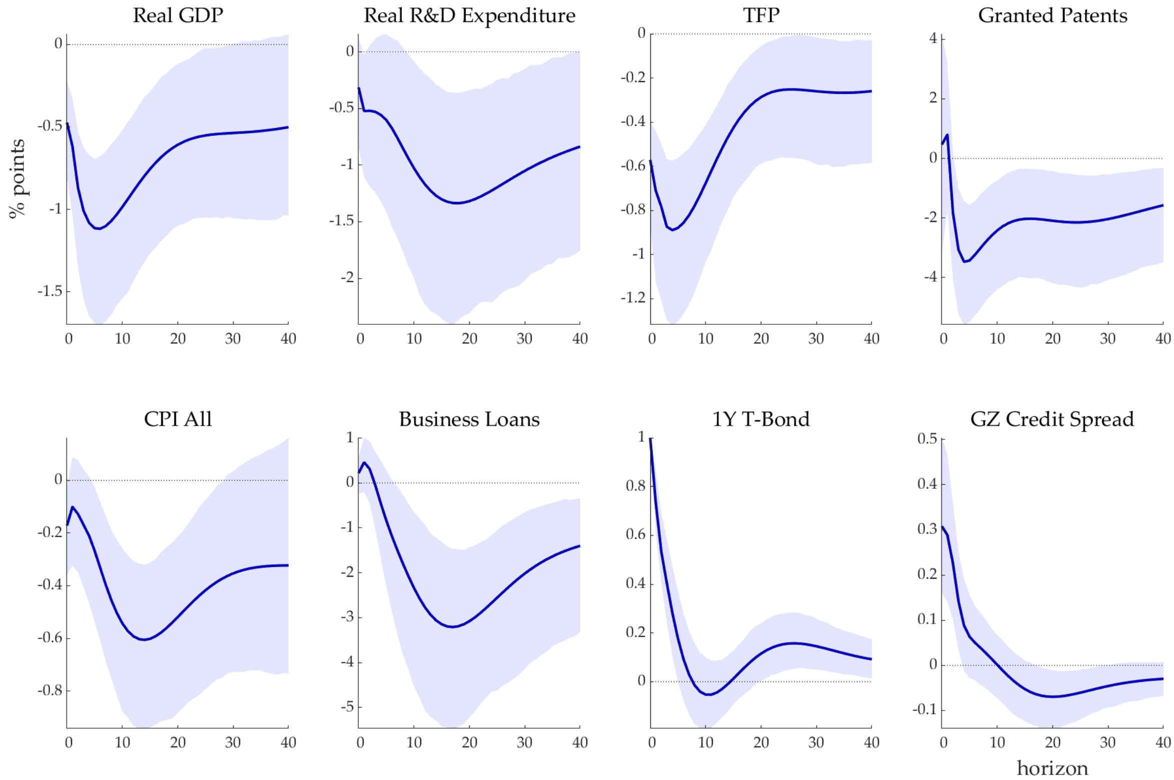


Figure 2: BVAR Impulse Responses

BVAR(2) impulse responses (blue, solid). Estimation sample from 1979:Q4 to 2015:Q4. Shock normalized to obtain a 100 basis points increase of policy rate. Shaded areas are 68% posterior coverage bands.

persistent downward adjustment.[5] Prices drop and exhibit the same dynamics as output, confirming that the identified shock is a purely demand one. In particular, their responses show a gradual decline in the first quarters after the shock, followed by a slow recovery. This behaviour is consistent with real and nominal rigidities that delay the adjustment of prices.

We now turn to our focal point. Private R&D expenditures, total factor productivity and real GDP are immediately affected by the contractionary monetary shock and exhibit common dynamics. A weak rebound occurs after a few quarters, despite the levels still remaining in the negative region. Though exhibiting an ambiguous response on impact, the number of granted patents declines after a few quarters.[6] Therefore, the variables display a clear hysteretic pattern. We interpret this persistent slump as supportive of the argument of monetary non-neutrality for growth, a channel alternative to those tradition-

[5]The presence of rigidities in the commercial credit market, such as legal constraints or a low demand elasticity to price, may explain the sluggish initial correction.

[6]The lag in the negative response of patents relative to R&D expenses could capture the time needed to convert innovation effort into new licences.

ally investigated.[7] This complements the evidence on the long-run effects of monetary policy provided by Jordà et al. (2023) and Furlanetto et al. (2023). In addition, our findings point to an amplification effect on real activity due to a financial accelerator mechanism.

In conclusion, the evidence points to the negative consequences of an adverse monetary policy shock through the credit channel: an increase in the credit spread leads to a tightening in credit volumes. As long as R&D investments are externally financed, worsening credit conditions impact the innovation potential, possibly determining a deterioration of productivity and long-lasting output effects.

3 The Model

The model economy comprises four sectors: households, firms, financial intermediaries, and a monetary authority. The firm sector includes producers of capital, final goods and intermediate goods. In addition, technology producers (innovators and adopters) perform the development of new technologies. Financial intermediaries finance firms' purchases of capital and intangible inputs. The central bank sets the risk-free interest rate.

3.1 Households

Following Gertler and Karadi (2011), households are split into f "bankers", who manage financial intermediaries, and *1-f* workers, who supply labor services to firms. Each period, there is turnover between the two groups: bankers keep their role with probability σ_t, thus remaining in charge of the financial intermediation activity for an average span of $1/(1-\sigma_t)$, while a fraction $f(1-\sigma_t)$ switch business and become workers. The funds of exiting bankers are rebated to households (the owners of financial intermediaries). New bankers, in turn, receive a start-up transfer from households.

Households solve the following optimization problem

$$\max_{C_{t+\tau},D_{t+1+\tau},L_{t+\tau}} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left\{ ln\left(C_{t+\tau} - hC_{t-1+\tau}\right) - \frac{\varrho}{1+\varphi} L_{t+\tau}^{1+\varphi} \right\} \tag{2}$$

[7] Conventional wisdom identifies the short run with an horizon of 32 quarters. See Comin and Gertler (2006).

subject to the budget constraint

$$C_{t+\tau} + D_{t+1+\tau} = W_{t+\tau}L_{t+\tau} + D_{t+\tau}R_{t+\tau} + \Pi_{t+\tau} \tag{3}$$

where C_{t+1} is consumption, D_{t+1} denotes real deposits in financial intermediaries, R_t is the real gross interest rate, L_t denotes labour, W_t is the real wage, ϱ is a parameter governing the disutility of labour, h captures habit formation in consumption and $\Pi_t = \sum_{i=\{f,b\}} d_t^i$ represents real dividends received from firms and financial intermediaries.

Households' optimizing conditions for consumption and labor supply are

$$u_{ct} = \left\{(C_t - hC_{t-1})^{-1} - \beta h\,(C_{t+1} - hC_t)^{-1}\right\} \tag{4}$$

$$u_{ct}W_t = \varrho L_t^{\varphi} \tag{5}$$

$$E_t\beta\Lambda_{t,t+1}R_{t+1} = 1 \tag{6}$$

where $\Lambda_{t,t+\tau} = u_{ct+\tau}/u_{ct}$, is the stochastic discount factor.

3.2 Financial Intermediaries

Financial intermediaries channel funds from households to firms.[8] Within each financial intermediary there is a branch specialized in financing intermediate good producers and a branch specialized in financing innovation activities. Following Gertler and Karadi (2011), we assume no financial frictions between financial intermediaries and firms, and that firms can borrow from financial intermediaries by issuing securities (i.e., claims on their future profits). Table 1 displays the balance sheet of branch i in representative financial intermediary j, where $i = \{k, z\}$ indexes the branches financing tangible and intangible capital, respectively. The total amount of loans is denoted by $S_{jt} = \sum_{i=\{k,z\}} S_{jt}^i$, Q_t^i and R_t^i are the price and retail interest rate on i-type loans and D_{jt+1}^i is the quantity of deposits backing the assets of branch i.

From the financial intermediary j's balance sheet, net worth is given by:

$$N_{jt} = \sum_{i=\{k,z\}} N_{jt}^i = \sum_{i=\{k,z\}} Q_t^i S_{jt}^i - D_{jt+1}^i. \tag{7}$$

[8]Similar to Gertler and Karadi (2011), the financial intermediation sector can be thought as comprising both banks and other categories of financial institutions.

Assets	Liabilities
$Q_t^i S_{jt}^i$	D_{jt+1}^i
	N_{jt}^i

Table 1: Balance sheet of branch i in financial intermediary j

After iterating forward and with the help of some algebra, we can re-express future wealth as

$$N_{jt+1} = \sum_{i=\{k,z\}} \left(R_{t+1}^i - R_{t+1}\right) Q_t^i S_{jt}^i + R_{t+1} N_{jt}^i. \tag{8}$$

The objective of branch i of the representative financial intermediary j is to maximize

$$\begin{aligned} V_{jt}^i &= \max_{S_{jt+1}^i} E_t \beta \Lambda_{t,t+1} \left[(1-\sigma_t) N_{jt+1}^i + \sigma_t V_{jt+1}^i\right] \\ &= \max_{S_{jt+1}^i} E_t \beta \Lambda_{t,t+1} \left\{(1-\sigma_t)\left[\left(R_{t+1}^i - R_{t+1}\right) Q_t^i S_{jt}^i + R_{t+1} N_{jt}^i\right] + \sigma_t V_{jt+1}^i\right\}. \end{aligned} \tag{9}$$

$1-\sigma_t$ is the probability that a banker alive in t exits in period $t+1$ and the banker turns into a worker. Similar to Coenen et al. (2018), the banker's survival rate σ_t is subject to a disturbance such that $\sigma_t = \sigma \varepsilon_t^{\sigma}$. This can be thought as a financial shock and allows to introduce the trigger for a financial crisis in the model.

We introduce a moral hazard problem of financial intermediaries as in Gertler and Karadi (2011). At the beginning of a period, the banker that operates branch i can choose to divert a fraction θ^i of assets and transfer them back to the household of which he or she is a member. The cost of doing so is that the depositors can force the branch into bankruptcy and recover the remaining fraction of assets. Consequently, the banker faces the following incentive compatibility constraint

$$V_{jt}^i \geq \theta^i Q_t^i S_{jt}^i. \tag{10}$$

The left side of equation 10 is what the banker would lose by diverting a fraction of assets. The right side is the gain from doing so. Guessing that the value function is linear in assets and net worth, this can be written as

$$V^i_{jt} = \upsilon^i_t Q^i_t S^i_{jt} + \eta^i_t N^i_{jt}. \tag{11}$$

with first order conditions expressed recursively as, $\forall i = \{k, z\}$,

$$\upsilon^i_t = E_t \beta \Lambda_{t,t+1} \left\{ (1-\sigma_t) \left(R^i_{t+1+\tau} - R_{t+1+\tau} \right) + \sigma_t x^i_{t,t+1} \upsilon^i_{t+1} \right\} \tag{12}$$

$$\eta^i_t = (1-\sigma_t) + \sigma_t E_t \beta \Lambda_{t,t+1} \left\{ z^i_{t,t+1} \eta^i_{t+1} \right\}. \tag{13}$$

υ^i_t is the expected discounted value of an additional unit of i-type assets (i.e. the marginal value of i-type assets) holding wealth and the amount of the other asset constant, η^i_t is the expected discounted value of one additional unit of wealth (i.e. the marginal value of net worth) holding assets constant, $x^i_{t,t+\tau} = Q^i_{t+\tau} S^i_{jt+\tau} / Q^i_t S^i_{jt}$ is the gross growth rate of assets, and $z^i_{t,t+\tau} = N^i_{jt+\tau} / N^i_{jt}$ is the gross growth rate of net worth. Combining 10 with 11, we obtain

$$\upsilon^i_t Q^i_t S^i_{jt} + \eta^i_t N^i_{jt} \geq \theta^i Q^i_t S^i_{jt}. \tag{14}$$

When this condition is binding, assets can be represented as a function of the leverage of the respective branch

$$Q^i_t S^i_{jt} = \phi^i_t N^i_{jt} \tag{15}$$

where the maximum leverage ratio by branch is $\phi^i_t = \eta^i_t / \left\{ \left(\theta^i - \upsilon^i_t \right) \right\}$. Moreover, considering that both wealth and the marginal value of assets are positive ($N^i_{jt} > 0, \upsilon^i_t > 0$), this constraint is binding whenever $0 < \upsilon^i_t < \theta^i$. Given the balance sheet identity, the optimal aggregate leverage ratio thus reads

$$\phi_t = \sum_{i=\{k,z\}} \phi^i_t \frac{N^i_{jt}}{N_{jt}}. \tag{16}$$

Substituting 15 into 8, it is then possible to rewrite the net worth dynamics of the financial intermediary to obtain

$$N^i_{jt+1} = \left\{ \left(R^i_{t+1} - R_{t+1} \right) \phi^i_t + R_{t+1} \right\} N^i_{jt}. \tag{17}$$

The latter shows how the growth of net worth is increasing in leverage and in the net premia on financial intermediaries' retail activity. Aggregating across financial intermediaries, the total demand for assets is

$$Q_t S_t = \phi_t N_t. \tag{18}$$

Thus, when their net worth declines, financial intermediaries reduce the amount of financing extended. The equation of motion for aggregate net worth is

$$N_t = \sum_{i=\{k,z\}} \sum_{y=\{O,N\}} N_t^{iy} \tag{19}$$

where the terms in O, N, respectively represent the wealth accumulated by existing (old) bankers and the start up transfer from households to new bankers. Finally, the expression for the fraction $\left(\epsilon^i/(1-\sigma_t)\right)$ of terminal assets of exiting financial intermediaries $\left((1-\sigma_t)Q_t^i S_{t-1}^i\right)$ reads

$$N_t^O = \sigma_t \left\{ \sum_{i=\{k,z\}} \left(R_t^i - R_t\right) \phi_{t-1}^i + R_t \right\} N_{t-1} \tag{20}$$

$$N_t^N = \sum_{i=\{k,z\}} \epsilon^i Q_t^i S_{t-1}^i. \tag{21}$$

3.3 Firms

3.3.1 Capital Producers

Perfectly competitive capital producers create new capital and refurbish depreciated capital. We normalize the cost of the latter activity to unity. Denoting by Q_t^k the market value of a new unit of capital, capital producers choose gross physical investment I_t^k solving the following problem:

$$\max_{I_{t+\tau}^k} E_t \sum_{\tau=0}^{\infty} \beta^\tau \Lambda_{t,t+\tau} \left\{ Q_{t+\tau}^k I_{t+\tau}^k - [1 + \Psi(\cdot)]\, I_{t+\tau}^k \right\} \tag{22}$$

with $\Psi(\cdot)$ representing the flow of investment adjustment costs. We posit the functional form

$$\Psi(\cdot) = \Psi\left(\frac{I_{t+\tau}^k}{I_{t-1+\tau}^k g_y} \right) \tag{23}$$

where $\Psi(\cdot)$ is increasing and concave, with $\Psi(1) = \Psi'(1) = 0, \Psi''(1) > 0$, and g_y is the investment growth rate along the balanced growth path. The law of motion of capital reads

$$I_t^k = K_{t+1} - \left(1 - \delta_t^k\right) K_t \tag{24}$$

where δ_t^k is the depreciation rate of capital, determined as a function of its utilization rate, $\delta_t^k = \delta(U_t)$. From the solution, we derive the capital supply condition:

$$Q_t^k = 1 + \Psi\left(\frac{I_t^k}{I_{t-1}^k g_y}\right) + \frac{I_t^k}{I_{t-1}^k g_y}\Psi'\left(\frac{I_t^k}{I_{t-1}^k g_y}\right) - E_t \beta \Lambda_{t,t+1}\left(\frac{I_{t+1}^k}{I_t^k g_y}\right)^2 \Psi'\left(\frac{I_{t+1}^k}{I_t^k g_y}\right). \tag{25}$$

3.3.2 Final good production

Monopolistically competitive firms (retailers) use intermediate goods X_t to manufacture differentiated retail final goods Y_{ft}. Aggregate final output is a CES aggregator of the retail final goods

$$Y_t = \left(\int_0^1 Y_{ft}^{\frac{1}{\varsigma}} df\right)^{\varsigma} \tag{26}$$

where Y_{ft} is the final good of retailer f and ς denotes the markup. The input-output ratio is 1:1, based on the following linear technology

$$Y_{ft} = X_{ft}. \tag{27}$$

The demand schedule stems from a standard cost-minimization problem of final good consumers, who choose the optimal composition of consumption among the retail final good varieties, compatible with minimum expenditure

$$Y_{ft} = \left(\frac{P_{ft}}{P_t}\right)^{\frac{\varsigma}{1-\varsigma}} Y_t. \tag{28}$$

It is associated with the following definition of the price index

$$P_t = \left(\int_0^1 P_{ft}^{\frac{1}{1-\varsigma}} df\right)^{1-\varsigma}. \tag{29}$$

As intermediate inputs are the only factor of production for retailers, their marginal costs depend upon the aggregate of the relative intermediate good prices

$$mc_t = \frac{P_{mt}}{A_t^{\vartheta-1}} \tag{30}$$

where, as discussed below, A_t denotes the measure of intermediate good varieties.

Price setting is subject to a Calvo nominal rigidity: only a fraction $(1-\omega)$ of retail firms can freely reset their price to the optimal current level, while the remaining index their price to the lagged inflation rate. Denoting with π_t the current inflation rate, a retail firm's pricing problem reads

$$\max_{P^*_{ft}} E_t \sum_{\tau=0}^{\infty} \omega^\tau \beta^\tau \Lambda_{t,t+\tau} \left(\frac{P^*_{ft}}{P_{ft+\tau}} \Gamma_{t,t+\tau} - mc_{t+\tau} \right) Y_{ft+\tau} \tag{31}$$

where $\Gamma_{t,t+\tau} = \prod_{\iota=1}^{\tau} \pi_{t+\iota-1}^{\omega^\pi} \overline{\pi}^{1-\omega^\pi}$ represents the indexation rule and ω^π is a parameter measuring the degree of price indexation. Retail firms unable to reset optimally adjust prices as

$$P_{ft} = P_{ft-1} \pi_{t-1}^{\omega^\pi} \overline{\pi}^{1-\omega^\pi} \tag{32}$$

with $\overline{\pi}$ denoting the steady state inflation rate. The first order condition for P^*_{ft} reads

$$E_t \sum_{\tau=0}^{\infty} \omega^\tau \beta^\tau \Lambda_{t,t+\tau} \left(\frac{P^*_{ft}}{P_{ft+\tau}} \Gamma_{t,t+\tau} \right)^{\frac{\varsigma}{1-\varsigma}} \left(\frac{P^*_{ft}}{P_{ft+\tau}} \Gamma_{t,t+\tau} - \varsigma\, mc_{t+\tau} \right) Y_{ft+\tau} = 0. \tag{33}$$

The adjustment dynamics of the aggregate price is then

$$P_t = \left\{ (1-\omega) \left(P^*_{ft} \right)^{\frac{1}{1-\varsigma}} + \omega \left(\pi_{t-1}^{\omega^\pi} \overline{\pi}^{1-\omega^\pi} P_{ft-1} \right)^{\frac{1}{1-\varsigma}} \right\}^{1-\varsigma}. \tag{34}$$

3.3.3 Intermediate good producers

A continuum A_t of monopolistically competitive intermediate good producers employ labour and capital to produce intermediate inputs. A_t stands for the stock of available technologies, capturing the range of intermediate inputs. Intermediate good producers need external financing in order to fund their purchases of capital. After production has taken place, they sell undepreciated capital back to capital producers.

The Cobb-Douglas production function is

$$X_{mt} = \varepsilon_t^A \left(U_{mt} K_{mt}\right)^{\alpha} L_{mt}^{1-\alpha} \tag{35}$$

where X_{mt} is the amount of intermediate good produced by intermediate firm m, $0 < \alpha < 1$ represents the capital input share in the economy and ε_t^A is the exogenous TFP component. In aggregate

$$X_t = \left(\int_0^{A_t} X_{mt}^{\frac{1}{\vartheta}} \, dm \right)^{\vartheta}. \tag{36}$$

Intermediate good producers choose the amount of labour, capital and the utilization rate of capital to maximize end-of-period profits, given their production function and the law of motion of capital. Their optimizing conditions are[9]

$$(1-\alpha) P_{mt} \frac{X_{mt}}{L_{mt}} = \mathcal{M} W_t \tag{37}$$

$$\alpha P_{mt} \frac{X_{mt}}{U_{mt}} = \mathcal{M} Q_t^k \delta' \left(U_{mt}\right) K_{mt} \tag{38}$$

$$\alpha P_{mt+1} \frac{X_{mt+1}}{K_{mt+1}} = \mathcal{M} \left\{ Q_t^k R_{t+1}^k - Q_{t+1}^k \left[1 - \delta\left(U_{mt+1}\right)\right] \right\} \tag{39}$$

where the last condition derives from the intermediate firms earning zero profits from the purchase and sale of physical capital, and paying the realized return on capital R_{t+1}^k to financial intermediaries. Finally, prices are perfectly flexible in the intermediate sector.

Taking a first order approximation of 35 and 36 at the symmetric equilibrium for intermediate goods,[10] we can express the production function for aggregate final output as:

$$Y_t = \left\{ A_t^{\vartheta - 1} \varepsilon_t^A \right\} \left(U_t K_t\right)^{\alpha} L_t^{1-\alpha}. \tag{40}$$

Terms within the first brackets capture total factor productivity, which can be decomposed into an exogenous $\left(\varepsilon_t^A\right)$ and an endogenous $\left(A_t^{\vartheta-1}\right)$ component. Innovation activities

[9] Each FOC of an intermediate producer includes the adjustment for a markup term $\mathcal{M}$ due to the monopolistic competition regime. This is smaller than the desired unconstrained markup ϑ to avoid the threat of entry from imitators (see Aghion and Howitt, 1997).

[10] $Y_t = \Omega_t \overline{Y_t}$, with $\overline{Y_t}$ defining the average output per firm and $\Omega_t = \left\{ \int_0^1 \left(Y_{ft}/\overline{Y_t}\right)^{1/\varsigma} df \right\}^{\varsigma} = 1$, to a first order approximation. Considering the unit mass of final good producers, their production function in 27 and $Y_t \sim \overline{Y_t}$, we obtain to a first order that $Y_t \sim X_t$.

determine productivity through the variety A_t of available intermediate goods. This endogenous TFP mechanism is the driver of long-run growth in our economy.[11]

3.3.4 Innovation Activities

In our setting, endogenous growth stems from the creation and adoption of new technologies. Innovators exert R&D effort for the creation of new potential intermediate good varieties, enhancing the potential level of technology. Adopters, in turn, perform the conversion of potential into effective technical instruments.

We posit that adopters do not have enough internal resources to carry out their activity, but require external financing. Each adopter issues S_{mt} securities against its future profits to financial intermediaries at the price Q^z_t. Then, he devotes external funding to acquiring the stock of potential technology, which is subsequently converted into effective technology. Thus, the individual borrowing position of an adopter is given by $Q^z_t Z_{t+1} = Q^z_t S^z_{mt}$, where Z_{t+1} denotes the stock of potential technology.

Innovators Innovators create new potential technology through investment in R&D. In the spirit of Aghion and Howitt (1997), they decide the R&D investment I^{rd}_t, which affects the probability μ_t of success of the R&D process.[12] After R&D is performed, innovators sell potential technology Z_{t+1} to adopters and purchase back the non-obsolete technology from them, where the existing technology stock depreciates at the rate δ^A. Thus, innovators determine the supply of technology. Their problem boils down to

$$\max_{I^{rd}_t} E_t \beta \Lambda_{t,t+1} \left\{ Q^z_t Z_{t+1} - Q^z_t \left(1 - \delta^A\right) Z_t - I^{rd}_t \right\} \tag{41}$$

s.t.

$$Z_{t+1} = \mu_t Z_t + \left(1 - \delta^A\right) Z_t \tag{42}$$

where the law of motion of potential technology defines its dynamics. Here, $\mu_t Z_t$ represents the "net" investment in R&D. The probability of success μ_t is a function of the R&D expenditure I^{rd}_t and its productivity χ, scaled by the maximum attainable level of

[11] It follows from the AR(1) definition of exogenous TFP ε^A_t, which implies its stationarity.

[12] This specification is in contrast to the accumulation process of physical capital, whose investment is successful with probability one.

technology Z_t^{max} [13]

$$\mu_t = \left(\frac{\chi I_t^{rd}}{Q_t^z Z_t^{max}} \right)^{\gamma}. \tag{43}$$

From the problem above, we obtain the dynamics of R&D investment I_t^{rd}:

$$I_t^{rd} = \left\{ \frac{Q_t^z Z_t \gamma \chi - Q_{t+1}^z \left(1-\delta^A\right) Z_t \gamma \chi}{Q_t^z Z_t^{max}} \right\}^{-\frac{1}{\gamma-1}} \frac{Q_t^z Z_t^{max}}{\chi}. \tag{44}$$

Adopters Adopters convert potential technology into intermediate good varieties of usable form, sold (as rights to the use) to the monopolistically competitive intermediate-good producers. Therefore, adopters' choice yields a demand for technology. However, adopters need to borrow from financial intermediaries to make their purchases, paying the interest rate R_t^z on the loans they receive. Finally, they sell back non-obsolete technology to innovators.

Let the price of an adopted technology be Q_t^A (where Π_{mt} are the profits that intermediate-good firms realize from production and the price of an adopted intermediate good variety is the present discounted value of its profits):

$$Q_t^A = \Pi_{mt} + \beta \Lambda_{t,t+1} \left(1-\delta^A\right) Q_{t+1}^A. \tag{45}$$

An adopter's problem reads

$$\max_{Z_t} \left\{ Q_t^z \left(1-\delta^A\right) Z_t - R_t^z Q_{t-1}^z Z_t + \beta \Lambda_{t,t+1} \left(1-\delta^A\right) \left[\lambda_t Q_{t+1}^A + (1-\lambda_t) Q_{t+1}^z \right] \right\} \tag{46}$$

s.t.

$$\lambda_t = \Delta_t (Z_t)^{\rho} (A_t)^{1-\rho}. \tag{47}$$

The probability λ_t of adopting a new technology depends positively on the potential technology Z_t and on the availability of non-rival effective output A_t, where $\Delta_t = \lambda / g_a^t$ (with λ denoting the steady-state level of adoption).[14] This specification implies that the adoption probability is increasing with respect to potential technology, however allowing

[13] Following Aghion and Howitt (1997), γ represents the step size of newly introduced varieties. Z_t^{max} captures the highest attainable technological level, where the distance to the frontier of the current level amounts to a factor σ_z, such that $Z_t^{max} = Z_t (1 + \sigma_z)$.

[14] According to Romer (1990), the influence of A_t reflects public learning-by-doing effects in adopting.

for diminishing returns to scale (governed by the parameter ρ) due to a congestion externality effect.

Effective technology is driven by adoption decisions and evolves according to the following law of motion

$$A_{t+1} = \lambda_t \left(1 - \delta^A\right)(Z_t - A_t) + \left(1 - \delta^A\right) A_t. \tag{48}$$

The (gross) growth rate of effective technology is then given by

$$g_a^{t+1} = \frac{A_{t+1}}{A_t} = \lambda_t \left(1 - \delta^A\right)\left(\frac{Z_t}{A_t} - 1\right) + \left(1 - \delta^A\right). \tag{49}$$

Because of the non-linear relation between output and technology, output growth satisfies:[15]

$$g_y^t = \left(g_a^t\right)^{\frac{\vartheta-1}{1-\alpha}}. \tag{50}$$

3.4 Monetary Authority

The central bank sets the risk-free interest rate r_t according to the following Taylor rule with smoothing:

$$r_t = \varepsilon_t^{mp} \left\{r_{t-1}\right\}^{\rho_R} \left\{\bar{r} \left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi} \left(\frac{mc_t}{\overline{mc}}\right)^{\phi_y}\right\}^{1-\rho_R}. \tag{51}$$

The weights ϕ_π and ϕ_y govern the response of the monetary authority to the gap between inflation and its target value $\overline{\pi}$ and to the output gap, respectively. We follow Anzoategui et al. (2019) and proxy the output gap with marginal costs relative to the flexible price level, $\overline{mc}$. $\bar{r}$ captures the steady-state nominal interest rate, ρ_R denotes the degree of intertemporal smoothing and ε_t^{mp} represents a monetary policy shock. In addition, a Fisher relation between nominal and real interest rates holds:

$$r_t = R_{t+1} E_t \pi_{t+1}. \tag{52}$$

3.5 Aggregation and Market Clearing

Market clearing implies that the value of the physical capital stock equals the amount of financing extended to intermediate producers. Similarly, the value of the potential

[15] We assume that potential and effective technology grow at a common rate, such that under our calibration equation 49 represents the growth rate of A and Z.

technology stock matches the amount of external financing to adopters. This implies the following relations

$$Q_t^k S_t^k = Q_t^k K_{t+1}, \tag{53}$$

$$Q_t^z S_t^z = Q_t^z Z_{t+1}. \tag{54}$$

The total financing extended by financial intermediaries is then given by

$$Q_t S_t = \sum_{i=\{k,z\}} Q_t^i S_t^i = Q_t^k K_{t+1} + Q_t^z Z_{t+1}. \tag{55}$$

The aggregate resource constraint states that output is used for consumption, investment and adjustment costs:

$$Y_t = C_t + I_t^k \left\{ 1 + \Psi\left(\frac{I_t^k}{I_{t-1}^k g_y} \right) \right\} + I_t^{rd}. \tag{56}$$

Exogenous shocks introduced in the previous sections (bankers' survival rate ε_t^σ, monetary policy ε_t^{mp}, and TFP ε_t^A) follow AR(1) processes as follows:

$$log(\varepsilon_t^i) = \rho_i \, log(\varepsilon_{t-1}^i) + \sigma_i \, \xi_t^i \tag{57}$$

where ρ_i denotes persistence and σ_i is the standard deviation of shock i, with ξ^i i.i.d. $\sim N(0,1)$.

3.6 Model Solution, Calibration, and Estimation

Model Solution To obtain a stationary version of the model, all quantities are detrended with respect to the deterministic balanced growth: each real variable is divided by g_y^t, except for technology, Z_t, A_t, which grow at their own rate g_a^t. We then solve the model by a first-order perturbation performed around the non-stochastic balanced growth path, i.e. the equilibrium where no shock hits the economy.[16]

Calibration and Estimation Table 2 presents the values of the calibrated parameters. We choose values common in the literature for standard parameters, namely the capital share α, the discount factor β, the habit in consumption h, the labour elasticity φ, and the

[16]We refer to Bonciani et al. (2023) for a discussion of advantages and alternatives of assuming different BGP specifications. The full stationary model is presented in the online technical appendix B.

Parameter	Definition	Value	Source / Target *
Households			
β	Discount Factor	0.995	Literature
ϱ	Labour Disutility	2.674	* $L_{bgp} = 0.33$
h	Habit Formation	0.815	Gertler and Karadi (2011)
φ	Inverse of Frisch Elasticity	0.276	Gertler and Karadi (2011)
Financial Intermediaries			
σ	Survival Rate	0.962	Gertler and Karadi (2011)
θ^k	Diversion Rate on K projects	0.282	*Leverage Ratio of 5
θ^z	Diversion Rate on Z projects	0.597	*Leverage Ratio of 3
ϵ^k	Startup Transfer	0.004	Gertler and Karadi (2011)
ϵ^z	Startup Transfer	0.005	Gertler and Karadi (2011)
Firms			
α	Capital Share	0.330	Literature
ς	Markup on Final Good Y	1.100	Anzoategui et al. (2019)
ϑ	Desired Markup on Intermediate Good X	1.350	Anzoategui et al. (2019)
$\mathcal{M}$	Effective Markup on Intermediate Good X	1.180	Anzoategui et al. (2019)
ω	Calvo Price Adjustment	0.800	Anzoategui et al. (2019)
ω^π	Price Indexation	0.250	Anzoategui et al. (2019)
δ	Capital Depreciation	0.020	Anzoategui et al. (2019)
Ψ	Elasticity of Adjustment Costs on K Investments	1.728	Gertler and Karadi (2011)
z	Elasticity of Marginal Depreciation w.r.t. Utilization	7.200	Gertler and Karadi (2011)
Innovation Sectors			
δ^A	Technological Depreciation	0.025	Anzoategui et al. (2019)
χ	R&D Productivity	0.030	* Innovation Prob., $\mu \sim 3\%$
ρ	Technology Spillover	0.950	Anzoategui et al. (2019)
Monetary Policy and Other Variables			
$\overline{\pi}$	Inflation Target	1.000	Bonciani et al. (2023)
ϕ^π	Inflation Reaction Coefficient	1.500	Gertler and Karadi (2011)
ϕ^y	Output Reaction Coefficient	0.125	Gertler and Karadi (2011)
$\overline{r}$	Nominal Interest Rate (SS level)	1.010	Derived from g_y/β
$\overline{mc}$	Marginal Costs (SS level)	0.910	Inverse of SS Markup
g_y	Gross Output Growth Rate	1.004	* Net Y Annual Rate = 1.8%
g_a	Endogenous Technology Growth Rate	1.008	* Net Y Annual Rate = 1.8%
Shock Processes			
ρ_{mp}	Monetary Policy Shock Persistence	0.000	Gertler and Karadi (2011)
ρ_σ	Survival Rate Shock Persistence	0.000	Coenen et al. (2018)
σ_σ	Survival Rate Shock SD	0.060	Similar to Coenen et al. (2018)

Table 2: Calibrated Parameters

physical capital depreciation rate δ. We choose the labour disutility ϱ so as to match a steady state labour supply of 1/3. An annual net output growth rate of 1.8%, equal to the value estimated in Anzoategui et al. (2019), is converted into the gross quarterly value for g_y.

As for firms' block, the degree of nominal rigidity of prices is calibrated with fairly standard values for ω and ω^π. We set effective and desired mark up values, $\mathcal{M}$, ς, ϑ, according to Anzoategui et al. (2019). Gertler and Karadi (2011) provide the variable utilization capacity parameters (Ψ, z). For the financial intermediation sector, for each branch we fix the transfer to entering bankers (ϵ^k, ϵ^k) and the capital diversion rates (θ^k, θ^z), by matching the following targets: the credit spread on physical capital, i.e., the difference between the *"BofA AAA US Corporate Index Effective Yield"* and the Federal Funds Rate; the spread on intangible capital, defined as the difference between the *"BofA BB US High Yield Index Effective Yield"* and the Federal Funds Rate; and the leverage ratios

Parameter	Definition	Value
σ_z	Distance to the Frontier	0.25
γ	Step Size of New Varieties	0.40
λ	Adoption Probability	0.25
ρ_R	Interest Rate Smoothing	0.50
σ_{mp}	Monetary Policy Shock SD	0.10

Table 3: Estimated Parameters

of each sector (reflecting the fact that R&D firms deal with more severe credit rationing due to the nature of their collateral, their uncertain output as well as adverse selection problems; Stiglitz and Weiss, 1981; Hall, 2002). The branch-specific leverage ratios imply an aggregate leverage ratio of 4. The bank survival probability σ is calibrated according to Gertler and Karadi (2011). For the innovation activities, in order to fix a value for the productivity of R&D (χ), we target the probability that an innovation occurs as in Benigno and Fornaro (2018). We instead rely on Anzoategui et al. (2019) to set the depreciation of the technology stock δ^A and the parameter ρ driving spillover effects in the adoption process.

Regarding the monetary conduct, we set the Taylor rule reaction coefficients on output and inflation $\left(\phi^y, \phi^\pi\right)$ to standard values. Following Bonciani et al. (2023), the inflation target $\overline{\pi}$ is set to 1, implying missing price-level growth along the BGP. Coenen et al. (2018) offer the coefficients to model a bank survival rate shock.

The remaining parameters of the model are estimated. In particular, we estimate a vector of parameter values until the distance between empirical and theoretical impulse responses is minimized. We focus on the responses to a monetary shock and on the estimation of the following parameters: the standard deviation of the monetary policy shock (σ_{mp}), the Taylor Rule interest rate smoothing coefficient (ρ_R), the steady-state adoption probability of new technologies (λ), the step size of newly introduced technical varieties (γ), and the distance to the technological frontier (σ_z). Table 3 reports the values of the estimated parameters.

4 Persistent Slumps

In Figure 3 we report the impulse response functions of our simulated model after an exogenous monetary shock, our primary shock of interest. We also compare the responses with those consequent to a bank survival rate shock, which can capture the trigger of a financial crisis.

The outcome of a monetary shock is contractionary for all variables of interest and, in particular, the behaviour of output and inflation is consistent with the demand nature of the shock.[17] The figure makes clear the persistence generated by our framework relative to conventional new-Keynesian models relying on an exogenous TFP assumption. A monetary shock is capable of generating hysteresis, as output remains persistently below its BGP level, with credit frictions and intangible investments acting as an amplification channel of the monetary transmission. More specifically, the monetary shock induces an increase in interest rates which translate into a spike in credit spreads. There is a direct impact on the amount of financing extended by financial intermediaries to the private sector. Then, the innovative sectors appear to amplify the contractionary effect. In fact, the credit tightening shrinks the resources devoted to the adoption of new technologies, reducing the disposable input Z_t for their adoption process. Thus, the adoption probability λ_t drops. In addition, there is a feedback effect between the two innovation phases, as creation is influenced by the maximum attainable level of technology Z_t^{max}, determined also by the current level of potential Z_t. Therefore, the combination of reduced creation and adoption rates triggers a persisting reduction in future technical means A_{t+1}, generating hysteresis in productivity and output.

Figure 4 compares the IRFs generated by the DSGE model with those of our BVAR following a monetary shock. The structural model satisfactorily tracks its empirical counterpart for the responses of output, R&D, the credit spread and the price level. The model captures the medium- and long-run behaviour of TFP, while all remaining theoretical dynamics are almost always within the 68% confidence bands of the estimated BVAR. Indeed, from a qualitative point of view, the dynamics are consistent with the estimated BVAR for the whole trajectory, even at long horizons. The transmission channel is thus consistent with observed data: the strongly hysteretic behaviour of real GDP and

[17] In appendix A we report the IRFS of all variables to all shocks.

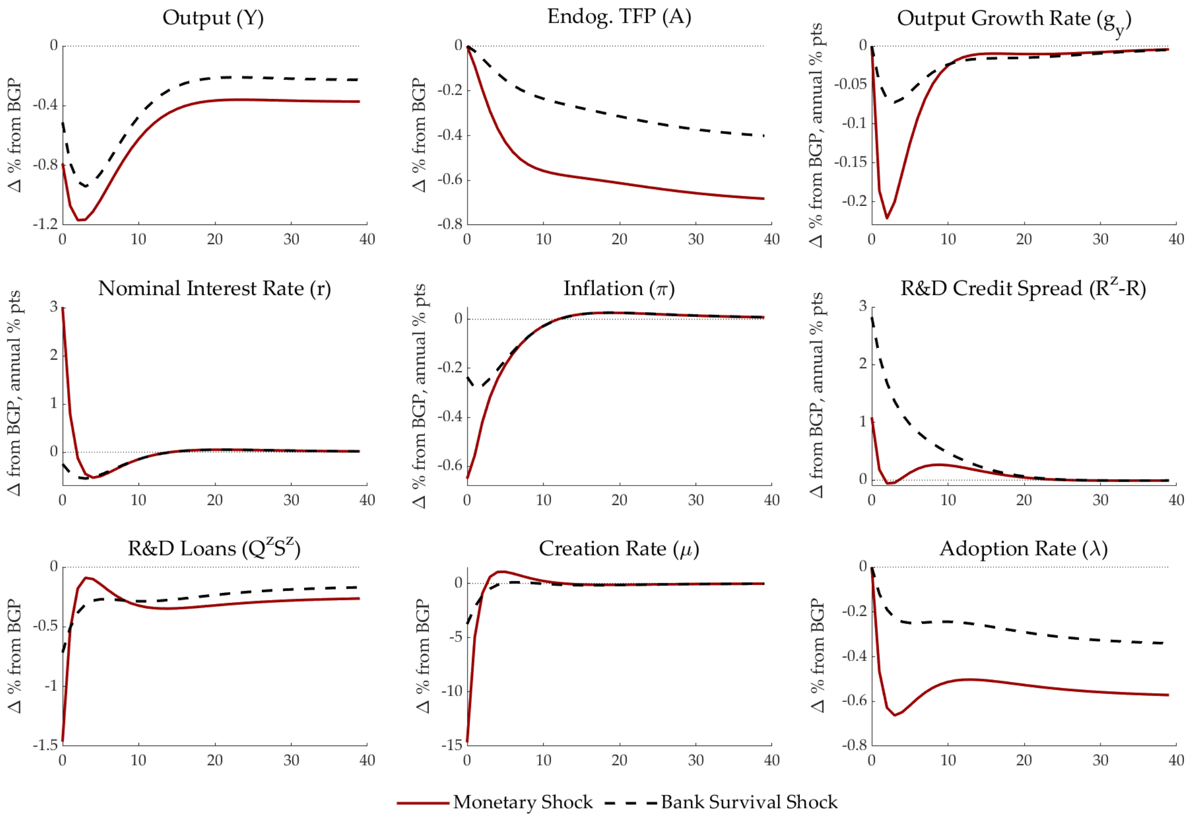


Figure 3: Impulse Responses to Monetary (+) and Bank Survival Rate Shock (-1 sd)

TFP is consistent with their realignment on a different trend suggested by the model. In particular, growth rates approach their BGP but remain steadily a little below it, in line with the *"super-hysteresis"* hypothesis (Ball, 2014). On the other hand, we detect a relatively fast rebound of inflation from negative territory: we attribute this short-lived deflationary effect to endogenous productivity, where the steady decline in TFP partially leads marginal costs, thus prices, to remain high.

Next, we consider the effects of a banks' survival probability shock to understand how credit frictions affect permanent output (see again Figure 3). The responses are analogous to those induced by a monetary shock from a qualitative point of view. The reason again lies in the endogenous innovation framework. The decrease in bankers' survival rate results in a deterioration of financial intermediaries' balance sheets as more financial intermediaries leave the market. This depresses financial intermediaries' leverage ratios and lending. Interestingly, the credit spread exhibits a sharper increase than following a monetary shock: the spread further rises due to the feedback-rule of the central bank, which reduces the interest rate to contrast deflationary pressures.

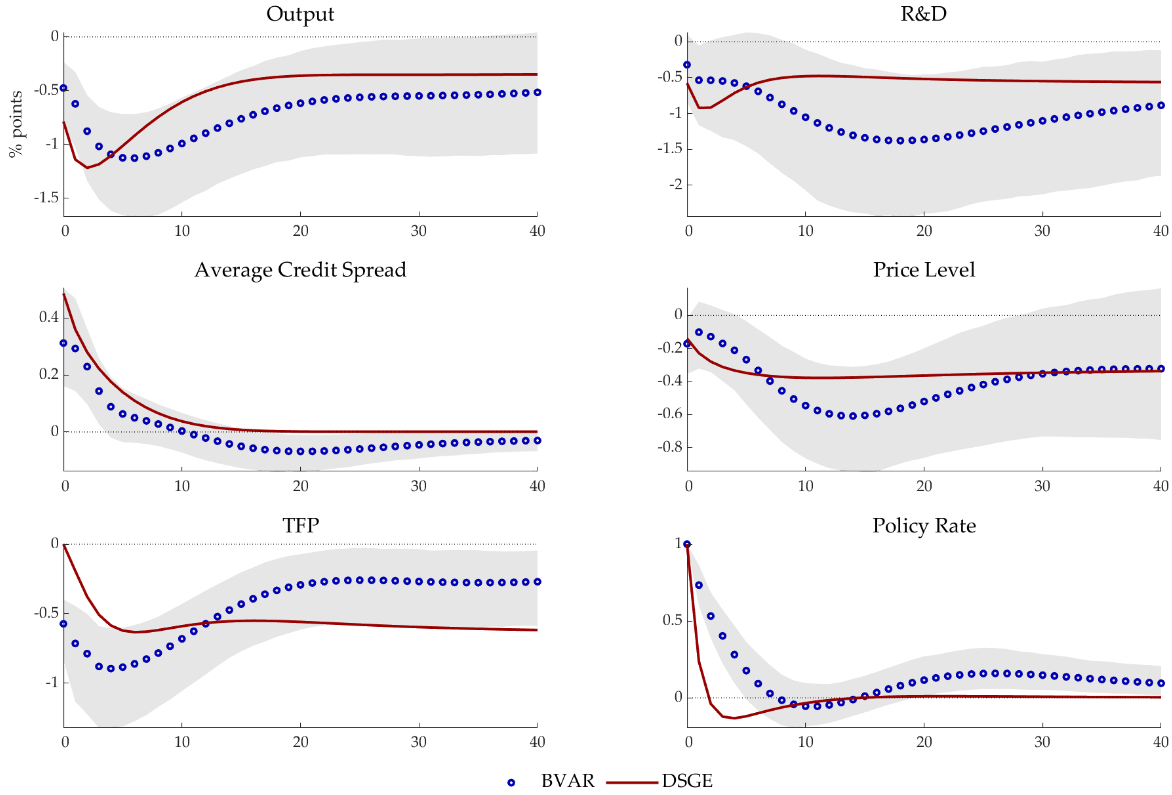


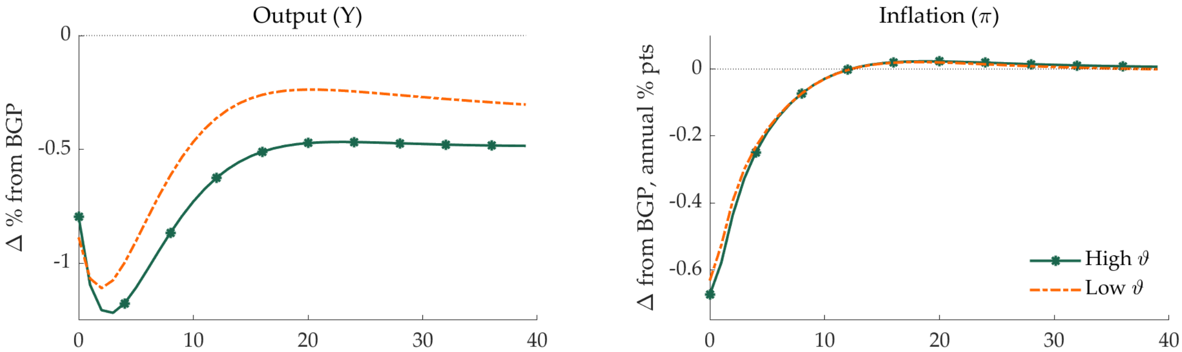
Figure 4: Impulse Response Matching
IRFs to a 1% shock to the policy interest rate

To sum up, the persistence of downturns is evident in the dynamic responses to both shocks. We interpret this as a sign of the interaction between endogenous productivity mechanisms and credit frictions in the model economy.

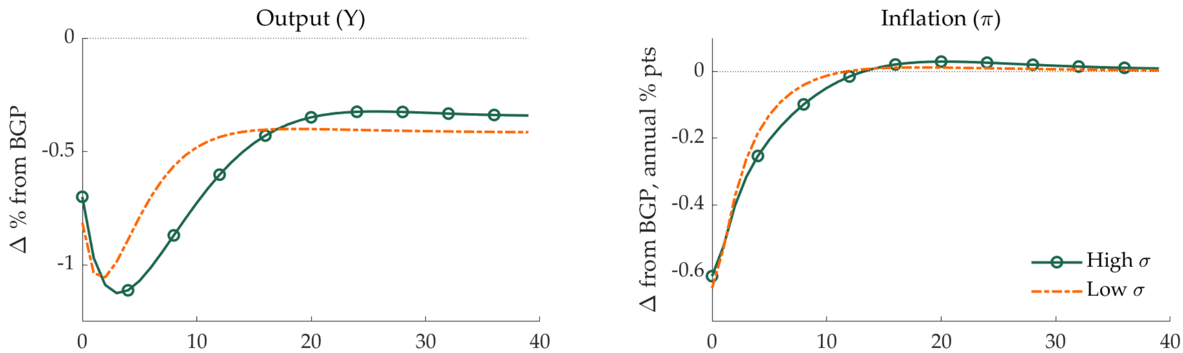
5 The Transmission Channels of Monetary Policy

How does monetary policy transmit to the macroeconomy? We address this question by inspecting the quantitative relevance of the identified amplification channels after a monetary shock. To this end, we perform a sensitivity analysis exercise, in which we analyze how the behaviour of salient variables depends on relevant parameters which drive the channels.

We focus on the core frictions of the model and study to what extent endogenous innovation and credit market imperfections interact in influencing the response of aggregate variables. Figure 5 displays the percentage deviation from BGP levels of key business cycle variables, i.e. output and inflation, along the simulated IRF horizon. We study how



(a) Sensitivity to Endogenous Growth



(b) Sensitivity to Credit Friction

Figure 5: Transmission Channels of Monetary Policy Shocks

Panel (a): impulse responses for high (1.50, green dotted) and low (1.20, orange dashed) levels of the desired markup on intermediate goods ϑ; Panel (b): impulse responses for high (0.97, green dotted) and low (0.93, orange dashed) levels of the bank survival probability σ.

their impulse responses depend on the desired markup on intermediate goods (ϑ), i.e. the parameter driving the endogenous growth engine, and the banks' survival rate (σ), a proxy for the magnitude of credit frictions. Panel (a) of Figure 5 considers the influence of endogenous productivity. For higher values of ϑ, that is a more substantial weight towards an endogenous growth framework, the contraction of output and inflation is deeper after a recessionary monetary shock.[18] This confirms the amplification role of the intangible investment channel. The difference in the response of inflation is negligible, on the other hand, suggesting that in this dimension the innovation channel exerts a smaller influence on the quantitative strength of the mechanisms.

The impact of the financial intermediation friction is even sharper (Panel (b) in Figure

[18] For the endogenous growth case, values are chosen so as to respect the lower bound for ϑ (1.20), which derives from the calibration of the effective markup on intermediate goods $\mathcal{M}$ (1.18). The upper bound is given by a symmetric gap around the calibrated value. For the banking sector survival probability, the two values are chosen based on the minimum (0.93, Bonciani et al., 2023) and maximum (0.97, Gertler and Karadi, 2011) generally adopted in the literature.

5). In this case, we detect an initial larger slump associated with healthier financial intermediation systems, captured by values of the survival rate σ closer to 1. We interpret this result as reflecting a stronger pass-through of the monetary stance when the solidity of financial intermediaries is stronger. The resilience of a healthier financial intermediation system emerges in the long run, as it helps to mitigate the long-term slump and to enable a faster recovery of lending. Again, the deflationary effects vanish in the long run but, in line with the output response, they are more pronounced in the first few periods for a high σ. This is consistent with the impact of the shock on the endogenous productivity component, which pushes marginal costs in a way that induces a faster but relatively weak growth in inflation.

6 The Role of Technology Creation and Adoption

How much do the creation and adoption of new technologies matter for aggregate fluctuations and for the stabilization goals of the central bank? What is the interplay between these two phases of the innovation process?

Starting from the results of Section 5, we examine in deeper detail the aggregate sensitivity to the innovation phases. Specifically, we compare the transmission of a monetary shock in scenarios characterized by different levels of technological production skills. To this end, we vary the parameters governing the adoption (λ) and creation (γ) of new technologies, in order to compare scenarios with high and low innovation intensity. Figure 6 displays the results. In line with the findings of the previous section (especially the dynamics associated with different ϑ values), the figure documents the exposure to business cycle contractions of an economy proficient in innovation activities. The negative impact of a monetary shock is sharper when the specialization in developing and adopting technology is high, suggesting worse repercussions for the economy as a whole when the innovations sectors feature high skills. The opposite can be observed in a scenario of *"low-low"* innovation intensity, confirming the importance of the deterioration of innovation activities in driving the amplification of short-run adverse shocks.

The most interesting results however refer to the two intermediate cases. We see that the more severe slumps are associated to a greater intensity of technology creation, suggesting that this phase exerts a larger influence than technology adoption on aggregate outcomes.

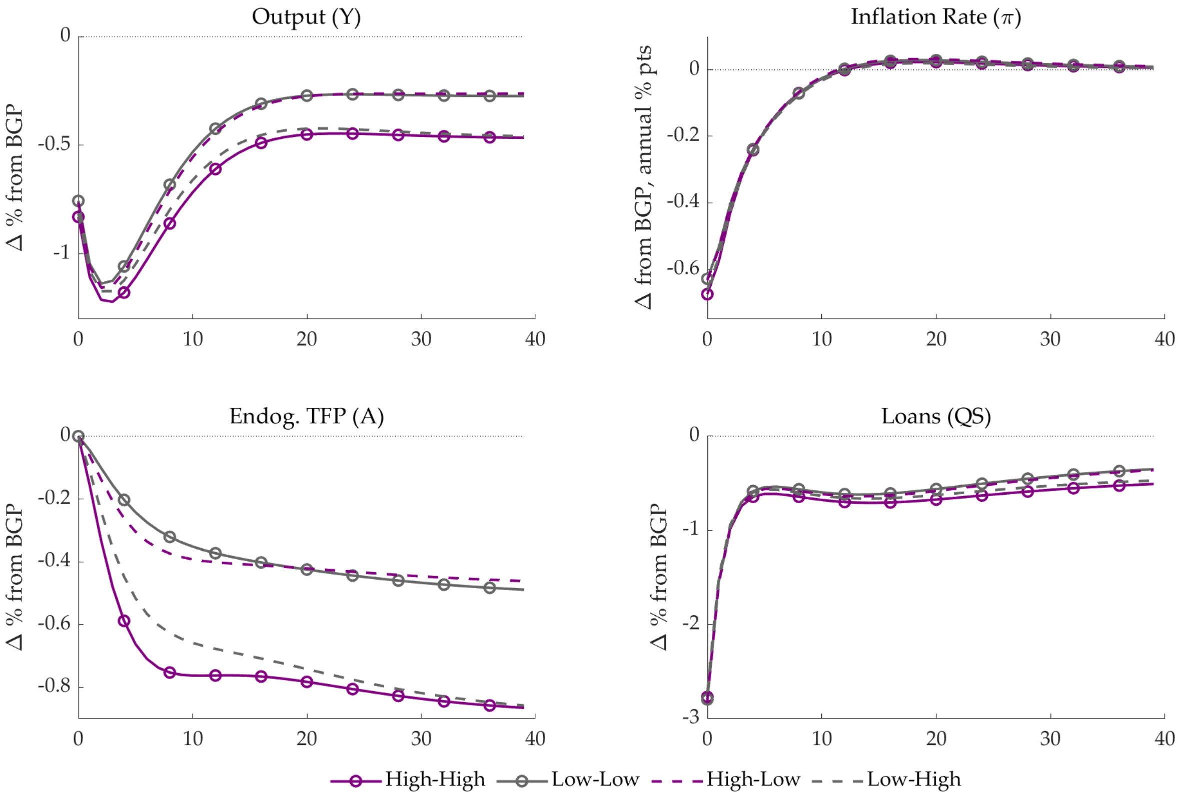


Figure 6: IRFs, Monetary Shock (+1 sd). High and Low Levels of Creation and Adoption

Impulse responses for the following combinations of creation and adoption of new technologies: high adoption - high creation (purple, solid-dotted); low adoption - low creation (grey, solid-dotted); high adoption - low creation (purple, dashed); low adoption - high creation (grey, dashed). Parameters vary by ±30% with respect to baseline values.

Thus, the more sophisticated the creation sector is, the deeper the recession when the activity of this innovation phase is harmed. Quantitatively, the average slump generated under high adoption and low creation (*"high-low"* case) amounts to 77% for output and 56% for TFP, relative to the *"low-high"* scenario. Finally, an interesting observation regards the behaviour of inflation, which appears to be quite insensitive to different levels of innovation intensity, in agreement with what seen in Figure 5.

7 Short- and Long-Run Stabilization

The analysis above points to the existence of long-run effects of monetary shocks. We now ask whether a central banker should take this into account when setting its conduct. In particular, we aim at ascertaining whether a direct response to variables mimicking future outcomes might help achieve better aggregate stabilization.

Following Christiano et al. (2015) and Vinci and Licandro (2021), we specify a conventional monetary policy that includes both short- and long-run variables as arguments (expressed as deviations from targets). In particular, we compare two Taylor rules: under the first, the central bank sets the policy interest rate in response to business cycle fluctuations, represented by movements of inflation and output (equation 51 of the model);[19] under the alternative rule, monetary policy expands its mandate to include proxies for prospective outcomes. This second, "growth-gap" Taylor rule targets deviations of inflation from target as well as the "growth gap", i.e the distance of the growth rate of output from its long-term value:

$$r_t = \varepsilon_t^{mp} \{r_{t-1}\}^{\rho_R} \left\{ \bar{r} \left(\frac{\pi_t}{\overline{\pi}} \right)^{\phi_\pi} \left(\frac{g_y^t}{\overline{g_y}} \right)^{\phi_y} \right\}^{1-\rho_R} . \tag{58}$$

Figure 7 displays the impulse responses to a monetary shock under the two Taylor rules. The "growth-gap" Taylor rule (dashed-dotted lines) proves to be undoubtedly worse than the commonly adopted rule (solid red lines). The ability to control the cycle appears to be impaired, with variables displaying a sharp deterioration on impact following a monetary shock. In addition, we observe scarring effects even at longer horizons, which

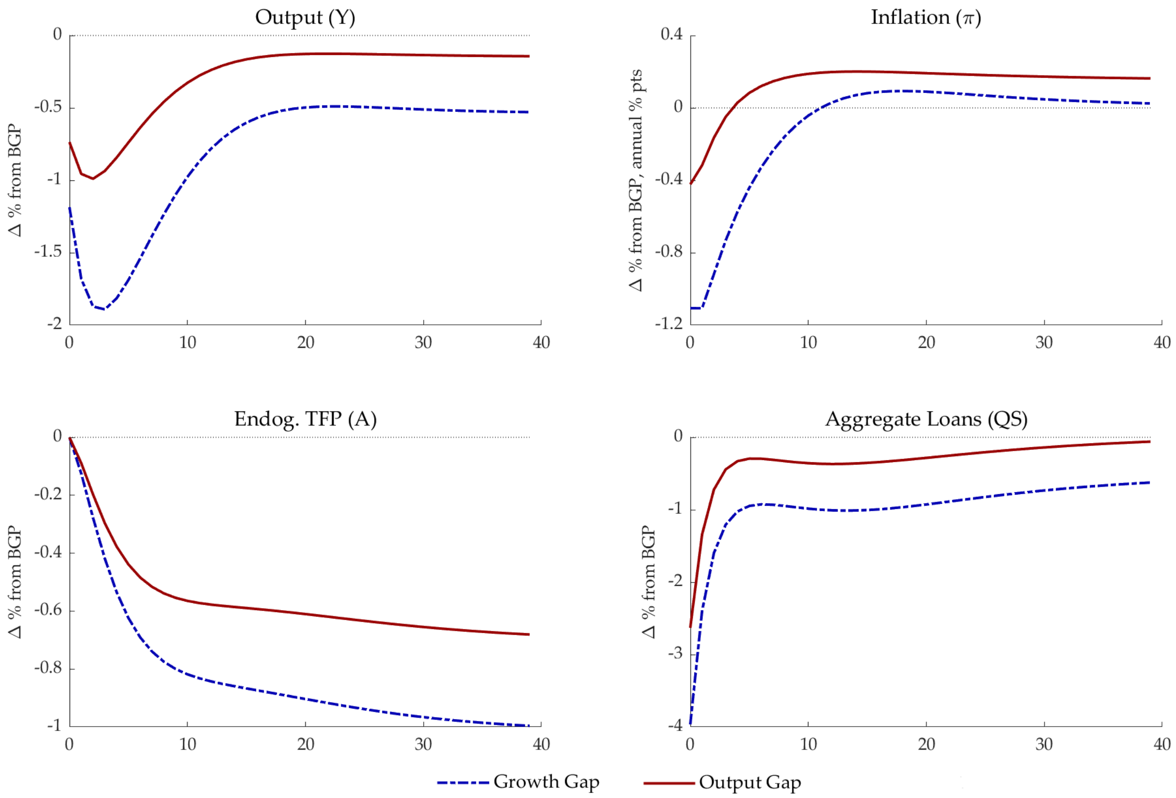


Figure 7: Impulse Responses to Monetary Shock (+1 sd). Alternative Taylor rules

[19] Here, to offer a fair comparison between rules, in this first specification we replace marginal costs from equation 51 with output.

suggests that just responding to GDP growth does not yield obvious benefits in terms of future stabilization. In our endogenous growth framework, indeed, an initial contraction is amplified and transmitted over time through the mechanisms discussed above, so that the larger initial impact implies larger and more persistent slumps.[20] Our results are in line with Vinci and Licandro (2021), who in a different context find that monetary rules targeting long-run (growth) outcomes do not outperform conventional monetary rules in speeding up the recovery from negative shocks.

8 Conclusion

This paper studies the transmission of monetary policy in an economy with endogenous innovation and growth and credit market frictions. We find that monetary policy shocks can generate long-lasting effects on macroeconomic aggregates, leading to persistent stagnation. We thus contribute to a growing literature that highlights monetary non-neutrality over longer horizons than generally believed.

In the paper, we first study empirically the effects of monetary shocks. We detect a significant adverse impact on variables driving innovation and credit conditions, associated with a persistent drop in GDP and productivity. We then rationalize these empirical findings through a theoretical model with endogenous growth and a frictional credit market. The analysis points to a powerful financial amplification channel that magnifies recessionary monetary shocks. A negative monetary shock worsens credit conditions, determining a drop in the financing of R&D investments. This, in turn, leads to a decrease in innovation activity and results in a persistent slowdown of TFP and output. Thus, the central banker faces a trade-off between short-term targets and long-term outcomes: a contractionary policy successfully controls inflation, at the cost of depressing future growth. Finally, we show the similarities between the effects of a monetary and a financial shock hitting directly the financial intermediation sector.

The analysis leaves relevant questions open. In particular, one could assess the influence of the ZLB on policy rates, such as that observed during the last decade, or of unconventional monetary policy measures and their ability to dampen the drawbacks on the

[20] This is also partly due to the fact that the alternative Taylor rule induces bigger deflationary effects, thus causing real loan rates to remain higher than under the conventional Taylor rule.

economic productive capacity of conventional monetary policy. We leave these and other issues to future research.

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A Appendix

A.1 Data

We estimate our empirical models over the span 1979:Q1 - 2015:Q4. Data on the following variables are obtained from the Federal Reserve Bank of St. Louis (FRED): Real GDP (GDPC1); Consumer Price Index, All Items (CPIAUCSL); Business Loans (BUSLOANS); 1-Year Treasury Bond Rate (GS1); Gross Private Expenditure in Research and Development (Y006RC1Q027SBEA). TFP levels are retrieved from TFP growth rates provided by the Federal Reserve Bank of San Francisco (Fernald, 2014), normalized around 2012:Q1 = 100. The GZ Credit Spread is the quarterly aggregation of monthly series provided by Favara et al. (2016). The number of granted patents is the quarterly aggregation of monthly data provided by the USPTO, Historical Patent Data Files. Nominal variables are transformed into real through the GDP deflator (GDPDEF). All variables enter in *log**100, except for interest rates and spreads.

A.2 Model Equations - Empirics

BVAR-IV, where, for lags $p = 2$, Y_t is the vector of endogenous variables, Y_{t-j} includes the lagged variables and B_j stores the estimated VAR coefficients, $\forall$ lag j. Prior coefficients are set according to Giannone et al. (2015).

$$Y_t = \sum_{j=1}^{p} B_j Y_{t-j} + u_t \tag{A.1}$$

A.3 Monetary Shock

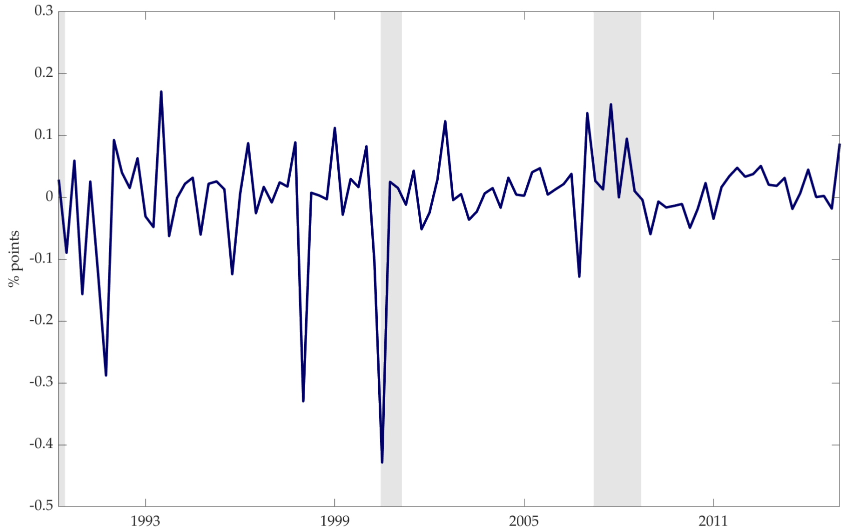

Figure A.1: Monetary Policy Instrument (MPI)

Quarterly version of the MPI series computed in Degasperi and Ricco (2021), 1991:Q1 - 2015:Q4 period.

	High Frequency (Monthly)	**Sum (Quarterly)**
Mean	9.9999 e-12	4.1633 e-19
Median	0.0129	0.0000
S.D.	0.0457	0.0829
Min	-0.3426	-0.4285
Max	0.2018	0.1712
# Obs.	300	100

Table A.1: Summary Statistics of Monetary Policy Shocks

Summary statistics of monetary policy shocks for the period 1991.1 - 2015.12. The high frequency instrument is provided in monthly frequency, from Degasperi and Ricco (2021). Our instrument is the time aggregated (quarterly) version of the latter, obtained by summing all shocks within a quarter.

A.4 Robustness - Theoretical Model

We report further IRFs to a monetary (figure A.2) and financial shock (figure A.3).

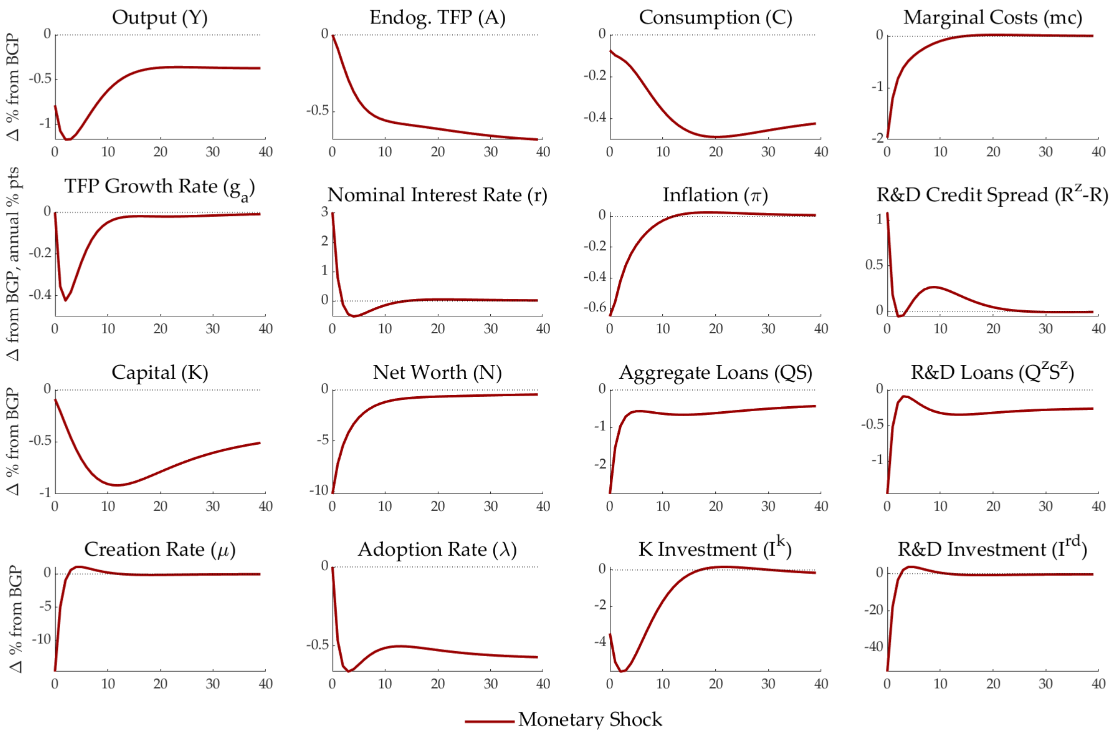

Figure A.2: Impulse Responses to a Monetary Shock (+1 sd)

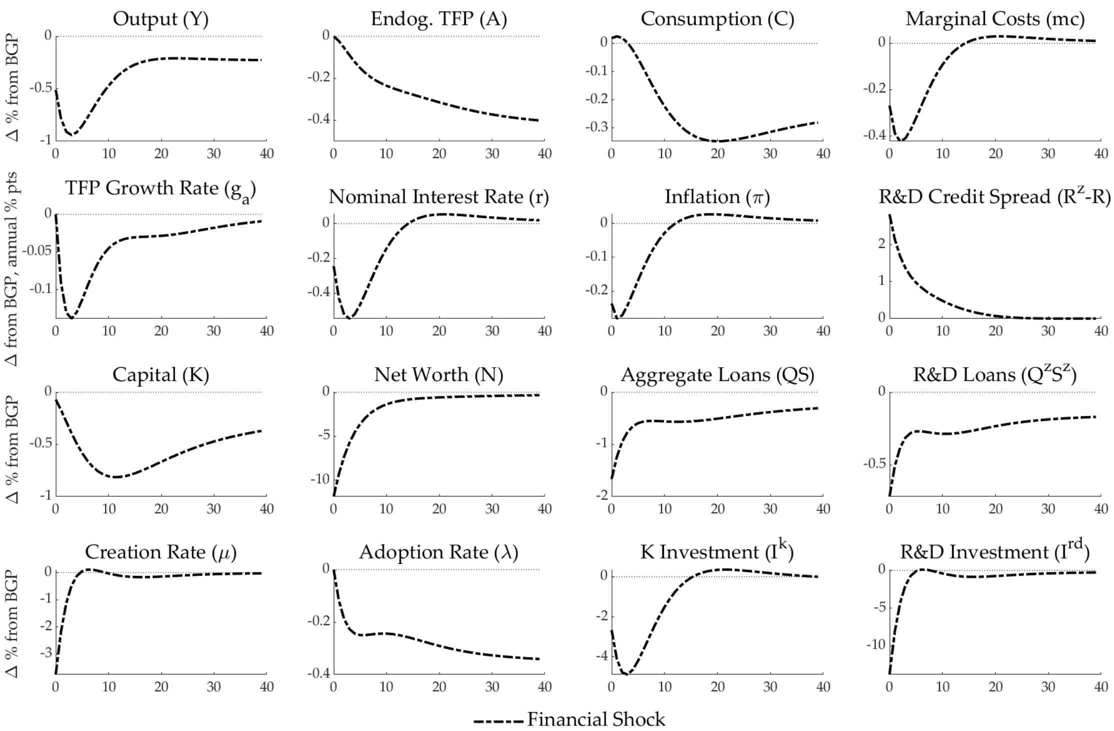

Figure A.3: Impulse Responses to a Financial Shock (-1 sd)

B Online Technical Appendix

B.1 Stationarized Model

A variable with tilde denotes the detrended version of the same variable: e.g., $\widetilde{X}_t = \frac{X_t}{g_y^t}$.

Households

$$\widetilde{u}_{ct} = \left(\frac{g_y \widetilde{C}_t - h\widetilde{C}_{t-1}}{g_y} \right)^{-1} - \beta h \left(\widetilde{C}_{t+1} g_y - h\widetilde{C}_t \right)^{-1} \tag{B.1.1}$$

$$\widetilde{u}_{ct} \widetilde{W}_t = \varrho L_t^{\varphi} \tag{B.1.2}$$

$$\Lambda_{t,t+1} = \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} \tag{B.1.3}$$

$$E_t \beta \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} R_{t+1} = 1 \tag{B.1.4}$$

Financial Intermediaries

$$\widetilde{v}_t^k = \beta \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} \left\{ (1-\sigma_t)(R_{t+1}^k - R_{t+1}) + \sigma_t x_{t,t+1}^k \widetilde{v}_{t+1}^k \right\} \tag{B.1.5}$$

$$\widetilde{v}_t^z = \beta \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} \left\{ (1-\sigma_t)(R_{t+1}^z - R_{t+1}) + \sigma_t x_{t,t+1}^z \widetilde{v}_{t+1}^z \right\} \tag{B.1.6}$$

$$\widetilde{\eta}_t^k = (1-\sigma_t) + \sigma_t \beta \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} z_{t,t+1}^k \widetilde{\eta}_{t+1}^k \tag{B.1.7}$$

$$\widetilde{\eta}_t^z = (1-\sigma_t) + \sigma_t \beta \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} z_{t,t+1}^z \widetilde{\eta}_{t+1}^z \tag{B.1.8}$$

$$\widetilde{z}_{t,t+1}^k = \left(R_{t+1}^z - R_{t+1} \right) \widetilde{\phi}_t^k + R_{t+1} \tag{B.1.9}$$

$$\widetilde{z}_{t,t+1}^z = \left(R_{t+1}^z - R_{t+1} \right) \widetilde{\phi}_t^z + R_{t+1} \tag{B.1.10}$$

$$\widetilde{x}^k_{t,t+1} = \frac{\widetilde{\phi}^k_{t+1}}{\widetilde{\phi}^k_t}\widetilde{z}^k_{t,t+1} \tag{B.1.11}$$

$$\widetilde{x}^z_{t,t+1} = \frac{\widetilde{\phi}^z_{t+1}}{\widetilde{\phi}^z_t}\widetilde{z}^z_{t,t+1} \tag{B.1.12}$$

$$\widetilde{\phi}^k_t = \frac{\eta^k_t}{\theta - v^k_t} \tag{B.1.13}$$

$$\widetilde{\phi}^z_t = \frac{\eta^z_t}{\theta - v^z_t} \tag{B.1.14}$$

$$\widetilde{\phi}_t = \widetilde{\phi}^k_t \frac{\widetilde{N}^k_t}{\widetilde{N}_t} + \widetilde{\phi}^z_t \frac{\widetilde{N}^z_t}{\widetilde{N}_t} \tag{B.1.15}$$

$$\begin{gathered} \widetilde{Q}^k_t \widetilde{S}^k_t = \widetilde{\phi}^k_t \widetilde{N}^k_t \\ \widetilde{Q}^k_t \widetilde{K}_{t+1} g_y = \widetilde{\phi}^k_t \widetilde{N}^k_t \end{gathered} \tag{B.1.16}$$

$$\begin{gathered} Q^z_t S^z_t = \phi^z_t N^z_t \\ \widetilde{Q}^{zz}_t \frac{\widetilde{Z}_{t+1}}{\widetilde{Z}_t} g_a = \widetilde{\phi}^z_t \widetilde{N}^z_t \end{gathered} \tag{B.1.17}$$

$$\widetilde{Q_t S_t} = \widetilde{\phi}_t \widetilde{N}_t \tag{B.1.18}$$

$$\widetilde{N}_t = \widetilde{N}^O_t + \widetilde{N}^N_t \tag{B.1.19}$$

$$\widetilde{N}^O_t = \widetilde{N}^{Ok}_t + \widetilde{N}^{Oz}_t \tag{B.1.20}$$

$$\widetilde{N}^N_t = \widetilde{N}^{Nk}_t + \widetilde{N}^{Nz}_t \tag{B.1.21}$$

$$\widetilde{N}^{Ok}_t = \sigma_t \widetilde{z}^k_{t-1,t} \frac{\widetilde{N}^k_{t-1}}{g_y} \tag{B.1.22}$$

$$\widetilde{N}_t^{Oz} = \sigma_t \widetilde{z}_{t-1,t}^{z} \frac{\widetilde{N}_{t-1}^{z}}{g_y} \tag{B.1.23}$$

$$\begin{aligned} N_t^{Nk} &= \epsilon^k Q_t^k S_{t-1}^k \\ \widetilde{N}_t^{Nk} &= \epsilon^k \widetilde{Q}_t^k \frac{\varepsilon_t^k \widetilde{K}_t g_y}{g_y} = \epsilon^k \widetilde{Q}_t^k \varepsilon_t^k \widetilde{K}_t \end{aligned} \tag{B.1.24}$$

$$\begin{aligned} N_t^{Nz} &= \epsilon^z Q_t^z S_{t-1}^z \\ \widetilde{N}_t^{Nz} &= \epsilon^z \widetilde{Q}_t^{zz} \frac{\varepsilon_t^z \widetilde{Z}_t g_a}{\widetilde{Z}_t g_a} = \epsilon^z \varepsilon_t^z \widetilde{Q}_t^{zz} \end{aligned} \tag{B.1.25}$$

$$\widetilde{N}_t^{O} + \widetilde{N}_t^{N} = \widetilde{N}_t^{k} + \widetilde{N}_t^{z} \tag{B.1.26}$$

Non-Financial Firms

$$\widetilde{S}_t^k = g_y \widetilde{K}_{t+1} \tag{B.1.27}$$

$$g_y \widetilde{K}_{t+1} = \widetilde{I}_t^k + \left(1 - \delta_t^k\right) \widetilde{K}_t \varepsilon_t^k \tag{B.1.28}$$

$$\widetilde{Q}_t^k = 1 + \Psi\left(\frac{\widetilde{I}_t^k}{\widetilde{I}_{t-1}^k}\right) + \left(\frac{\widetilde{I}_t^k}{\widetilde{I}_{t-1}^k}\right)\Psi'\left(\frac{\widetilde{I}_t^k}{\widetilde{I}_{t-1}^k}\right) - E_t \beta \frac{\widetilde{\Lambda}_{t,t+1}}{g_y}\left(\frac{\widetilde{I}_{t+1}^k}{\widetilde{I}_t^k}\right)^2 \Psi'\left(\frac{\widetilde{I}_{t+1}^k}{\widetilde{I}_t^k}\right) \tag{B.1.29}$$

Definitions:

$$\begin{aligned} L_t &= A_t L_{mt} \\ K_t &= A_t K_{mt} \\ U_t &= U_{mt} \\ mc_t &= \frac{P_{mt}}{A_t^{\vartheta - 1}} \end{aligned}$$

Moreover, assuming K and Y growing at the same rate along the BGP (L does not grow):

$$\frac{Y_t}{Y_{t-1}} = \left(\frac{A_t}{A_{t-1}}\right)^{\vartheta-1} \left(\frac{K_t}{K_{t-1}}\right)^{\alpha} \left(\frac{L_t}{L_{t-1}}\right)^{1-\alpha}$$

$$g_y^{1-\alpha} = g_a^{\vartheta-1}$$

Then, applying the definitions above, we get:

$$Y_t = A_t^{\vartheta} X_{mt}$$

$$Y_t = A_t^{\vartheta-1} X_t$$

$$\widetilde{Y}_t = \widetilde{A}_t^{\vartheta-1} \varepsilon_t^A \left(U_t \varepsilon_t^k \widetilde{K}_t\right)^{\alpha} L_t^{1-\alpha} \tag{B.1.30}$$

$$\pi_t = \left\{(1-\omega) p_t^{*\frac{1}{1-\varsigma}} + \omega \left(\pi_{t-1}^{\omega^{\pi}} \pi^{1-\omega^{\pi}}\right)^{\frac{1}{1-\varsigma}}\right\}^{1-\varsigma} \tag{B.1.31}$$

The Phillips curve is rewritten in terms of inflation rate π_t and optimal reset price $p_t^* = \left(P_t^*/P_{t-1}\right)$:

$$E_t \sum_{\tau=0}^{\infty} \omega^{\tau} \beta^{\tau} \frac{\widetilde{\Lambda}_{t,t+\tau}}{g_y} \left(\frac{p_t^* \Gamma_{t,t+\tau}}{\pi_{t+\tau}}\right)^{\frac{\varsigma}{1-\varsigma}} \left(\frac{p_t^* \Gamma_{t,t+\tau}}{\pi_{t+\tau}} - \varsigma mc_{t+\tau}\right) \widetilde{Y}_{t+\tau} = 0 \tag{B.1.32}$$

In the Matlab codes, we then follow the approach from Gertler and Karadi (2011) and express p_t^* as a function of the terms F_t^{pc}, Z_t^{pc}:

$$p_t^* = \left(\frac{F_t^{pc}}{Z_t^{pc}}\right)^{\frac{1-\varsigma}{1+\varsigma}}$$

where:

$$F_t^{pc} = E_t \sum_{\tau=0}^{\infty} \omega^{\tau} \beta^{\tau} \frac{\widetilde{\Lambda}_{t,t+\tau}}{g_y} mc_{t+\tau} \varsigma \left(\frac{\Gamma_{t,t+\tau}}{\pi_{t+\tau}}\right)^{-\frac{1}{1-\varsigma}} \widetilde{Y}_{t+\tau}$$

$$Z_t^{pc} = E_t \sum_{\tau=0}^{\infty} \omega^{\tau} \beta^{\tau} \frac{\widetilde{\Lambda}_{t,t+\tau}}{g_y} \left(\frac{\Gamma_{t,t+\tau}}{\pi_{t+\tau}}\right)^{\frac{\varsigma}{1-\varsigma}} \widetilde{Y}_{t+\tau}$$

Recursively, the same factors can be defined as:

$$F_t^{pc} = \left[mc_t \varsigma \left(\frac{\Gamma_t}{\pi_t} \right)^{-\frac{1}{1-\varsigma}} \widetilde{Y}_t \right]^{\frac{1-\varsigma}{1+\varsigma}} + \beta\omega \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} E_t F_{t+1}^{pc}$$

$$Z_t^{pc} = \left[\left(\frac{\Gamma_t}{\pi_t} \right)^{\frac{\varsigma}{1-\varsigma}} \widetilde{Y}_t \right]^{\frac{1-\varsigma}{1+\varsigma}} + \beta\omega \frac{\widetilde{\Lambda}_{t,t+1}}{g_y} E_t Z_{t+1}^{pc}$$

Then:

$$(1-\alpha)\, mc_t \frac{\widetilde{Y}_t}{L_t} = \mathcal{M} \widetilde{W}_t \tag{B.1.33}$$

$$\alpha\, mc_t \frac{\widetilde{Y}_t}{U_t} = \mathcal{M} \delta'(U_t) \widetilde{Q}_t^k \varepsilon_t^k \widetilde{K}_t \tag{B.1.34}$$

$$\alpha\, mc_{t+1} \frac{\widetilde{Y}_{t+1}}{\widetilde{K}_{t+1}} = \mathcal{M} \left\{ \widetilde{Q}_t^k R_{t+1}^k - \widetilde{Q}_{t+1}^k \left[1 - \delta(U_{t+1})\right] \varepsilon_{t+1}^k \right\} \tag{B.1.35}$$

Technology Sectors

Following Anzoategui et al. (2019), Q_t^A, Q_t^z are modified to embody the related technology A_t, Z_t. This way, they incorporate the trend and the terms Q_t^{AA}, Q_t^{zz} can be stationarized by g_y. Then, assuming Z_t and A_t growing at the same rate, a unique g_a is used to detrend technological output.

$$\widetilde{Q}_t^{AA} = \left(\frac{\mathcal{M} - 1}{\mathcal{M}} \right) mc_t \widetilde{Y}_t + \beta \widetilde{\Lambda}_{t,t+1} \left(1 - \delta^A\right) \widetilde{Q}_{t+1}^{AA} \frac{\widetilde{A}_t}{\widetilde{A}_{t+1} g_a} \tag{B.1.36}$$

$$\widetilde{I}_t^{rd} = \left\{ \frac{\widetilde{Q}_t^{zz} \varepsilon_t^z \gamma \chi_t - \widetilde{Q}_{t+1}^{zz} \frac{\widetilde{Z}_t}{\widetilde{Z}_{t+1}} \frac{g_y}{g_a} \left(1 - \delta^A\right) \varepsilon_{t+1}^z \gamma \chi_t}{\widetilde{Q}_t^{zz} (1 + \sigma_z)} \right\}^{\frac{1}{1-\gamma}} \frac{\widetilde{Q}_t^{zz} (1 + \sigma_z)}{\chi_t} \tag{B.1.37}$$

$$\lambda_t = \lambda \left(\varepsilon_t^z \widetilde{Z}_t \right)^{\rho} \left(\widetilde{A}_t \right)^{1-\rho} \tag{B.1.38}$$

$$\mu_t = \left(\chi_t \widetilde{I}_t^{rd} \right)^{\gamma} \left(\widetilde{A}_t \right)^{1-\gamma} \tag{B.1.39}$$

$$R_t^z = \frac{\widetilde{Q}_t^{zz}\left(1-\delta^A\right)\varepsilon_t^z + \beta\frac{\widetilde{\Lambda}_{t,t+1}}{g_y}\left(1-\delta^A\right)\left[\lambda\rho\left(\frac{\widetilde{A}_t}{\widetilde{\overline{Z}}_t}\right)^{1-\rho}\left(\varepsilon_t^z\right)^{\rho}\left(\widetilde{Q}_{t+1}^{AA}\frac{\widetilde{Z}_t}{\widetilde{A}_{t+1}g_a} - \widetilde{Q}_{t+1}^{zz}\frac{\widetilde{Z}_t}{\widetilde{\overline{Z}}_{t+1}g_a}\right)\right]}{\widetilde{Q}_{t-1}^{zz}\varepsilon_t^z\frac{\widetilde{Z}_t}{\widetilde{\overline{Z}}_{t-1}}\frac{g_a}{g_y}} \tag{B.1.40}$$

$$\widetilde{S}_t^z = \widetilde{Z}_{t+1}g_a \tag{B.1.41}$$

$$g_a\widetilde{A}_{t+1} = \lambda_t\left(1-\delta^A\right)\left(\varepsilon_t^z\widetilde{Z}_t - \widetilde{A}_t\right) + \left(1-\delta^A\right)\widetilde{A}_t \tag{B.1.42}$$

$$g_a\widetilde{Z}_{t+1} = \mu_t\varepsilon_t^z\widetilde{Z}_t + \left(1-\delta^A\right)\varepsilon_t^z\widetilde{Z}_t \tag{B.1.43}$$

Monetary Policy

$$r_t = \varepsilon_t^{mp}\left\{r_{t-1}\right\}^{\rho_R}\left\{\overline{r}\left(\frac{\pi_t}{\overline{\overline{\pi}}}\right)^{\phi_\pi}\left(\frac{mc_t}{\overline{\overline{mc}}}\right)^{\phi_y}\right\}^{1-\rho_R} \tag{B.1.44}$$

$$R_t = \frac{r_t}{\pi_{t+1}} \tag{B.1.45}$$

Market Clearing

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t^k\left\{1 + \Psi\left(\frac{\widetilde{I}_t^k}{\widetilde{I}_{t-1}^k}\right)\right\} + \widetilde{I}_t^{rd} \tag{B.1.46}$$

$$\widetilde{Q_tS_t} = \widetilde{Q}_t^k\widetilde{K}_{t+1}g_y + \widetilde{Q}_t^{zz}\frac{\widetilde{Z}_{t+1}}{\widetilde{Z}_t}g_a \tag{B.1.47}$$

B.2 Balanced Growth Path

The simulated baseline model is composed of the following variables (52 endogenous and 4 shocks).

Variable	Definition	Variable	Definition
Baseline Model			
C_t	Consumption	u_{ct}	Marginal Utility of Consumption
$\Lambda_{t,t+1}$	Stochastic Discount Factor	W_t	Real Wage
L_t	Labour	mc_t	Real Marginal Costs
p_t^*	Optimal Relative Price $\left(P_t^*/P_{t-1}\right)$	π_t	Inflation Rate
R_t^k	Return on Capital	R_t^z	Return on Technology
R_t	Real Gross Risk-free Interest Rate	r_t	Nominal Gross Risk-free Interest Rate
σ_t	Banks' Survival Probability	Y_t	Final Aggregate Output
K_t	Capital Stock	I_t^k	Capital Investment
U_t	Capital Utilization Rate	Z_t	Potential Technology
A_t	Effective Technology	I_t^{rd}	Technology Investment
μ_t	Innovation Probability	λ_t	Adoption Probability
g_y^t	Output Growth Rate	g_a^t	Endogenous TFP Growth Rate
Q_t^k	Price of Capital	Q_t^{zz}	Price of Unadopted Technology, scaled by Z_t $\left(Q_t^z Z_t\right)$
Q_t^{AA}	Price of Adopted Technology, scaled by A_t $\left(Q_t^A A_t\right)$	$Q_t S_t$	Aggregate Value of Loans
S_t^k	Loans to Capital Acquisition	S_t^z	Loans to Technology Acquisition
N_t	Banks' Net Worth	N_t^O	Existing Banks' Net Worth, Total
N_t^N	Entrant Banks' Net Worth, Total	N_t^k	Net Worth covering Capital Asset
N_t^z	Net Worth covering Technology Asset	N_t^{Ok}	Existing Banks' Net Worth, in K
N_t^{Oz}	Existing Banks' Net Worth, in Z	N_t^{Nk}	Entrant Banks' Net Worth, in K
N_t^{Nz}	Entrant Banks' Net Worth, in Z	v_t^k	Marginal Value of Capital Asset
v_t^z	Marginal Value of Technology Asset	η_t^k	Marginal Value of Net Worth to K
η_t^z	Marginal Value of Net Worth to Z	$x_{t,t+1}^k$	Growth Rate of Capital Asset
$x_{t,t+1}^z$	Growth Rate of Technology Asset	$z_{t,t+1}^k$	Growth Rate of Net Worth to K
$z_{t,t+1}^z$	Growth Rate of Net Worth to Z	ϕ_t^k	Optimal Leverage to Capital Asset
ϕ_t^z	Optimal Leverage to Technology Asset	ϕ_t	Optimal Aggregate Leverage Ratio
spk_t	Spread on K Loans	spz_t	Spread on Z Loans
ς	Mark up	ε_t^A	Exogenous TFP Shock
ε_t^{mp}	Monetary Policy Shock	ε_t^σ	Banks' Survival Rate Shock

Table B.1: List of Variables

We assume that the following conditions hold along the BGP: $\widetilde{Z} = 1$, $U = 1$, $\pi = 1$. L is calibrated according to conventional values for the labor share of the economy ($L = 0.33$).

$$\widetilde{u}_c = \left(\frac{g_y\widetilde{C} - h\widetilde{C}}{g_y}\right)^{-1} - \beta h\left(\widetilde{C}g_y - h\widetilde{C}\right)^{-1} \tag{B.2.1}$$

$$\varrho L^{\varphi} = \widetilde{u}_c \widetilde{W} \tag{B.2.2}$$

$$\widetilde{\Lambda} = 1 \tag{B.2.3}$$

$$R = \frac{g_y}{\beta} \tag{B.2.4}$$

Rearranging B.1.5, B.1.6, B.1.7, B.1.8, B.1.9, B.1.10, B.1.11, B.1.12, B.1.13, B.1.14, we obtain:

$$\widetilde{v}^k = \frac{\frac{\beta}{g_y}(1-\sigma)\left(R^k - R\right)}{1 - \frac{\beta}{g_y}\sigma\widetilde{x}^k} \tag{B.2.5}$$

$$\widetilde{v}^z = \frac{\frac{\beta}{g_y}(1-\sigma)\left(R^z - R\right)}{1 - \frac{\beta}{g_y}\sigma\widetilde{x}^z} \tag{B.2.6}$$

$$\widetilde{\eta}^k = \frac{1-\sigma}{1 - \sigma\frac{\beta}{g_y}\widetilde{z}^k} \tag{B.2.7}$$

$$\widetilde{\eta}^z = \frac{1-\sigma}{1 - \sigma\frac{\beta}{g_y}\widetilde{z}^z} \tag{B.2.8}$$

$$\widetilde{z}^k = \left(R^k - R\right)\widetilde{\phi}^k + R \tag{B.2.9}$$

$$\widetilde{z}^z = \left(R^z - R\right)\widetilde{\phi}^z + R \tag{B.2.10}$$

$$\widetilde{x}^k = \widetilde{z}^k \tag{B.2.11}$$

$$\widetilde{x}^z = \widetilde{z}^z \tag{B.2.12}$$

$$\widetilde{\phi}^k = \frac{\widetilde{\eta}^k}{\theta^k - \widetilde{v}^k} \tag{B.2.13}$$

$$\widetilde{\phi}^z = \frac{\widetilde{\eta}^z}{\theta^z - \widetilde{v}^z} \tag{B.2.14}$$

Substituting B.1.7, B.1.5 in B.1.13, and B.1.8, B.1.6 in B.1.14, the problem reduces to solving a second order equation (i.e. $aa\,\phi^{i2} + bb\,\phi^i + cc = 0$) for ϕ^k and ϕ^z, which are determined by the following coefficients:

$$aa = \theta^i \frac{\beta}{g_y}\sigma\, sp_i$$

$$bb = -(1-\sigma)\left(\theta^i - \frac{\beta}{g_y}sp_i\right)$$

$$cc = 1 - \sigma$$

while the auxiliary variables spk, spz denote premiums:

$$spk = R^k - R$$

$$spz = R^z - R$$

We calibrate the spreads on capital and intangible investments and derive the returns, given the risk-free interest rate R. Leverage ratios ϕ^k, ϕ^z are calibrated.

Then, from B.1.15:

$$\widetilde{\phi} = \widetilde{\phi}^k \frac{\widetilde{N}^k}{\widetilde{N}} + \widetilde{\phi}^z \frac{\widetilde{N}^z}{\widetilde{N}} \tag{B.2.15}$$

From B.1.16:

$$\widetilde{N}^k = \frac{\widetilde{Q}^k \widetilde{K} g_y}{\widetilde{\phi}^k} \tag{B.2.16}$$

From B.1.17:

$$\widetilde{N}^z = \frac{\widetilde{Q}^{zz} g_a}{\widetilde{\phi}^z} \tag{B.2.17}$$

From B.1.18 and B.1.47:

$$\widetilde{QS} = \widetilde{\phi}\widetilde{N} = \widetilde{Q}^k \widetilde{K} g_y + \widetilde{Q}^{zz} g_a \tag{B.2.18}$$

From B.1.19:

$$\widetilde{N} = \widetilde{N}^O + \widetilde{N}^N \tag{B.2.19}$$

From B.1.20:

$$\widetilde{N}^O = \widetilde{N}^{Ok} + \widetilde{N}^{Oz} \tag{B.2.20}$$

From B.1.21:

$$\widetilde{N}^N = \widetilde{N}^{Nk} + \widetilde{N}^{Nz} \tag{B.2.21}$$

From B.1.22:

$$\widetilde{N}^{Ok} = \sigma \widetilde{z}^k \frac{\widetilde{N}^k}{g_y} \tag{B.2.22}$$

From B.1.23:

$$\widetilde{N}^{Oz} = \sigma \widetilde{z}^z \frac{\widetilde{N}^z}{g_y} \tag{B.2.23}$$

From B.1.24:

$$\widetilde{N}^{Nk} = \epsilon^k \widetilde{Q}^k \frac{\widetilde{S}^k}{g_y} = \epsilon^k \widetilde{Q}^k \frac{\widetilde{K} g_y}{g_y} = \epsilon^k \widetilde{K} \tag{B.2.24}$$

In the codes, we obtain N^{Nk} given N^k, as follows:

$$\widetilde{N}^{Nk} = \widetilde{N}^k - \widetilde{N}^{Ok}$$

From B.1.25:

$$\widetilde{N}^{Nz} = \epsilon^z \widetilde{Q}^{zz} \frac{\widetilde{S}^z}{\widetilde{Z} g_a} = \epsilon^z \widetilde{Q}^{zz} \frac{\widetilde{Z} g_a}{\widetilde{Z} g_a} = \epsilon^z \widetilde{Q}^{zz} \tag{B.2.25}$$

In the codes, we obtain N^{Nz} given N^z, as follows:

$$\widetilde{N}^{Nz} = \widetilde{N}^z - \widetilde{N}^{Oz}$$

From B.1.26:

$$\widetilde{N}^{O} + \widetilde{N}^{N} = \widetilde{N}^{k} + \widetilde{N}^{z} \tag{B.2.26}$$

$$\widetilde{S}^{k} = \widetilde{K} g_{y} \tag{B.2.27}$$

$$\widetilde{I}^{k} = \widetilde{K}\left(g_{y} - 1 + \delta\right) \tag{B.2.28}$$

$$\widetilde{Q}^{k} = 1 \tag{B.2.29}$$

$$\widetilde{Y} = \widetilde{A}^{\vartheta-1}\widetilde{K}^{\alpha}L^{1-\alpha} \tag{B.2.30}$$

$$p^{*} = \pi \tag{B.2.31}$$

$$mc = \frac{1}{\varsigma} \tag{B.2.32}$$

$$\widetilde{W} = \frac{(1-\alpha)}{\mathcal{M}\varsigma}\frac{\widetilde{Y}}{L} \tag{B.2.33}$$

$$\delta^{k} = \delta\left(U\right) = \delta + \frac{b}{1+z}U^{1+z} \tag{B.2.34}$$

where δ, b, z are calibrated such that along the BGP, $U = 1$, and $\delta'(1) = \delta$.

$$R^{k} = \frac{\alpha\, mc\, \frac{\widetilde{Y}}{\widetilde{K}} - \mathcal{M}\left(\delta - 1\right)}{\mathcal{M}} \tag{B.2.35}$$

$$\widetilde{Q}^{AA} = \left[\left(\frac{\mathcal{M}-1}{\mathcal{M}\varsigma}\right)\widetilde{Y}\right]\left(\frac{g_{a}}{g_{a} - \beta\left(1-\delta^{A}\right)}\right) \tag{B.2.36}$$

From B.1.37:

$$\widetilde{I}^{rd} = \frac{\mu^{1/\gamma}\widetilde{Q}^{zz}\left(1+\sigma_{z}\right)}{\gamma} \tag{B.2.37}$$

From B.1.38:

$$\overline{\lambda} = \lambda \widetilde{Z}^{\rho} \widetilde{A}^{1-\rho} \tag{B.2.38}$$

From B.1.43:

$$\mu = g_a - \left(1 - \delta^A\right) \tag{B.2.39}$$

From B.1.40:

$$R^z = \frac{\widetilde{Q}^{zz}\left(1 - \delta^A\right) + \frac{\beta}{g_y}\left(1 - \delta^A\right)\left[\frac{\lambda\rho}{g_a}\left(\frac{\widetilde{A}}{\widetilde{Z}}\right)^{1-\rho}\left(\widetilde{Q}^{AA}\frac{\widetilde{Z}}{\widetilde{A}} - \widetilde{Q}^{zz}\right)\right]}{\widetilde{Q}^{zz}\frac{g_a}{g_y}} \tag{B.2.40}$$

$$\widetilde{S}^z = \widetilde{Z} g_a \tag{B.2.41}$$

From B.1.42:

$$\left(1 - \delta^A\right)\left(\lambda\widetilde{A}^{-\rho} - \lambda\widetilde{A}^{1-\rho} + 1\right) - g_a = 0 \tag{B.2.42}$$

$$R = \frac{r}{\pi} \tag{B.2.43}$$

$$\widetilde{C} = \widetilde{Y} - \widetilde{I}^k - \widetilde{I}^{rd} \tag{B.2.44}$$