Optimal Monetary Policy in the Presence of Financial Frictions

By

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Abstract

I study the welfare properties and the behavior of a model economy where financial intermediaries face endogenously determined balance sheet constraints and monetary policy follows simple instrument rules. An optimal commitment policy is used as a point of comparison. I use the framework to assess the performances of alternative interest rate rule regimes and to clarify the explicit target variables that contribute the most to the welfare-maximizing optimal monetary policy. I also evaluate the effects of unconventional monetary policy intervention and its interplay with the conventional inflation targeting Taylor-rule as well as the proposed optimal interest rate rule. My findings suggest that quantitative easing within my model framework have a moderating effect in a financial crisis situation under an inflation targeting regime but damaging effects under the optimal monetary policy. If monetary policy is conducted under a nominal GDP growth targeting regime in a crisis situation, then the benefits from this policy change is substantially higher than using unconventional tools.

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1 Introduction

The prolonged aftermath of the Financial Crisis of 2008-09 signaled that central banks are struggling to revive the economy in most developed countries. The crisis unveiled a concerning issue about inflation targeting that it might lack the appropriate monetary policy implications for financial stability and cannot prosper economic growth effectively. As a result, optimal monetary policy resurfaced at monetary policy debates along with nominal GDP targeting and price-level targeting as alternative monetary policy frameworks.

A growing number of studies have examined the implications of financial frictions in standard DSGE models. Although price-level targeting and nominal GDP targeting have practical qualitative aspects, they have not been under adequate scrutiny within the context of a quantitative framework which incorporates financial frictions. This thesis contributes to this literature by analyzing the main features of alternative interest rate rules within a financial accelerator New Keynesian model where financial intermediaries are balance sheet constrained. The model I use is built upon a simplified version of Gertler and Karadi (2011) which also allows us to investigate the effect of unconventional balance sheet operations of the central bank in a closed economy.

Specifically, in my thesis I characterize different types of interest rate rules that central banks could follow. Based on impulse response analyses, I consider the welfare gains from the different specifications of monetary policy and analyze the behavior of key macroeconomic variables under the alternative policy frameworks. I also assess the welfare implications of unconventional credit injections of the central bank. In the model economy, business cycles are driven by stochastic variations in the level of total factor productivity, government spending and capital quality. Shock to the quality of aggregate capital enables us to simulate a financial crisis situation and analyze the performances of the different specifications of interest rate rules in a crisis experiment.

My results suggest that the unconventional balance sheet operation of the central bank proves to be beneficial and increases welfare in the conventional inflation targeting regime but it is still far from optimal. On the other hand, nGDP growth targeting without unconventional

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tools is nearly an optimal monetary policy framework when there is distress in the financial market. In a crisis situation, the other alternative interest rate rules also performed better from a welfare perspective than unconventional IT, which implies that history-dependence might be an important factor in the conduct of monetary policy as Woodford (2003) suggested.

The remainder of the paper is organized as follows. Section 2 reviews the impact of the Financial Crisis on the conduct of monetary policy in the United States and the EU, focusing on the quantitative easing of the Fed. In this section, I also describe some of the main issues of inflation targeting and introduce other interest rate rule policies that central banks could consider as their conventional monetary policy framework. Section 3 reviews the relevant literature on optimal monetary policy, alternative interest rate rules and frictions in the financial sector. In Section 4 I present the alternative interest rate rules that I investigate in this paper, then describe the model economy sector-by-sector. The simulation results are discussed in Section 5, with a focus on a crisis experiment and the performances of the alternative policy frameworks in this scenario. Finally, Section 6 concludes.

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2 Background

Monetary policy framework in advanced economies is mainly characterized by some form of inflation targeting (IT), where central banks have an explicit target inflation rate in the medium term which they use to anchor inflation expectations. To achieve price stability, central banks use their official interest rates to influence a range of borrowing and lending rates set by commercial banks and other financial institutions and as a consequence, to tie down the price level in the long run. However, interest rates are usually bounded from below; thus, central banks cannot effectively adjust their nominal interest rate around the zero lower bound. When interest rates are at their lower bound there are several possibilities: central banks can engage in quantitative easing (QE), inject new money into the economy, or use expectations management or forward guidance.

In the wake of the Financial Crisis, the Federal Reserve quickly reduced its Federal Funds rate to effectively zero, reaching its maximum potential to drive economic growth. As a result, the United States, along with the EU and other developed countries, fell into a liquidity trap where people were no longer incentivized to invest and rather held onto their money, leading conventional monetary policies to be ineffective. This led many central banks to start expanding the monetary base by open market operations, where not only government securities were traded but also other debt instruments owned by financial institutions including asset- and mortgage backed securities.

Moving beyond the traditional tools of monetary policy, the Federal Reserve responded aggressively to the financial crisis by extending the scope of existing facilities (e.g. TSLF or PDCF)[1] as well as undertaking a massive QE program that caused its balance sheet to increase dramatically. Figure 2.1 shows the asset and liability structure of the Fed's balance sheet during their first credit easing and QE program. From March 2008, the Fed already started injecting credit directly to financially constrained major institutions by selling them US Treasury securities in exchange for longer-term or riskier securities. In the wake of the crisis, however, the Fed more than doubled its balance sheet size in two months and by 2015 it reached around $4.5

[1] In March 2008, the Federal Reserve established the Term Securities Lending Facility (TSLF) and the Primary Dealer Credit Facility (PDCF) to provide liquidity to primary dealers in exchange for other eligible collateral.

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trillion which is stagnating since. The bottom panel of Figure 2.1 shows the changes in liabilities that accompanied the Fed's QE program, more importantly the increase in the quantity of excess reserves for which the Fed is paying interest on. It should be noted that the drastic increase in the excess reserves held by the Fed should be seen as a by-product of the Fed's direct lending and large-scale asset purchase programs (Keister and McAndrews, 2009).

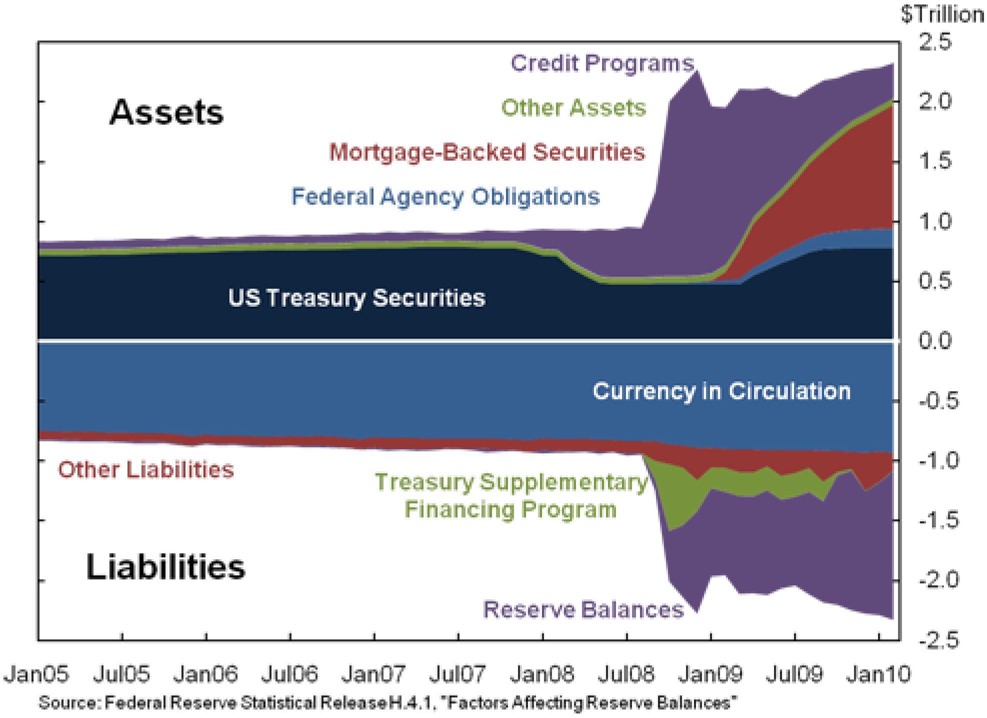

Figure 2.1: Assets and Liabilities of the Federal Reserve from 2005 till 2010

As we can see, direct lending and large-scale asset purchases of the Fed (and the EU) seem like a last resort of monetary policy to be effective and help to end the recession and promote economic recovery. The crucial questions, therefore, are how effective quantitative easing is, and how should monetary policy develop in the future to promote and maintain prosperity during business cycles. Hence, a burgeoning literature contributed to the analysis of two main topics of monetary policy: the effectiveness of unconventional monetary policy and optimal monetary policy. In the pursuit of optimal monetary policy, alternative monetary policy frameworks has been laid out for decades. With interest rates at effectively zero and a weak economy, many people started to criticize the current forms of inflation targeting regimes, and nominal GDP targeting and price-level targeting resurfaced at monetary policy debates. In the following section, I briefly mention some of the concerns with inflation targeting and then introduce the

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key concepts of the previously mentioned alternative policy frameworks.

2.1 Issues with inflation targeting

Despite its world-wide success before the Financial Crisis, certain drawbacks of inflation targeting has been at the focus of many researchers in academia and central banks since then. Inflation targeting came under fire and a key issue with it was the lack of monetary policy implications for financial stability. Instead of rehabilitating the conventional side of monetary policy, central banks opted for a range of unconventional tools to tamper the recession. But there are some basic issues as well with inflation targeting.

When an economy is experiencing inflation, it can either reflect supply side factors or demand side factors. If macroeconomic stability is the key objective of central bankers then different types of shocks have different implications for monetary policy. In the case of aggregate demand shocks, there is no trade-off between stabilizing inflation and output; however, when policymakers face a transitory supply shock, they have a short-run trade-off between stabilizing inflation and economic activity. It is sometimes difficult to find out which type of shock occurred and this is one of the key problems with strict inflation targeting because inflation alone is not a reliable guide as to whether an economy is overheating (due to strong demand) or below its potential level (due to negative supply shocks).

The main concern with inflation targeting, however, is the measurement of the output gap. Estimating the output gap (the difference between the actual output of an economy and its potential output) along the business cycle is difficult as it cannot be measured directly or known with certainty.[2] The vague concept of the output gap in the general public also contributes to the management of inflation expectations, which plays an essential role in the implementation of IT. Another concern with inflation targeting is the purely forward looking behavior, while policies that target an explicit level of a nominal anchor cares about past shortcomes as well. As Mark Carney (2012) said, "bygones are not bygones": past failures should affect future policy. As argued by Woodford (2003), a history-dependent policy can largely mitigate the effects of

[2]A famous speech given at the Conference on Price Measurement for Monetary Policy at the Federal Reserve Bank of Dallas was given by Mishkin (2007) who focused on the measurement issues regarding the potential output.

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adverse shocks and can improve stabilization outcomes.

Inflation targeting was always under scrutiny, even before crisis. To withstand the constant scrutiny, proponents argue that flexible inflation targeting gives policy makers some leeway that a simple Taylor rule cannot retain. As Bernanke et al. (1999b) pointed out, an inflation targeting monetary policy framework should be thought of as a constrained discretionary policy that even permits deviations of inflation in the short-run without incurring a loss in credibility. Flexibility is indispensable for an IT regime to work as monetary policy cannot react fast enough to contemporaneous shocks and perfectly control current inflation (Hallett et al., 2016).

2.2 Nominal GDP targeting

One tool in the armory of central banks would be implementing nominal GDP targeting as their monetary policy framework. Nominal GDP (nGDP) targeting is where the central bank sets an explicit path for nominal GDP or nominal income (e.g. 4% growth per year). Proponents of nGDP targeting argue that nominal GDP is a better indicator of the stance of an economy than inflation. Instead, nGDP targeting focuses on things that matters for the public, (e.g. employment stability or smoothing out the business cycle) and nominal GDP is a variable that is better correlated with stability in the labor market or smoothing out the credit cycles.

There are practical arguments against nominal GDP targeting such as nominal GDP is subject to large and frequent revisions. There could be credibility issues as well. Also, most of the public generally don't have a clear understanding of what nominal GDP is. On the other hand, advocates argue that nGDP targeting does not rely on proper estimates of the level of output gap, and thus can avoid using uncertain estimates in the interest rate setting policy. Also, flexible IT does almost the same as nGDP targeting since it does not focuses merely on inflation. The only difference is between the policy response to the second variable, either to respond to deviations in the output gap (IT) or output growth (nGDP). As such, nGDP growth targeting could be considered as a form of a flexible inflation targeting where monetary policy reacts equally to deviations of inflation and real output growth.

By targeting a path for the level of nominal GDP, monetary policy would be history-dependent since any past deviations from target would be undone in the future. This can help in managing

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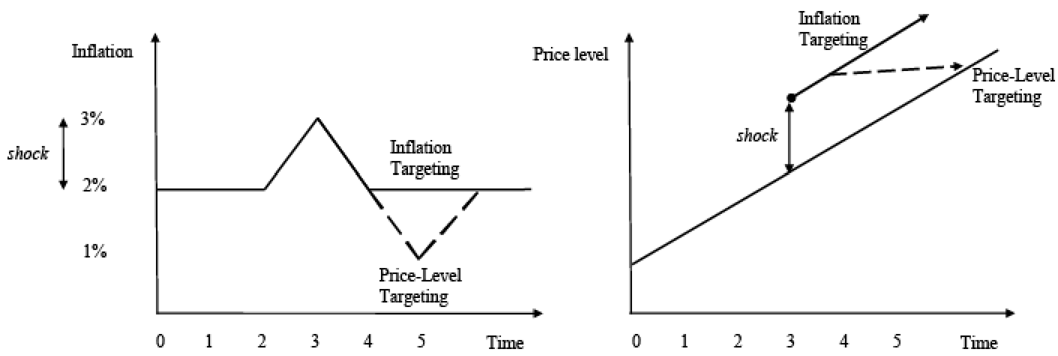
inflation expectations better; however, nGDP level targeting would allow larger inflation volatility in the short-run to offset the disruption in the real output. At the expense of higher inflation in the short-run, nGDP level targeting could get an economy out of a liquidity trap better than IT as we will see later.

2.3 Price-level targeting

In a price-level targeting (PT) regime, the central bank's aim is to stabilize price level around a predetermined target path. The key difference between price-level targeting and strict inflation targeting is that monetary policy not only reacts to inflation deviation but the previous price level deviation is also taken into account by the same amount. Hence, the main difference between inflation targeting and price-level targeting is the consequence of missing the target.



(Source: Hatcher and Minford (2014))

Figure 2.2: Implications of price-level targeting vs. inflation targeting

As Figure 2.2 illustrates, unanticipated shocks to inflation are treated as "bygones" under an IT regime and the shock to the inflation rate has a permanent effect on the price level since inflation targeting is purely forward looking (Ambler, 2009). On the other hand, past failures lead to corrective actions when the price level is the target and the central bank would act in order to reduce the price level back to its targeted level. Because the central bank is obliged to offset past inflationary shocks in this way, targeting prices (just as nGDP level targeting) is history-dependent (Woodford, 2003). This mechanism is important for understanding why price-level targeting gives different outcomes to inflation targeting in New Keynesian models.

If the monetary authority fails short to achieve the target price level, the public would know

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that corrective actions will take place next period, hence better management of expectations of expansionary future monetary policy could help the economy to escape a liquidity trap. This is one of the major advantages of PT, and why it is considered to replace the current IT regime, which has been struggling for a decade to revive and prosper economic growth.

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3 Related Literature

Quantitative evaluation of monetary policies gained a lot of attention long before the Financial Crisis. McCallum (1988) began to explore the properties and settings of an instrument rate rule by which the monetary authority specifies an instrument variable to achieve a specified target (e.g. keeping nominal GNP close to a 3% target growth rate). Then, in a seminal contribution, Taylor (1993) presented his famous Taylor-rule which called for an interest rate setting, which reacts to deviations in inflation and real output from their targets. Rotemberg and Woodford (1997) wrote a fundamental paper about the monetary policy implications of macroeconomics, where the authors developed a structural econometric model to quantitatively evaluate proposed rules for monetary policy. Optimal fiscal and monetary policy analysis in (medium-scale) DSGE models with staggered price settings became prominent in the early 2000s (e.g. Schmitt-Grohe and Uribe (2004a), Schmitt-Grohe and Uribe (2004b), Faia and Monacelli (2004), Benigno and Woodford (2004) and Schmitt-Grohe and Uribe (2007) among many others).

Although there is some disagreement on the specific framework that central banks should follow as their monetary policy, there is consensus that commitment is preferred to discretion. A rule-based policy can attain credibility and ensures the ability of commitment. A thorough quantitative analysis on the alternative monetary policy and optimal rules can be found in Woodford (2003) and Friedman and Woodford (2010). Researchers have already investigated the effects of the zero lower bound on nominal interest rates even before the crisis of 2007-08. Eggertsson and Woodford (2003) and Adam and Billi (2006) are great examples of the analysis of optimal monetary policy and interest rate rules at the zero lower bound.

However, most of the papers studying optimal monetary policy dates back before the crisis.[3] These papers tried to address questions such as how much inflation volatility should an economy have or which specific interest rate rules should central banks follow, and are conducted in the context of standard DSGE models with frictionless financial sectors undermining the potentially significant role of the stabilization capabilities of central banks under financial distress. In the post-crisis period, a growing number of studies have examined the implications of financial

[3] See Rotemberg and Woodford (1997), Eggertsson and Woodford (2003) and Schmitt-Grohe and Uribe (2007) among many others.

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frictions on the optimal conduct of monetary policy (e.g. Kolasa and Lombardo (2014), Curdia and Woodford (2015) and Adolfson et al. (2011)) in different settings, but their focus was more on the Ramsey-optimal monetary policy rather than alternative simple interest rate rules.

Price-level targeting has been surveyed by Ambler (2009) who assessed the costs and benefits of this alternative interest rate policy. His results suggest that the main benefit from a price-level targeting regime would be an improved trade-off between inflation and output when expectations are forward-looking. In 2006, the Bank of Canada launched a research program to identify the relative merits and the possible welfare improvements associated with PT. Cote (2007) analysis concluded that price-level targeting has promising prospects towards the future but before drawing strong conclusions, more research into this topic is needed.

As mentioned in Section 2.2, nGDP targeting does not rely on proper estimates of the level of output gap, and thus can avoid using uncertain estimates in the interest rate setting policy. In light of this, McCallum (1999), Orphanides (2003) and lately Sumner (2014) suggested that monetary policy should rather focus on alternative interest rate rules like nominal output growth. On a more quantitative basis, Garin et al. (2015) evaluated the welfare properties of nominal GDP targeting in the context of a New Keynesian model and similarly to my thesis compared it to other targeting rules as well. Their analysis showed that output gap targeting yielded the least welfare loss among the examined policy rules but nGDP level targeting performed almost as well.

Much of the literature, however, diverted towards the analysis of financial and credit frictions after the crisis. Standard New Keynesian models assume a frictionless banking sector where capital earns the same return as riskless bonds. The Global Financial Crisis led many researchers to abandon this simplifying assumption and started to investigate the effects of financial frictions in business cycles. The majority of macroeconomic models with financial frictions are either built upon some form of costly state verification problem following Carlstrom and Fuerst (1997) and Bernanke et al. (1999a) or include credit frictions via collateral constraints as in Kiyotaki and Moore (1997). A leading article that augments a standard dynamic general equilibrium model with the former is presented by Christiano et al. (2014), while Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) (which forms the basis of my model)

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follow the latter and include credit frictions in their models to evaluate the effects of unconventional monetary policies (i.e. direct central bank intermediation).

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4 The Model

In my model framework, the central bank is assumed to follow a simple conventional policy rule along with a credit policy rule[4]. As my focus here is to examine the main features of optimal monetary policy and to compare the efficiency of different alternative interest rate rules under a financial stress period, I describe the alternative conventional policy rules first in Section 4.1 and the rest of the model framework in Section 4.2.

4.1 Alternative interest rate rules

In each specification, the central bank's interest rate rule is characterized by interest-rate smoothing where the smoothing parameter ρ lies between zero and unity. A rule-based policy can attain credibility and ensures the ability of commitment. The model equations are derived under a zero inflation steady state, thus the price level is constant in the steady state and its level can be chosen arbitrarily. As such, I normalize the steady state price level to unity, so that $\bar{p} = 0$. The Fisher relation between the nominal and real interest rate is assumed to hold in each case. The alternative interest rate rules analyzed in this paper are the following:

- Inflation targeting:

$$i_t = \rho i_{t-1} + (1-\rho)\left(i + \kappa_\pi \pi_t + \kappa_x x_t\right)$$

- nGDP level targeting:

$$\begin{aligned} i_t &= \rho i_{t-1} + (1-\rho)\left(i + \kappa_z\left(z_t - \bar{z}\right)\right) \\ &= \rho i_{t-1} + (1-\rho)\left(i + \kappa_z\left(p_t + y_t - \bar{p} - \bar{y}\right)\right) \\ &= \rho i_{t-1} + (1-\rho)\left(i + \kappa_z \pi_t + \kappa_z p_{t-1} + \kappa_z\left(y_t - \bar{y}\right)\right) \end{aligned}$$

[4]See discussion about the credit policy rule later in Section 4.2 and 4.2.

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- nGDP growth targeting:

$$\begin{aligned} i_t &= \rho i_{t-1} + (1-\rho)\left(i + \kappa_z \left(z_t - z_{t-1}\right)\right) \\ &= \rho i_{t-1} + (1-\rho)\left(i + \kappa_z \pi_t + \kappa_z \left(y_t - y_{t-1}\right)\right) \end{aligned}$$

- Price-level targeting:

$$\begin{aligned} i_t &= \rho i_{t-1} + (1-\rho)\left(i + \kappa_p \left(p_t - \bar{p}\right)\right) \\ &= \rho i_{t-1} + (1-\rho)\left(i + \kappa_p \pi_t + \kappa_p p_{t-1}\right) \end{aligned}$$

where i_t represents the nominal interest rate set by the central bank, π_t and x_t denote inflation and output gap (actual from potential output) respectively, z_t denotes nominal GDP, p_t represents the aggregate price level of final output in the economy, y_t represents real output (or real GDP), $\bar{y}$ and $\bar{p}$ denote the target levels of real output and aggregate price level respectively and κ_π, κ_x, κ_z and κ_p are the policy reaction parameters. As I estimate my model under a zero balanced growth path, $\bar{y}$ coincides with the steady state value of y.

There are some key observations about the policy rules that should be noted. First, nGDP level targeting differs from price-level targeting with only one additional component as the former reacts not only to inflation and past price level deviations from target but to real output deviations from steady state as well. Second, as mentioned in Section 2.2, nGDP growth targeting can be taught of as a special form of a flexible inflation targeting policy where monetary policy reacts equally to deviations of inflation and real output growth. As we will see later, this change in the form of "output stabilization" has key implications towards the optimal conduct of monetary policy under financial distress.

4.2 Model setup

The rest of the model framework is closely related to the financial accelerator model developed by Gertler and Karadi (2011). In this model financial intermediaries are faced with an endogenous leverage constraint. Credit market frictions of this kind help to amplify and propagate

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shocks to the economy. The principal-agent problem is between the banks and the depositors, where the financial accelerator is an interplay between the banks' leverage and the cost of loanable funds.

Households

The unit mass of households consist of bankers and workers. In this setup, finitely-lived bankers are incorporated into the model, thus within each household there are two types . At any moment in time, a fraction of the bankers become workers and the same number of workers become bankers, who get a little lump-sum start-up capital from households. Otherwise, the household sector is fairly general; each household maximizes its lifetime utility function that is given by

$$E_t \sum_{i=1}^{\infty} \beta^i \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\varphi}}{1+\varphi} \right] \tag{4.1}$$

where C_t and L_t denote consumption and labor supply respectively at time t.

Households can save in riskless intermediary deposit or government bond, which in equilibrium are perfect substitutes, so there is no differentiation of them by the household sector. Let B_{t+1} be the total holdings of one-period risk-free assets, then households maximize (4.1) subject to the budget constraint:

$$C_t + B_{t+1} = W_t L_t + \Pi_t + T_t + R_t B_t$$

where W_t is the real wage, Π_t is lump-sum profits from all financial and non-financial firms, and T_t is lump-sum government transfer. The standard Euler-equation and the labor supply relation of the households maximization problem is given by:

$$\begin{aligned} 1 &= \beta E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} R_{t+1} \\ L_t^{\varphi} &= C_t^{-\sigma} W_t \end{aligned}$$

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Financial intermediaries

The financial intermediary (banking) sector is isomorphic to the one in Gertler and Karadi (2011). Though the reader can consult Gertler and Karadi (2011) for an elaborate discussion of this sector, I summarize the main elements and key equations of this part.

The intermediary balance sheet identity is given by:

$$Q_t S_{j,t} = N_{j,t} + B_{j,t+1}$$

where $S_{j,t}$ is the quantity of financial claims on non-financial (intermediate good-producing) firms, Q_t is the relative price of each claim, $N_{j,t}$ is the amount of wealth or equity that an intermediary holds at time t, and $B_{j,t+1}$ is the deposits that the intermediary obtains from households. Assets $Q_t S_{j,t}$ earn a stochastic return $R_{k,t+1}$, while deposits earn a non-contingent return R_{t+1}. Bank's net worth evolves according to

$$N_{j,t+1} = R_{k,t+1} Q_t S_{j,t} - R_{t+1} B_{j,t+1} = (R_{k,t+1} - R_{t+1}) Q_t S_{j,t} + R_{t+1} N_{j,t} \tag{4.2}$$

As (4.2) implies, the premium $R_{k,t+1} - R_{t+1}$ determines the changes in net worth above the risk-free rate. Notice that, like in Bernanke et al. (1999a), the stochastic return $R_{k,t+1}$ is the key driving factor behind the unexpected changes in the constrained agent's net worth.

Without frictions, the expected premium would be zero; otherwise banks would extend their capital purchases indefinitely. However, with frictions the expected premium will be positive, whereas the banks' ability to raise sufficient amount of borrowed funds is limited. To limit the banks' ability to expand its assets indefinitely, Gertler and Karadi (2011) introduce a principal-agent moral hazard problem between the intermediaries and the depositors. Every period bankers can choose to divert a fraction λ of their assets and transfer them to the household they belong to. When bankers divert the assets, the depositors can force the intermediary into bankruptcy and the remaining assets serve as bankruptcy assets. Due to this agency problem, the following incentive constraint must be satisfied:

$$V_{j,t} \geq \lambda Q_t S_{j,t}$$

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where $V_{j,t}$ is the maximized expected terminal wealth of the bank, which is defined by the present value of its expected future net worth.

I describe the optimization problem of the financial intermediary sector in Appendix A. The evolution for the banking sector's net worth is also derived in the Appendix and is given by:

$$N_t = \theta \left(\left(R_{k,t} - R_t \right) \phi_{p,t-1} + R_t \right) N_{t-1} + \omega Q_t S_{t-1} \tag{4.3}$$

where θ is the survival rate of bankers in each period and $\phi_{p,t} = \frac{Q_t S_t}{N_t}$ is the private leverage ratio. The first term in (4.3) is equity of the surviving bankers, while the last term is the start-up equity of new bankers. New bankers get a small lump-sum transfer from households equal to a fraction (ω) of last-period banking assets. The fraction per new banker is $\omega/(1-\theta)$, which is small enough to not matter for the household's decision-making. The start-up equity is necessary for new bankers to be able to borrow.

Credit policy

In addition to the banking sector, the government can also borrow from households at rate R_{t+1} and lend to non-financial intermediaries at rate $R_{k,t+1}$. Thus, the government earns a premium $R_{k,t+1} - R_{t+1}$ from its credit support. The government has no problem with commitment as its borrowing is unconstrained; however, there is an efficiency cost τ per unit of government credit. The rationale behind this deadweight loss is that raising government debt is usually costly or governments have hard times finding the best lending opportunities Gertler and Karadi (2011).

Accordingly, suppose that the government (or central bank) is willing to fund and intermediates an exogenous fraction ψ_t of assets. Then total assets (intermediated privately and publicly) are:

$$Q_t S_t = \phi_t N_t + \psi_t Q_t S_t$$

We can thus define total leverage ratio as:

$$\phi_t = \frac{\phi_{p,t}}{1 - \psi_t}$$

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where $\phi_{p,t}$ is the private leverage ratio defined before based on the banks' borrowing constraint. We can then write:

$$Q_t S_t = \frac{\phi_{p,t}}{1-\psi_t} N_t$$

Intermediate good-producing firms

Intermediate good-producing firms borrow funds $(Q_t S_t)$ from banks and purchase capital $(Q_t K_{t+1})$ with it. Unlike in Bernanke et al. (1999a), intermediate good-producing firms don't face frictions or borrowing constraint; however, frictions in the banking sector affect the availability and cost of borrowed funds. All intermediate good-producing firms employ a Cobb-Douglas production function:

$$Y_{m,t} = A_t \left(\xi_t K_t\right)^{\alpha} L_t^{1-\alpha}$$

where ξ_t is exogenous aggregate shock to capital quality. Incorporating shocks to capital quality, explicitly in this form, enables the model to adhere to crises. Upon granting the loan $Q_t K_{t+1}$ to intermediate good-producing firms in period t, the bank collects capital rent and left-over capital stock. Denoting intermediate output price as $P_{m,t}$, profit-maximization of the intermediate good-producing firms yields the capital rent and subsequently, the rate of return on loans:

$$R_{k,t+1} = \frac{P_{m,t+1}\alpha \frac{Y_{m+1}}{K_{t+1}} + Q_{t+1}\left(1-\delta\right)\xi_{t+1}}{Q_t}$$

Capital producers

Following Christiano et al. (2005), Burnside et al. (2004) and Christoffel et al. (2008), there is a perfectly competitive market where capital producers create physical capital. The physical capital stock evolves according to the following capital accumulation equation:

$$K_{t+1} = K_t \xi_t \left(1-\delta\right) + \left[1 - \Psi\left(\frac{I_t}{I_{t-1}}\right)\right] I_t$$

where $\Psi\left(1\right) = 0$, $\Psi'\left(1\right) = 0$, $\Psi''\left(1\right) > 0$, implying that there is a cost associated with changing

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the level of investment. The adjustment costs formulated in terms of the rate of change in gross investment is zero at the steady state, and this cost is increasing in the change in investment. Following the standard specification in the literature, the adjustment cost function is assumed to take the following form:

$$\Psi\left(\frac{I_t}{I_{t-1}}\right)=\frac{\psi}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2$$

with $\psi>0$.

A capital-producing firm's current-period profit function is given by:

$$\Pi_{c,t}=Q_t\left[K_t-K_{t-1}\xi_{t-1}\left(1-\delta\right)-\left[1-\Psi\left(\frac{I_t}{I_{t-1}}\right)\right]I_t\right]$$

In equilibrium, the capital producer's profit is zero, thus the profit maximization with respect to I_t sets the market price of capital, that is:

$$Q_t=1+Q_t\frac{\psi}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2+Q_t\psi\left(\frac{I_t}{I_{t-1}}-1\right)\frac{I_t}{I_{t-1}}-\beta E_t\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}Q_{t+1}\psi\left(\frac{I_{t+1}}{I_t}-1\right)\left(\frac{I_{t+1}}{I_t}\right)^2$$

Just as in Bernanke et al. (1999a), the adjustment cost function is specified in such a way that the price of capital goods in the steady state is equal to 1.

Retail firms and final good

Retailers $j\in[0,1]$ purchase intermediate goods, differentiate them costlessly, and sell them to the final-good producer, which has the standard CES production function:

$$Y_t=\left[\int_0^1 Y_{j,t}^{\frac{\epsilon-1}{\epsilon}}dj\right]^{\frac{\epsilon}{\epsilon-1}},\qquad \epsilon>1 \tag{4.4}$$

The final-good producer's profit-maximization implies the downward-sloping demand for each retailer's output:

$$Y_{j,t}=\left(\frac{P_{j,t}}{P_t}\right)^{-\epsilon}Y_t \tag{4.5}$$

Equations (4.4) and (4.5) produce the definition of the nominal price of the final good:

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$$P_t = \left[\int_0^1 P_{j,t}^{1-\epsilon} \, dj \right]^{\frac{1}{1-\epsilon}}$$

I introduce nominal rigidities following Christiano et al. (2005) and the standard New Keynesian framework. In each period a firm is unable to adjust its prices with probability γ. In between these periods, those who can freely adjust, index their prices to the lagged rate of inflation. The optimal pricing problem of the retailers is discussed in detail in Appendix B. As a result, if period t optimal price choice is denoted P_t^*, the optimization problem of the retailers yield:

$$P_t^{1-\epsilon} = (1-\gamma)\left(P_t^*\right)^{1-\epsilon} + \gamma P_{t-1}^{1-\epsilon}$$

Resource constraint and government policy

The resource constraint for the final good is given as:

$$Y_t = C_t + I_t + G_t + \tau \psi_t Q_t K_{t+1}$$

where the last term is expenditures on government intermediation. Government expenditures are financed by lump sum taxes and government intermediation, thus:

$$G_t + \tau \psi_t Q_t K_{t+1} = T_t + \left(R_{k,t} - R_t\right) \psi_{t-1} Q_{t-1} K_t$$

The government raises revenues at period t through taxes and earning a premium on the amount of intermediated assets by lending $\psi_{t-1} Q_{t-1} K_t$ in the previous period. As noted in Section 4.2, government intermediation involves an efficiency cost of τ, thus the total government spending in each period is assumed to be equal to an exogenous amount G plus $\tau \psi_t Q_t K_{t+1}$.

Following Gertler and Karadi (2011), I suppose that the interest rate rule is sufficient to characterize monetary policy in normal times without intermediating in the credit market; however; to analyze the effects of unconventional monetary policy in a crisis situation, the central bank follows a credit policy rule of:

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$$\psi_t = \psi + \kappa E_t \left[(ln\, R_{k,t+1} - ln\, R_{t+1}) - (ln\, R_k - ln\, R) \right]$$

where $\kappa \geq 0$, and ψ is the steady state fraction of publicly intermediated assets and $ln\, R_k - ln\, R$ is the steady state premium. In normal times (baseline scenario), the central bank sets $\kappa = 0$ but in a crisis situation, it responds aggressively to a rise in the credit spread and sets $\kappa = 100$.

4.3 Optimal monetary policy

Optimal monetary policy can be characterized by either a welfare-maximizing policy which maximizes the welfare of the representative agent, given frictions in the economics environment or with a linear quadratic objective function that well approximates this expected utility objective. As shown by Woodford (2003) and Friedman and Woodford (2010), policy objectives based on a second-order approximation to the welfare of the representative agent depends on the exact structure and first order conditions of the model. Although within the context of the model it would be preferable to derive an exact consumer welfare-based approximation to the loss function consistent with the microfoundations of the model, I will leave this for future work as the intricacy of the problem is outside of the scope of my thesis. Hence, following much of the traditional approach to optimal monetary policy, I consider the following decision problem based on Levin and Williams (2003) that minimizes an ad hoc quadratic intertemporal loss function of the form:

$$L_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left(\pi_t^2 + \lambda_x x_t^2 + \lambda_i \left(i_t - i_{t-1} \right)^2 \right)$$

where $\lambda_x,\ \lambda_i \geq 0$.

As Friedman and Woodford (2010) pointed out, the first two terms represent the welfare costs associated from nominal and real fluctuations from desired levels, while the third term captures welfare costs associated with large swings in interest rates (and presumably other asset prices). The weights assigned to the output gap and the first difference of the interest rate in the loss function are determined by the preferences of the central bank. As defined in Rudebusch and Svensson (1998), "strict" inflation targeting refers to the situation where the central

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bank only considers variations in the inflation in the loss function ($\lambda_x = \lambda_i = 0$), while non-zero weights on the other target variables is consistent with an interest-rate smoothing flexible inflation targeting policy, which loosely can be thought of as a characterization of conventional monetary policy in most developed countries. As Levin and Williams (2003) noted that the literature lacks consensus regarding the appropriate parameter values of the weights in the loss function, I will specify the weights following Adolfson et al. (2011).

This completes the description of the model. In the following section, I present the results and the impulse response analyses of the model with the different specifications of monetary policy.

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5 Model Results

5.1 Calibration

Table 1 reports the choice of parameter values for the baseline model and for the ones with different monetary policy rules. The baseline model contains 16 parameters from which 13 are conventional and follows standard values found in the literature, while 3 are specific to the financial intermediary sector developed by Gertler and Karadi (2011). First, I describe the choice of conventional parameter values, then move to discuss the model-related specific ones.

The parameters regarding the household sector (β, σ, φ) take conventional values. The discount factor β is calibrated to be 0.99, which implies an annual steady state real interest rate of 4%. The relative risk aversion parameter implies log utility for consumption to make the utility function consistent with a balanced growth path, in case I would introduce trend real growth into the model. The Frisch elasticity of labor supply φ^{-1} is set to a standard value. The capital share in intermediate output implies a steady state share of capital income roughly equal to one third. I set $\delta = 0.025$, which implies an annual rate of depreciation on capital equal to 10%. The investment-adjustment cost parameter is based on an average value estimated by Christiano et al. (2005). The elasticity of substitution between different goods implies a steady state markup of 20%. The Calvo price rigidity parameter implies an average price duration a bit more than one year.

In the baseline scenario, I switch off the credit policy intervention of the government and only take it into account under a crisis scenario to illustrate the effects of this kind of unconventional monetary policy. Gertler and Karadi (2011) analyzed the welfare gains from central bank credit policy and the optimal degree of intervention under different values of inefficiency cost of governmental intermediation. As such, if the central bank intermediates, I set the credit policy sensitivity parameter along with the efficiency cost of governmental intermediation according to their estimates, where the central bank intervenes quite aggressively in order to stabilize the economy and the widening credit spread under financial distress.

In the alternative interest rate rules, I set the interest rate smoothing parameter of the central

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bank to 0.8. Under the baseline inflation targeting regime, I use the conventional Taylor rule parameters of 1.5 for the feedback coefficient on annual inflation and 0.5 on the annualized output gap. The $\kappa_x = 0.125$ value used in the model results from rewriting the original Taylor rule in terms of quarterly interest and inflation rates. Under nominal income and price-level targeting, I set the monetary policy responsiveness parameters to fairly moderate values ($\kappa_z = \kappa_p = 1.5$) to match the feedback coefficient on inflation in the inflation targeting policy rule. For the calibration of the quadratic intertemporal loss function I follow Adolfson et al. (2011).

The remaining 3 parameters (λ, θ, ω) are specific to the financial sector of this model. I picked these parameters to calibrate the model to have a steady state interest rate spread of one hundred basis points, a steady state private leverage ratio between $4-5$, and an average horizon of bankers of ten years.

5.2 Impulse response analysis

Figures C.1 to C.3 show the impulse response functions of the baseline inflation targeting model to three distinct structural shocks: a transitory technology shock, a government spending shock and a capital quality shock. The first two shocks provide examples of a supply and a demand shock respectively, while the third one is meant to illustrate a financial crisis situation. All impulse responses are reported as percentage deviations from the model's non-stochastic steady state, except for those of the nominal and real interest rates and the credit spread (premium), which are reported as annualized percentage-point deviations. As a point of comparison, the impulse responses from the optimal commitment monetary policy is depicted as well.

5.2.1 Technology shock

The impulse response functions of the baseline model (IT) to a one-standard-deviation TFP shock are presented in Figure C.1. The technology shock follows an AR(1) process with a quarterly autoregressive factor of 0.9.

The decrease in productivity produces the usual hump-shaped response of the real GDP, where the trough of the cycle is at the third quarter. As the transitory technology shock triggers a marked increase in real marginal cost, it increases the relative intermediate output prices and

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the aggregate price level as well. Due to price stickiness the demand side adjusts sluggishly, and as a consequence, output declines less than it would by having flexible prices, which creates a positive output gap. As the supply shock creates a short-run trade-off between stabilizing inflation and output, monetary policy under an inflation targeting framework aims at counteracting the induced inflationary pressure by slightly increasing the nominal interest rate. Under this flexible IT regime, the central bank does not stabilize the inflation immediately because its reaction parameter $\kappa_{\pi} = 1.5$ is not aggressive enough to threaten economic agents that it will react strongly to deviations in inflation from target. It takes approximately 3 years for inflation to reach its steady state.

As the optimal commitment policy is shown in Figure C.1, it is worth noting a couple of key differences between the two policies. As we can see, the optimal policy stabilizes the inflation and the output gap in just 6 quarters, which is half of what the monetary authority could achieve under IT. The main reason for this, is because optimal monetary policy responds much more aggressively to deviations of its targets. Under the optimal commitment policy, the nominal interest rate increases four times as much as under IT. Due to the trade-off, the consequence of this aggressive policy results in a 20% higher decline in the trough of the real output response and remains slightly under all periods. The amplification of the optimal policy responsiveness is also seen in the reaction of investment, capital and equity, which are all below the IT counterparts. The main difference, however, is in the estimated loss from the structural supply shock. Over a 5 year period, the estimated loss from a temporary technology shock is 21 times larger in the IT regime than under an optimal commitment policy framework.

5.2.2 Government spending shock

The impulse response functions of the baseline model (IT) to a one-standard-deviation government spending shock are presented in Figure C.2. The technology shock follows an AR(1) process with a quarterly autoregressive factor of 0.85.

The decline in premium stimulates the demand for capital, which in turn further stimulates investment and the price of capital. Similarly to Bernanke et al. (1999a), the central mechanism is the unanticipated increase in asset prices associated with the initial rise in investment, which

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raises the net worth of bankers, which in turn decreases the premium and further stimulates investment. The negative demand shock puts downward pressure on output and inflation, so the "divine coincidence" of Blanchard and Gali (2007) is present. As such, monetary policy can stabilize both by lowering nominal interest rates. Due to the lack of trade-off, the recovery of the economy is much quicker than at a supply side shock. The persistent government expenditure shock generates an increase in unemployment and the (negative) crowding-out effect is also clear in both consumption and investment.

Moving on to the comparison of the impulse responses generated under an IT regime and the optimal monetary policy framework, we can see that again there is a stark difference in the policy aggressiveness. Under the optimal policy, inflation and output gap remain fairly stable and normalize after 6 quarters due to the substantial monetary easing. The sluggish response of capital and equity are also amplified and the deviations from their non-stochastic steady state are twice as much under the optimal policy than under inflation targeting. As the negative demand shock produces an output decline larger than its potential counterpart, a persistent negative output gap characterizes the conventional policy. This explains the short and medium run loss difference between the two policies.

5.2.3 Crisis experiment

Now I turn to the crisis experiment, which tries to mimic a financial crisis situation with a following prolonged recession. Following Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), the initiating disturbance is an exogenous decline in capital quality. The initial size of the shock is set to 5%, with a quarterly autoregressive factor of 0.66. This transitory capital quality shock is calibrated to capture the observed decline in real output (in the baseline scenario) and capture some of the dynamics of intermediary balance sheets. The initial decline in capital quality reduces the value of intermediary assets, which in turn affects their value of net worth because of the endogenous leverage constraint. The weakening of intermediary balance sheets induces a drop in asset demand, which reduces asset prices and investment. As banks start to deleverage, the economy steps into downward spiral effect, which amplifies the initial shock to capital.

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First, I consider the behavior of the baseline model without credit policy and then illustrate the effects of this type of unconventional monetary policy. In both cases, the optimal commitment policy is used as a point of comparison, as this is the main focus of the thesis.

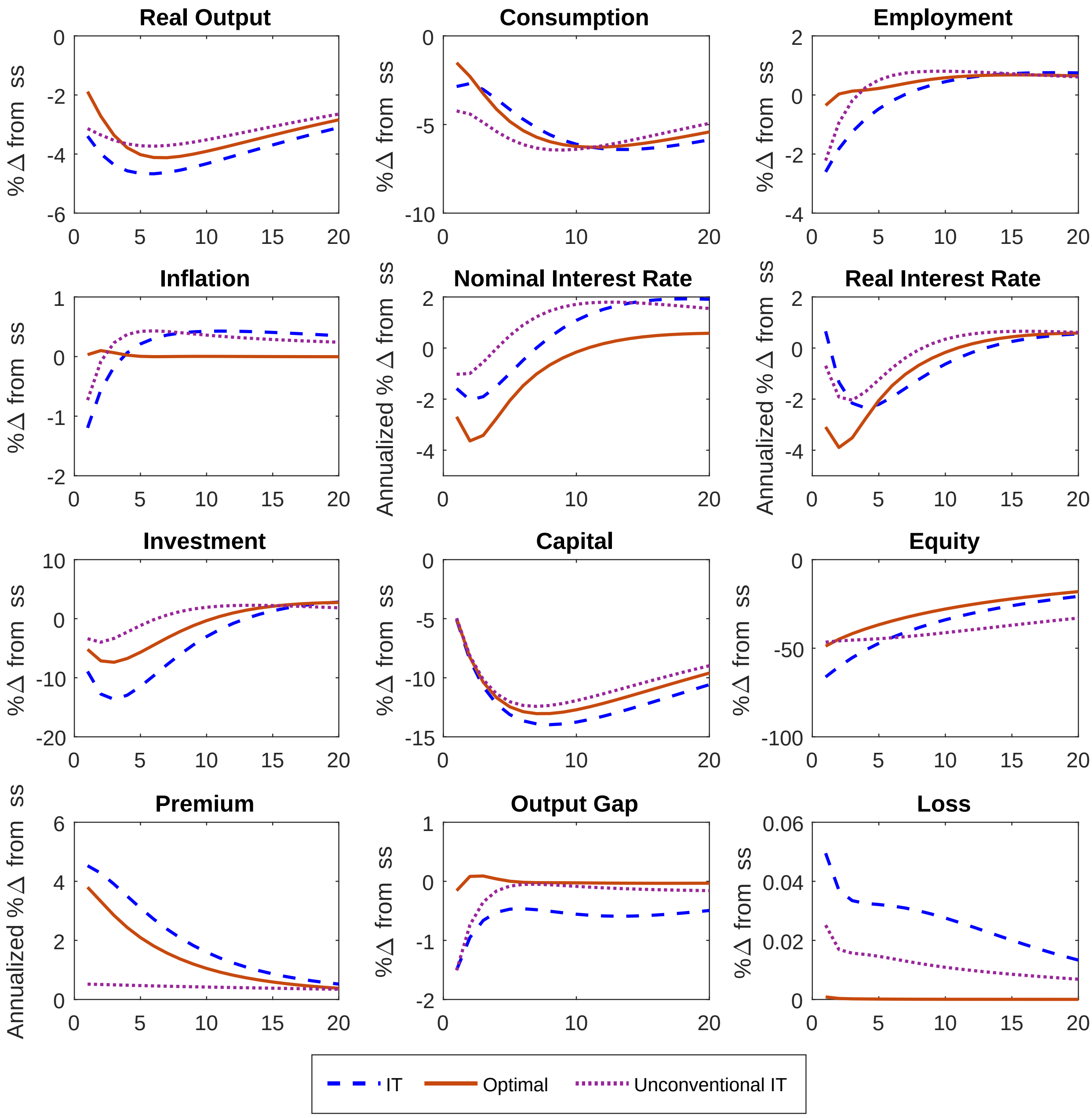

Figure 5.1: Impulse responses to a 5% negative capital quality shock - Inflation targeting with credit policy, crisis scenario (percentage deviations from steady state by quarters)

As Figure 5.1 illustrates, the initiating shock to capital produces a $3 - 3.5\%$ decline in consumption and output. The output decline at the trough is roughly -4.7%. The 5% decline in the quality of capital leads to a roughly 65% decline in the net worth of the intermediaries. The

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enhanced decline in the banks' net worth is attributed to the leverage constraint and the fall in asset prices. The contraction in asset prices also induces a drop in investment, which is roughly 2.5 times larger, on average, than the output decline during the first two years. Associated with the drop in intermediary capital, the premium increases. The slow recovery of output is accompanied by a persistently above-trend credit spread movement and a delayed deterioration of intermediary capital.

As my model is a simpler version of Gertler and Karadi (2011) apart from the intermediary sector, nominal interest rate falls by only 2% (annualized) compared to their 5%, thus the zero lower bound constraint is satisfied. However, as optimal monetary policy would indicate, the central bank should decrease its policy rate approximately twice as much as under inflation targeting. As opposed to the baseline IT specification, the greater loosening of optimal monetary policy stabilizes inflation and output gap almost perfectly. As a consequence, the decline in investment and equity moderate. One caveat to conduct monetary policy optimally is the lower bound constraint on the policy rate. Absence further shocks to the economy, the optimal interest rate remains just above zero; however, assuming the economy is below its trend the constraint would be binding, which would enhance the decline in output and the contractions in the economy.

Now I turn to the case where the monetary authority tries to offset the severe capital quality shock with the help of governmental intermediation. Since the central bank aggressively injects money into the economy when the credit spread widens, the premium remains moderately close to its steady state value. As such, the decline in asset prices and investment is even more modest than under optimal monetary policy. Apart from the earlier periods after the shock, inflation targeting with a credit policy can offset the decline in the output gap and alleviate the recession much better than just conventional inflation targeting monetary policy. This is in line with the findings of Gertler and Karadi (2011). Another key observation is the lack of need to decrease the policy rate. As the credit policy can partly substitute the interest rate setting of the central bank, the policy rate decreases even less than without governmental intermediation. This shows that if nominal interest rates are close to their lower bound, unconventional monetary policy can still be effective. The loss function also tells us that inflation targeting with an aggressive credit

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policy is closer to the optimal policy and increases welfare compared to its purely conventional counterpart.

One key observation is that both conventional and unconventional IT fails to manage inflation expectations in the short-run. The lack of history-dependence is a drawback of the purely forward-looking IT regime with or without a credit policy since it implies a less effective use of the expectations channel of monetary policy (Woodford, 2003).

5.2.4 Performances of the alternative monetary policy regimes

As we have seen in the previous section, inflation targeting with a credit policy performed better from a welfare perspective than just conventional inflation targeting. However, incorporating history-dependence or output growth stabilization into the interest rate setting of the central bank might prove to be beneficial from a welfare perspective and could manage inflation expectations better in the short-run. In the following, I assess the performance of the alternative interest rate rules mentioned in Section 4.1.

Figure 5.2 shows the impulse response functions under the alternative monetary policy frameworks in the same crisis experiment. The initial decline in capital quality triggers the financial accelerator mechanism of the model as previously; however, monetary policy reactions to deviations of their target variables have different implications for the impulse responses of key macroeconomic variables.

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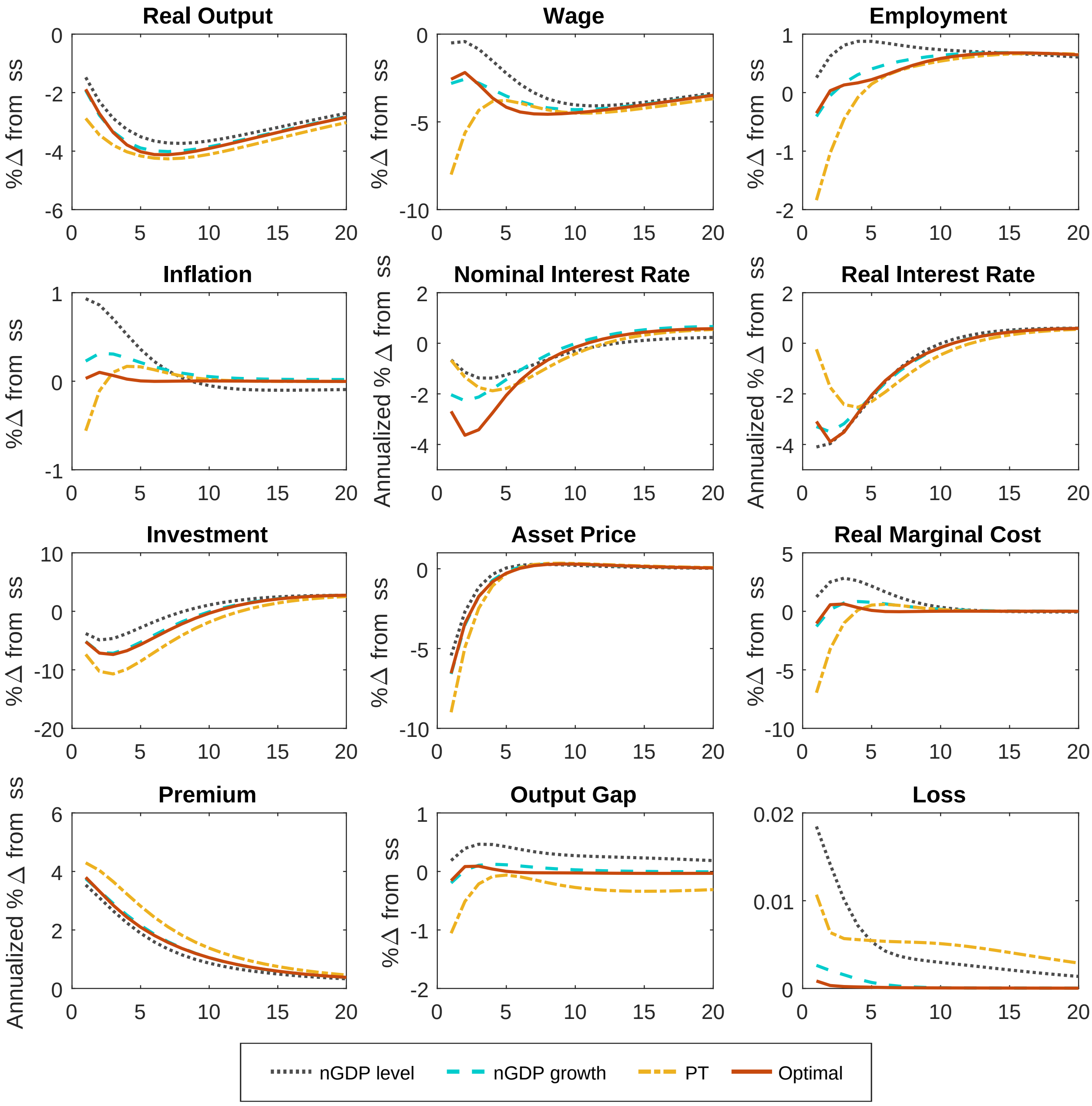

Figure 5.2: Impulse responses to a 5% negative capital shock - Alternative interest rate rules, crisis scenario (percentage deviations from steady state by quarters)

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Price-level targeting

Starting with price-level targeting, monetary policy does not take into account output stabilization and only reacts to current inflation and the previous aggregate price level. As a consequence, the contraction in output is the largest across the alternative policy rules. Aggregate demand, wages and employment falls initially together with the rate of return on capital, which causes an amplified decline in the real marginal cost. In models with staggered price setting, as in the standard New Keynesian DSGE models, inflation is a function of current and future expected real marginal costs. The real marginal cost is an increasing function of the wage rate and the rental rate of capital (Christiano et al., 2005). Monetary policy does not respond strongly enough to offset the contractions in the economy since it does not stabilize output directly. This allows real marginal costs and output gap to fall in impact., which explains the decline in the inflation rate. However, since price-level targeting is history-dependent, it is able to manage inflation expectations in the short-run, which contributes to smaller welfare loss than unconventional IT.

nGDP level targeting

As emphasized in Section 4.1, nGDP level targeting augments its interest rate setting with a reaction to real output deviation from the steady state target level as compared to price-level targeting. This, however, has several key implications towards the dynamics of the economy, which differs considerably from price-level targeting. As opposed to inflation targeting, nGDP level targeting is concerned with the output gap from the steady state level, while the former is concerned with the output gap from its potential level. Secondly, nGDP level targeting gives higher weight to output than IT; hence the contraction in real output is the modest among the alternative policy rules. Since nGDP level targeting focuses on stabilizing the nominal output, the central bank allows the price level to increase just as much to offset the decline in real output. As monetary policy does not let the real output to fall sufficiently, the economy is overheated, which is reflected in the positive output gap. The eventual need to bring prices back to steady state makes a prolonged period of below target inflation rate necessary when real output starts growing again.

One important observation that is also made by Motyovszki (2013), is that even though nGDP level targeting is a stricter monetary policy framework than inflation targeting regarding the reaction parameters, the central bank does not have to engage in as aggressive monetary easing as in the case of flexible IT, and still can achieve outcomes associated with a looser policy. As Motyovszki (2013) noted: “the power of the more efficient expectations channel does much of the work, rather than the brute force of actually lowering interest rates”.

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nGDP growth targeting

From a welfare perspective, nGDP growth targeting comes closest to the optimal monetary policy under a crisis scenario. By nearly replicating the optimal responses of the variables of the model, the resulting welfare loss is negligible compared to other interest rate rules. The nominal interest rate decreases by the same amount as under the inflation targeting framework, which is still not as sharp as optimal policy would indicate; however, inflation does not increase as much as under nGDP level targeting but remains relatively modest. As the output gap is almost perfectly stabilized, the only welfare loss takes place in the first 2 years after the initiating shock while inflation is above the target path.

Since nGDP growth targeting is almost optimal, it suggests that a credit policy would worsen the performance of this policy framework. Indeed, as shown in Figure C.4, the active credit policy increases the supply of money, which ultimately raises inflation expectations and lead to increased prices. Similarly to IT, the credit policy helps to alleviate the deterioration of output and even boosts investment after 3 quarters but the increased inflation rate and positive output gap result in a larger welfare loss than just conventional nGDP growth targeting. The only justification to employ unconventional tools in this framework would be the case of the zero lower bound; however, the initial drop in the policy rate is of similar magnitude.

As nGDP growth targeting performed the best among the alternative interest rate rules, it is worth comparing it to the unconventional inflation targeting monetary policy framework, which is thought to be a characterization of monetary policy in the United States and the European Union after the Financial Crisis.

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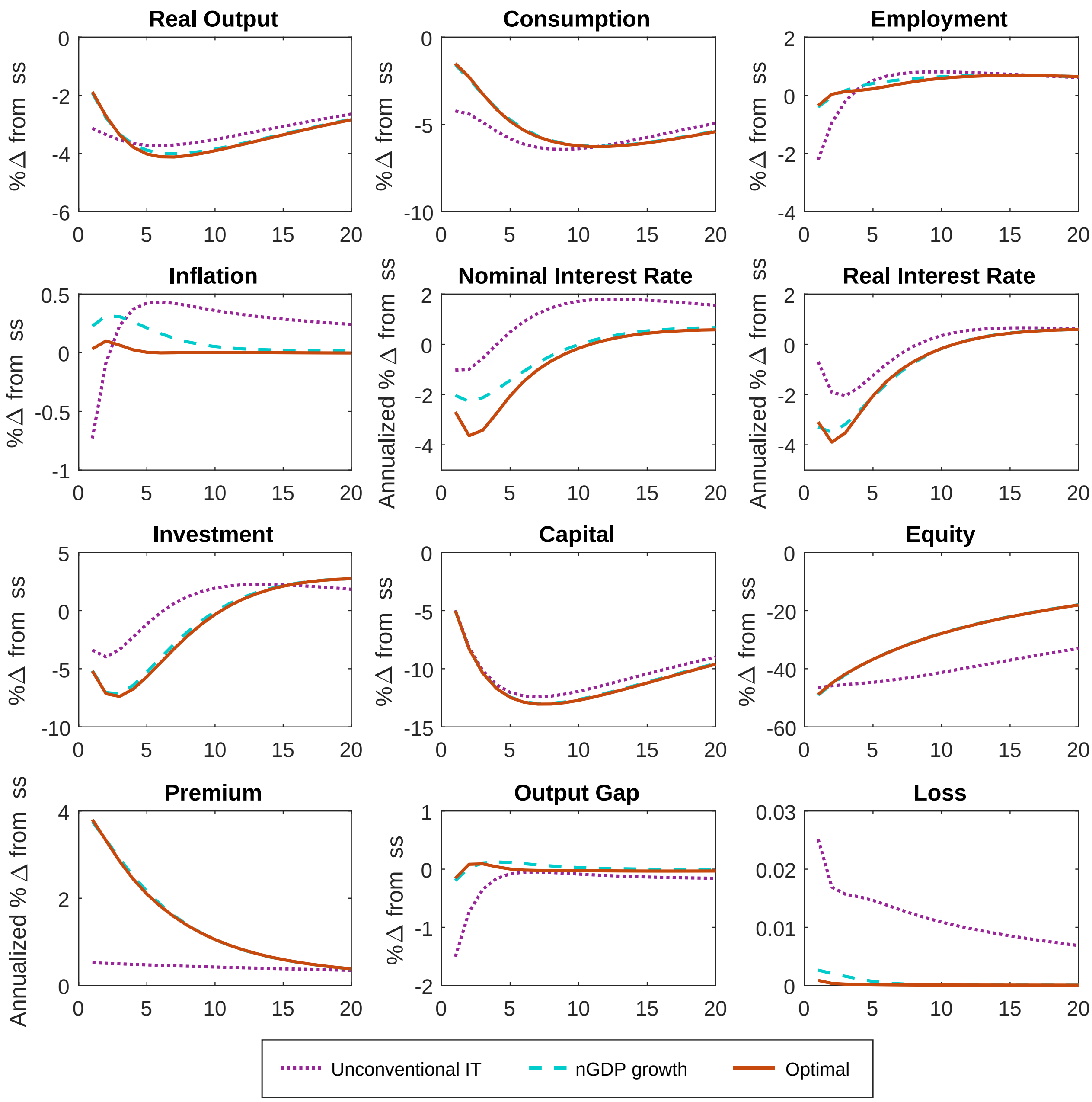

Figure 5.3: Impulse responses to a 5% capital quality shock - Unconventional IT vs. nGDP growth targeting (percentage deviations from steady state by quarters)

As Figure 5.3 illustrates, in the model with nGDP growth targeting, monetary policy can successfully manage inflation expectations while unconventional IT fails to bring back inflation to its steady state in the short-run. The stabilization process of the intermediary sector takes much longer under unconventional IT as the net worth of banks is still 35% below their steady state level while under nGDP growth targeting the deviation is only half of that.

To conclude the analysis with respect to welfare, the resulting loss from the transitory capital quality shock is significantly larger under the unconventional IT regime than under nGDP

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growth targeting. Hence, the main result of my thesis is that nGDP growth targeting is nearly an optimal monetary policy framework when there is distress in the financial market. The other alternative interest rate rules also performed better from a welfare perspective than unconventional IT, which implies that history-dependence might also be an important factor in the conduct of monetary policy as Woodford (2003) suggested.

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6 Concluding Remarks

In this thesis I compared various interest rate rules along with an optimal monetary policy rule to analyze the behavior of a model economy based on Gertler and Karadi (2011) to certain exogenous shocks. In particular, I focused on a crisis experiment to assess the performance of a flexible inflation targeting policy rule under financial distress and compared the impulse responses of key variables to the ones ruled by the optimal policy. I also investigated the effect of unconventional balance sheet operations by the central bank, and how effectively it could alleviate a recession.

My results suggest that quantitative easing can moderate the decline in output in a recession even more than what optimal monetary policy would yield; however, it fails to accommodate inflation back to its target path in the short-run. However, from a welfare perspective, flexible inflation targeting with a credit policy has desirable effects, especially in the vicinity of the zero lower bound.

In the search for a conventional monetary policy framework which moves the economy closer to the optimal monetary policy, I characterized different types of interest rate rules that central banks could follow. I assessed the performances of these alternative monetary policy frameworks and their implications towards the impulse responses of key macroeconomic variables under the same crisis experiment, and concluded that history-dependent monetary policies are superior to inflation targeting even if it is amended by a credit policy.

Out of the examined interest rate rules, nominal GDP growth targeting came closest to the optimal monetary policy by replicating almost perfectly the optimal responses of key variables of the model. Since nominal GDP growth targeting can be thought of as a modified flexible inflation targeting, my results imply that central banks should consider stabilizing the growth rate of real output just as importantly after a financial crisis as stabilizing inflation.

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Appendix

A Optimization Problem of the Financial Intermediary Sector

As highlighted in Section 4.2, without financial frictions the expected premium would be zero. However, with frictions banks want to accumulate net worth as much as possible. To avoid indefinite net worth accumulation and to keep the banks constrained, assume banks exit the market randomly, with probability $1-\theta$ in every period. As a consequence, the bank maximizes its net worth upon exit:

$$E_t \sum_{i=0}^{\infty} (1-\theta)\, \theta^i \beta^{i+1} \Lambda_{t,t+1+i} N_{j,t+1+i}$$

Plugging equation for the evolution of net worth to obtain the bank's value function:

$$V_{j,t} = max\, E_t \sum_{i=0}^{\infty} (1-\theta)\, \theta^i \beta^{i+1} \Lambda_{t,t+1+i} \left[(R_{k,t+1+i} - R_{t+1+i})\, Q_{t+i} S_{j,t+i} + R_{t+1+i} N_{j,t+i} \right]$$

Due to this agency problem, the following incentive constraint must be satisfied

$$V_{j,t} \geq \lambda Q_t S_{j,t} \tag{A.1}$$

Let us define:

$$\nu_t = E_t \sum_{i=0}^{\infty} (1-\theta)\, \theta^i \beta^{i+1} \Lambda_{t,t+1+i} (R_{k,t+1+i} - R_{t+1+i})\, Q_{t+i} S_{j,t+i} \tag{A.2}$$

(A.2) can be expressed recursively:

$$\nu_t = E_t \left[(1-\theta)\, \beta \Lambda_{t,t+1} (R_{k,t+1} - R_{t+1}) + \beta \Lambda_{t,t+1} \theta x_{t,t+1} \nu_{t+1} \right] \tag{A.3}$$

Let χ denote the optimal growth rate of the bank's assets:

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$$\chi_{t,t+1} = \frac{Q_{t+1}S_{j,t+1}}{Q_t S_{j,t}}$$

Similarly, let us define:

$$\eta_t = E_t \sum_{i=0}^{\infty} (1-\theta)\,\theta^i \beta^{i+1} \Lambda_{t,t+1+i} R_{t+1+i} N_{j,t+i}$$

Noticing that $\beta E_t\left[\Lambda_{t,t+1} R_{t+1}\right] = 1$, we can express η_t recursively:

$$\eta_t = (1-\theta) + \beta\theta E_t\left[\Lambda_{t,t+1} \mathrm{z}_{t,t+1} \eta_{t+1}\right] \tag{A.4}$$

where z denotes the optimal growth rate of the bank's net worth:

$$\mathrm{z}_{t,t+1} = \frac{N_{j,t+1}}{N_{j,t}}$$

Given definitions of ν_t and η_t, the intermediary value function can be summarized as:

$$V_{j,t} = \nu_t Q_t S_{j,t} + \eta_t N_{j,t} \tag{A.5}$$

In a frictionless economy's equilibrium, $\nu_t = 0$ (zero expected premium); otherwise the bank would raise deposits and expand assets indefinitely. With frictions, $\nu_t > 0$ (positive expected premium), and the bank's constraint is binding. Using the simplified expression for the value function in (A.5), rewriting (A.1) gives us:

$$Q_t S_{j,t} \geq \frac{\eta_t}{\lambda - \nu_t} N_{j,t} \tag{A.6}$$

The constraint is binding when $0 < \nu_t < \lambda$. This means that when $0 < \nu_t$, the bank wants to expand its asset holding due to positive expected premium. On the other hand, $\nu_t < \lambda$ must hold, otherwise the increase in asset holdings always promises better payoff from banking than from diverting.

Finally, we can summarize the binding constraint as

$$Q_t S_{j,t} = \phi_{p,t} N_{j,t}$$

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where $\phi_{p,t}$ is the private leverage ratio, which also equals:

$$\phi_{p,t} = \frac{\eta_t}{\lambda - \nu_t} \tag{A.7}$$

when (A.6) is binding. Substituting (A.7) into the evolution of bank's net worth given in (4.2) yields:

$$N_{j,t+1} = \left[\left(R_{k,t+1} - R_{t+1} \right) \phi_{p,t} + R_{t+1} \right] N_{j,t}$$

Note that the sensitivity of the response of bank's net worth to capital return is multiplied by the leverage ratio. Using the simplified expression for the evolution of bank's net worth, we get optimal growth rates of bank's equity and assets:

$$\mathrm{z}_{t,t+1} = \frac{N_{j,t+1}}{N_{j,t}} = \left(R_{k,t+1} - R_{t+1} \right) \phi_{p,t} + R_{t+1} \tag{A.8}$$

$$\chi_{t,t+1} = \frac{Q_{t+1} S_{j,t+1}}{Q_t S_{j,t}} = \frac{\phi_{p,t+1}}{\phi_{p,t}} \mathrm{z}_{t,t+1} \tag{A.9}$$

Optimal growth rates $\{\mathrm{z}_{t,t+1},\, \chi_{t,t+1}\}$, values of additional assets and equity $\{\nu_t,\, \eta_t\}$, and private leverage ratio $\phi_{p,t}$ are collectively defined by equations (A.3), (A.4), and (A.7)-(A.9) in terms of aggregate prices. Therefore, every bank j, regardless of its initial net worth (as long as it is positive[5]), will choose the same optimal leverage and the growth rate of assets and equity. Therefore, the distribution of equity between banks does not matter, and the borrowing constraint can be aggregated:

$$Q_t S_t = \phi_{p,t} N_t$$

To aggregate the equation for the evolution of net worth, notice that a fraction $1 - \theta$ of bankers exit the banking sector every period and are replaced with new bankers:

$$N_t = \theta \left(\left(R_{k,t} - R_t \right) \phi_{p,t-1} + R_t \right) N_{t-1} + \omega Q_t S_{t-1}$$

[5] That is why new bankers must receive a small starting capital from households.

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This completes the description of the optimization problem of the financial intermediary sector and the derivation of the evolution of the total bank's net worth.

B Nominal Rigidities

Each retailer gets to choose the optimal price in each period with a chance $1-\gamma \in (0,1)$. If the optimal choice $P^*_{j,t}$ in period t stays unchanged, the retailer's output in period $t+i$ in the future is:

$$Y^*_{j,t+i} = \left(\frac{P^*_{j,t}}{P_{t+i}}\right)^{-\epsilon} Y_{t+i}$$

The retailer, thus, sets the price $P^*_{j,t}$ to maximize the expected profit:

$$\underset{P^*_{j,t}}{max} \sum_{i=0}^{\infty} (\gamma\beta)^i E_t \left[\Lambda_{t,t+1}\left(\frac{P^*_{j,t}}{P_{t+i}} - P_{m,t+i}\right) Y^*_{j,t+i}\right]$$

The first order condition equates measures of expected marginal cost and marginal revenue:

$$\sum_{i=0}^{\infty} (\gamma\beta)^i E_t \left[\Lambda_{t,t+1} Y^*_{t+i}\left(\frac{P^*_{j,t}}{P_{t+i}} - \frac{\epsilon}{\epsilon-1} P_{m,t+i}\right)\right] = 0 \quad \text{(B.1)}$$

The first order condition, (B.1), can be written as:

$$\frac{P^*_t}{P_t} = \frac{\epsilon}{\epsilon-1} \frac{\sum_{i=0}^{\infty} (\gamma\beta)^i E_t \left[\Lambda_{t,t+1} P_{m,t+i} P^{\epsilon}_{t+i} P_t^{-\epsilon} Y_{t+i}\right]}{\sum_{i=0}^{\infty} (\gamma\beta)^i E_t \left[\Lambda_{t,t+1} P^{\epsilon-1}_{t+i} P_t^{1-\epsilon} Y_{t+i}\right]} \quad \text{(B.2)}$$

Defining $\pi_t = \frac{P_t}{P_{t-1}}$, and $\pi^*_t = \frac{P^*_t}{P_t}$, both the numerator and denominator in (B.2) can be expressed recursively:

$$\Xi_{n,t} = P_{m,t} Y_t + \gamma\beta E_t \left[\Lambda_{t,t+1} \pi^{\epsilon}_{t+1} \Xi_{n,t+1}\right] \quad \text{(B.3)}$$

$$\Xi_{d,t} = Y_t + \gamma\beta E_t \left[\Lambda_{t,t+1} \pi^{\epsilon-1}_{t+1} \Xi_{d,t+1}\right] \quad \text{(B.4)}$$

Then the first order condition of the retailers maximization problem becomes:

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$$\pi_t^* = \frac{\epsilon}{\epsilon - 1}\frac{\Xi_{n,t}}{\Xi_{d,t}} \tag{B.5}$$

Finally, from the definition of the nominal price index, we have

$$P_t^{1-\epsilon} = (1-\gamma)\left(P_t^*\right)^{1-\epsilon} + \gamma P_{t-1}^{1-\epsilon}$$

Dividing by $P_t^{1-\epsilon}$, we get

$$1 = (1-\gamma)\left(\pi_t^*\right)^{1-\epsilon} + \gamma \pi_{t-1}^{\epsilon-1} \tag{B.6}$$

Equations (B.3)-(B.6) recursively define the New Keynesian Phillips Curve.

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C Figures and Tables

Parameter	Value	Description
β	0.990	Discount factor
σ	1	Relative risk aversion
φ	2	Labor-supply elasticity
λ	0.4	Share of assets that a bank can appropriate when diverting
θ	0.975	Survival rate of bankers
ω	0.001	Transfer of start-up capital to new bankers from households
α	0.330	Capital share in intermediate output
δ	0.025	Depreciation of capital
ψ	2	Investment-adjustment costs
ϵ	6	Elasticity of substitution between goods in the retailer's market
γ	0.779	Calvo price rigidity
τ	0.001	Inefficiency of government's financial intermediation
ρ	0.8	Interest-rate smoothing by the central bank
κ_π	1.5	Monetary-policy sensitivity to inflation gap
κ_x	$0.5/4$	Monetary-policy sensitivity to output gap
κ_z	1.5	Monetary-policy sensitivity to nominal GDP gap from target
κ_p	1.5	Monetary-policy sensitivity to price gap from target
κ	0	Credit-policy sensitivity (Baseline scenario)
κ	100	Credit-policy sensitivity (Crisis scenario)
λ_x	0.5	Output gap weight in the loss function
λ_i	0.2	Interest rate smoothing weight in the loss function

Table 1: Parameter Values

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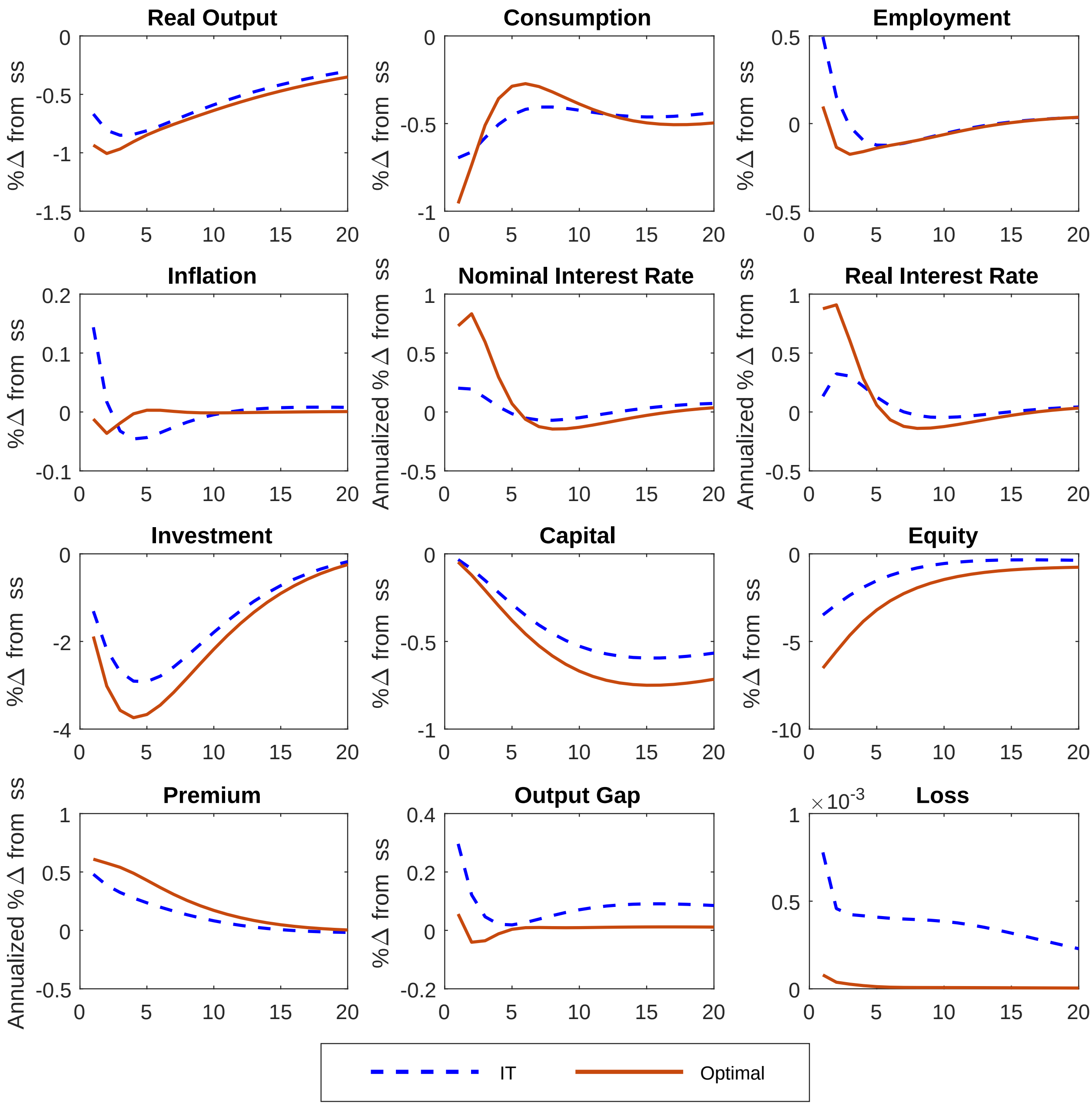

Figure C.1: Impulse responses to a 1% negative TFP shock - Inflation targeting, baseline scenario (percentage deviations from steady state by quarters)

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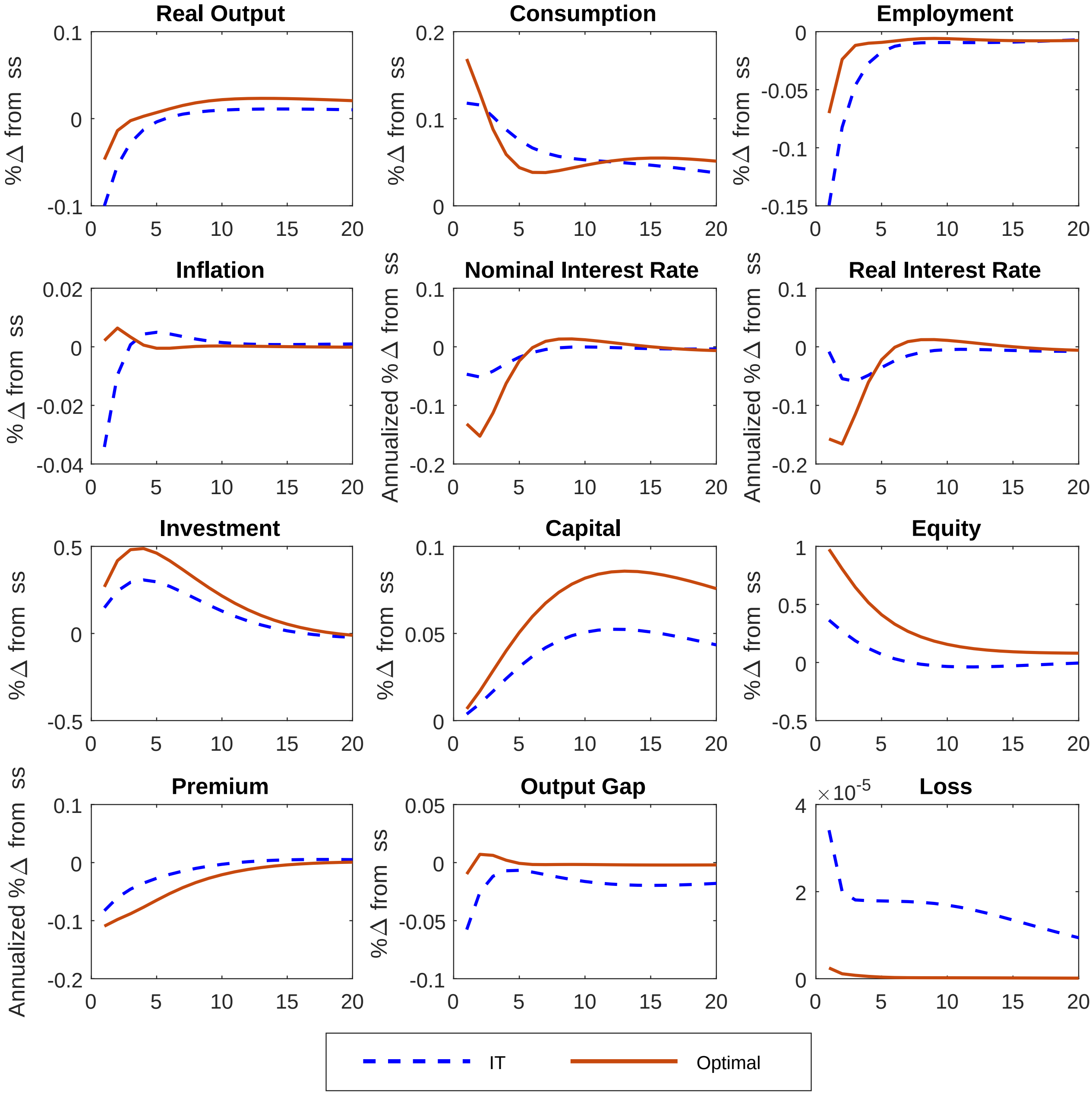

Figure C.2: Impulse responses to a 1% negative demand shock - Inflation targeting, baseline scenario (percentage deviations from steady state by quarters)

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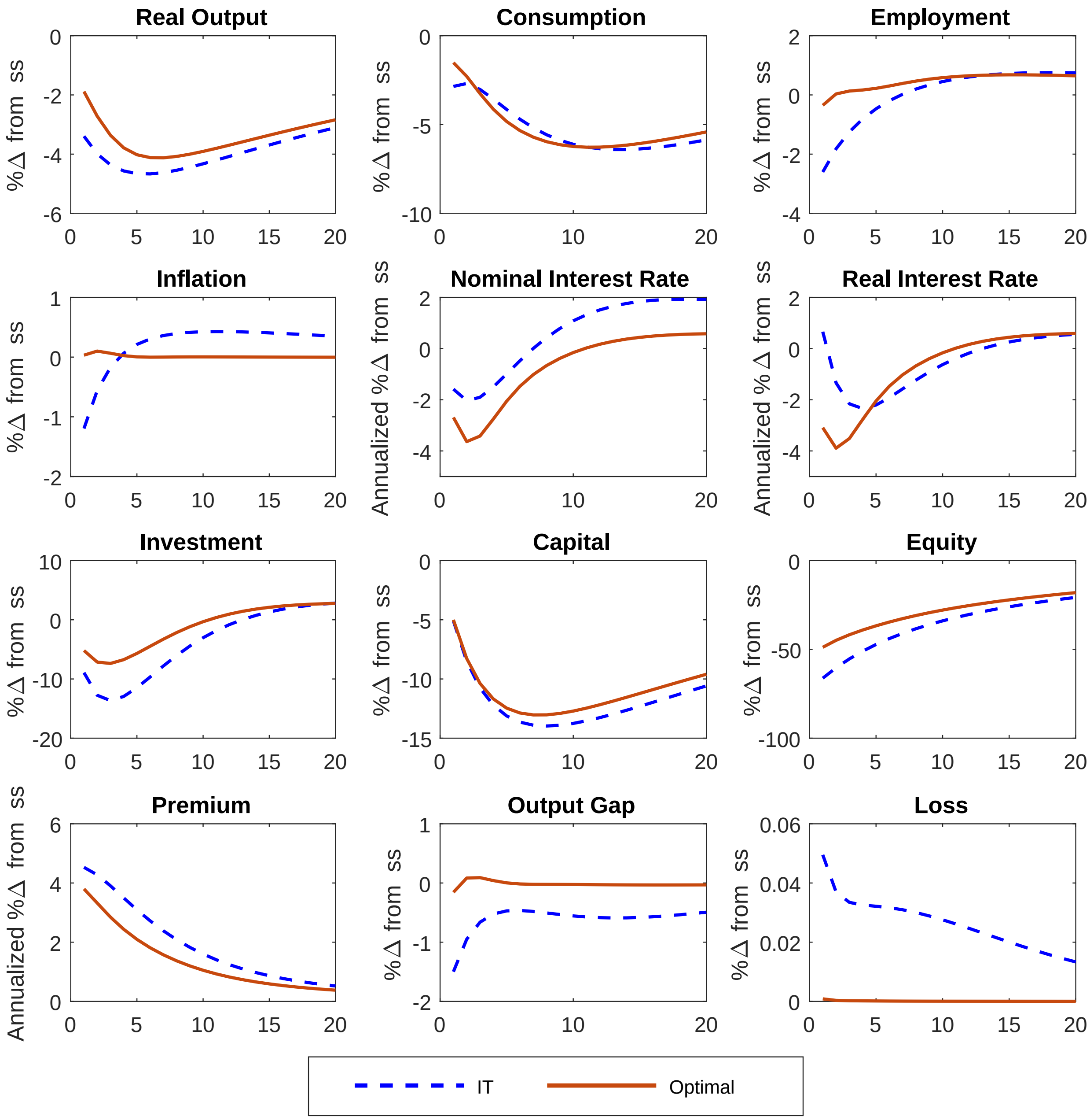

Figure C.3: Impulse responses to a 5% capital quality shock - Inflation targeting, crisis scenario (percentage deviations from steady state by quarters)

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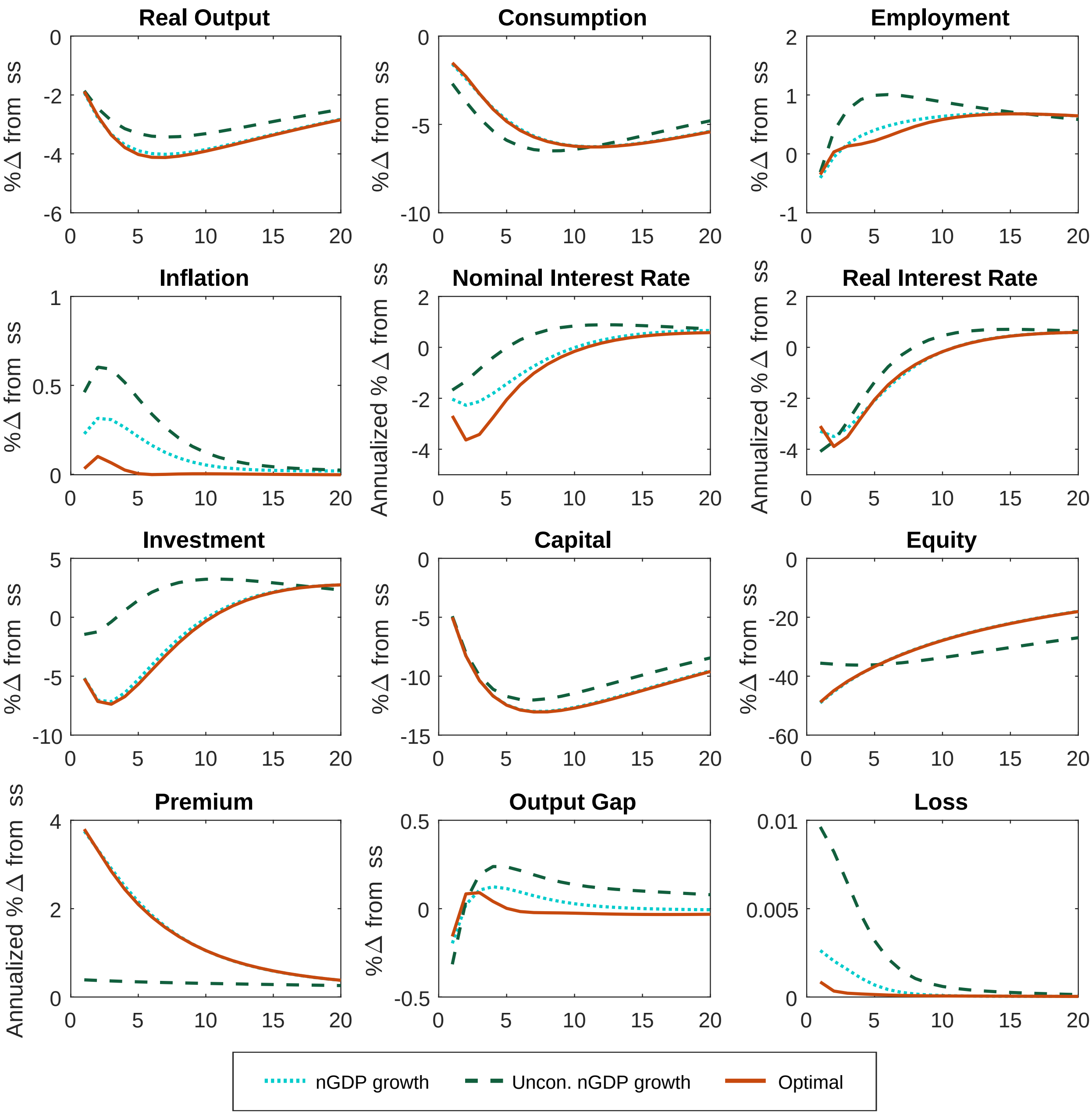

Figure C.4: Impulse responses to a 5% capital quality shock - nGDP growth targeting with credit policy (percentage deviations from steady state by quarters)

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