Unemployment Risk, Liquidity Traps, and Monetary Policy

Dario Bonciani* Joonseok Oh†

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Abstract

We study optimal monetary policy in a model with incomplete markets, in the form of uninsurable unemployment risk, and an occasionally binding zero lower bound (ZLB) constraint. The optimal policy consists of keeping the nominal rate at zero longer than implied by current macroeconomic conditions. Such policy improves expected labour market conditions, substantially mitigating the rise in unemployment risk and precautionary savings. As a result, we find that market incompleteness does not significantly amplify contractions in output and inflation at the ZLB. However, when the central bank follows more realistic policy rules instead of the optimal policy, incomplete markets exacerbate the fall in demand, emphasising the importance of unemployment insurance for output stabilisation.

Keywords: Unemployment risk, Liquidity trap, Zero lower bound, Optimal monetary policy

JEL Classification: E21, E24, E32, E52, E61

*Department of Economics and Law, Sapienza University of Rome, Via del Castro Laurenziano 9, 00161 Rome, Italy. E-mail: dario.bonciani@uniroma1.it.

†Department of Economics, School of Economic, Social and Political Sciences, University of Southampton, Murray Building (58), Highfield Campus, Southampton SO17 1BJ, United Kingdom. E-mail: joonseok.oh@soton.ac.uk.

1 Introduction

The Great Recession in 2008-2009 caused a significant and persistent increase in the unemployment rate across major advanced economies. The deterioration in labour market conditions increased uncertainty about job prospects, which potentially gave rise to precautionary savings, which further dampened economic activity and inflation (see, e.g., Den Haan et al., 2018; Challe, 2020). In response to the sharp drop in demand, central banks swiftly cut short-term nominal interest rates, which quickly approached the zero lower bound (ZLB). This combination of elevated unemployment risk and constrained monetary policy created a challenging macroeconomic environment. Understanding how unemployment risk affects the monetary policy transmission at the ZLB is therefore crucial. This is true both in a liquidity trap and more generally, as forward guidance remains an active part of central banks' toolkits.

Previous research (see, e.g., Challe, 2020) has shown that, in normal times, central banks can fully neutralise deflationary pressures from uninsurable unemployment risk. However, this result may not hold when monetary policy is constrained by the ZLB. This raises the question: How effective is monetary policy at responding to a contraction in demand and an increase in uninsurable unemployment risk when the nominal rate is at the ZLB?

We address the research question above by studying optimal monetary policy in a Heterogeneous Agents New Keynesian (HANK) model with nominal price rigidities, labour search frictions, imperfect unemployment insurance, and an occasionally binding ZLB constraint. In particular, similarly as Ravn and Sterk (2017), the model features two types of households: workers and firm owners. Workers face the risk of becoming unemployed and earning a lower income. The presence of idiosyncratic unemployment risk leads employed workers to save for precautionary reasons. Additionally, we assume that workers feature bounded rationality (Gabaix, 2020), which mitigates the excessive power of forward guidance under rational expectations (Del Negro et al., 2015).[1] Firm owners do not face any idiosyncratic risk. Both household types face a zero-debt constraint and consume their full income, allowing us to abstract from distributional effects and focus on the interaction between monetary policy and countercyclical unemployment risk. On the production side of the economy, wholesale firms operate in a monopolistically competitive market and face adjustment costs when adjusting prices. These nominal rigidities allow monetary policy to affect real economic activity. The central

[1] Werning (2015) highlights that incomplete markets exacerbate the forward guidance puzzle. If we did not account for this result, we would overestimate the ability of optimal monetary policy to counteract the fall in demand in the presence of incomplete markets. For this reason, our baseline analysis assumes workers to be boundedly rational, making the power of forward guidance more realistic. Moreover, we analyse how the results change for different degrees of bounded rationality (discussed in Section 4.3) and show that our main conclusions remain substantially unaltered when we mitigate the power of forward guidance.

bank responds to aggregate demand shocks by setting the nominal policy rate, subject to a ZLB constraint.

In such a context, we study the impact of monetary policy in response to a negative demand shock that leads the economy into a liquidity trap. We first consider a benchmark case where the central bank follows strict inflation targeting and compare outcomes under complete and incomplete markets. Under incomplete markets, a negative demand shock reduces job creation, raises unemployment risk, and induces more precautionary savings, deepening the downturn. Inflation and expectations fall more sharply. Since the nominal rate is stuck at zero, the real rate rises, exacerbating the fall in consumption and output. Thus, incomplete markets amplify the adverse effects of demand shocks at the ZLB, creating a deflationary spiral.

Given this benchmark, we then study how the economy responds when the central bank follows the Ramsey optimal monetary policy. Unlike the strict inflation targeting case, under optimal policy, the central bank commits to keeping interest rates at zero longer than implied by current conditions. This commitment boosts inflation expectations and lowers the real rate. The anticipation of improved labour market conditions reduces precautionary savings, helping stabilise real activity. Notably, with such policy, incomplete markets no longer amplify the shock. In other words, the contraction in real activity is similar under complete and incomplete markets. Hence, even if constrained by the ZLB, optimal monetary policy can still neutralise the deflationary spiral induced by market incompleteness.

Next, we study how our results vary with the degree of bounded rationality. Greater cognitive myopia weakens the power of forward guidance and reduces the efficacy of optimal policy. However, it also makes households less sensitive to future unemployment risk, diminishing the precautionary savings motive. As a result, even with muted forward guidance, incomplete markets do not substantially amplify the fall in demand when monetary policy is conducted optimally.

Finally, we examine the effectiveness of simple history-dependent policy rules in mitigating the effects of demand shocks under market incompleteness. We consider: (*i*) price-level targeting, (*ii*) a Taylor rule augmented with the lagged shadow rate (i.e., the theoretical policy rate that would prevail in the absence of a ZLB constraint), and (*iii*) average inflation targeting. These rules, by keeping nominal rates at zero for longer, raise inflation expectations and reduce real rates, thereby mirroring the mechanism of optimal policy. However, we find that these rules imply a weaker commitment than the Ramsey policy. The reason is that, unlike the Ramsey policy, these rules do not take into account market incompleteness or the degree of bounded rationality. As such, they only partially offset the deflationary spiral. For this reason, we conclude that, in practice, unemployment insurance policies aimed at reducing market incompleteness are desirable tools, alongside monetary policy, to stabilise output at the ZLB.

Related Literature This paper builds primarily on two strands of the literature. First and foremost, by analysing the optimal monetary policy conduct in a model with uninsurable unemployment risk and labour market frictions, our paper is particularly related to the literature on HANK models with incomplete markets. By studying the interaction between incomplete markets and the ZLB, our work is also strictly related to the literature on monetary policy in a liquidity trap. To the best of our knowledge, we are the first to study optimal monetary policy at the ZLB in a model with uninsured unemployment risk arising endogenously from labour market frictions and agents featuring boundedly rational expectations.

This work builds on the growing literature on unemployment risk in models with incomplete markets. McKay and Reis (2016) document that a reduction in unemployment benefits, increasing precautionary savings against uninsured unemployment risk, may raise investment and the capital stock, thereby reducing consumption volatility. Challe et al. (2017) estimate a medium-scale DSGE model with imperfect unemployment insurance and show that an adverse feedback loop between precautionary savings and aggregate demand contributes to explain the severity of the Great Recession. Ravn and Sterk (2017) build a model where households face uninsured unemployment risk, sticky prices, and search-and-matching frictions. In such a framework, a higher risk of job loss and worse job-finding prospects induce a precautionary savings motive that causes a decline in the demand for goods. Lower demand, in turn, reduces job vacancies and the job-finding rate, producing an amplification mechanism due to endogenous countercyclical income risk. Den Haan et al. (2018) show that incomplete markets together with sticky nominal wages increase business cycle volatility. Acharya et al. (2023) study optimal monetary policy in a HANK framework, where the planner's objective function includes reducing consumption inequality, in addition to stabilising output and inflation. When income risk is countercyclical, they find that policy curtails the fall in output in recessions to alleviate the increase in inequality. Ravn and Sterk (2021) show that in a heterogeneous agents model with labour market frictions, the precautionary-savings motive may lead the economy to get stuck in a high-unemployment steady-state. Challe (2020) analyses optimal monetary policy in a similar framework. By increasing unemployment risk, contractionary cost-push or productivity shocks lead to a rise in precautionary savings and a fall in inflation, which calls for an accommodative monetary policy.[2] Our work extends the analysis in Challe (2020) to the liquidity trap case, where the deflationary spiral induced by countercyclical

[2] Other papers dealing with monetary policy in heterogeneous agents models with incomplete markets and sticky prices are Heathcote et al. (2010), Braun and Nakajima (2012), Heathcote and Perri (2018), Kekre (2019), Oh and Rogantini Picco (2025), and Cui and Sterk (2021).

unemployment risk is particularly severe. Unlike McKay et al. (2016), and in line with Werning (2015) and Acharya and Dogra (2020), our results imply that incomplete markets do not attenuate the effects of forward guidance if idiosyncratic income risk is countercyclical. These two papers examine the sensitivity of aggregate demand to future monetary policy shocks using models where the cyclicality of idiosyncratic income risk can be time-varying but parameterised. Our work, instead, studies optimal policy at the ZLB in a model where labour market frictions endogenously give rise to countercyclical income risk. Cho (2023) estimates a one-asset HANK model to study the role of unemployment risk. Moreover, within a HANK model incorporating both liquid and illiquid assets, Graves (2022) finds that unemployment risk triggers a flight-to-liquidity mechanism, serving as a significant automatic stabiliser, especially at ZLB. In our paper, we focus on the case when short-term rates are at the ZLB and show that the type of monetary policy is crucial to determining the importance of uninsured unemployment risk. In a representative-agent NK model, Leduc and Liu (2016) highlight how search-and-matching frictions in the labour market amplify the negative effects of aggregate uncertainty shocks via an option-value channel.

This paper is also related to the strand of the macroeconomic literature studying the optimal conduct of monetary policy when nominal short-term rates are at the ZLB. Eggertsson and Woodford (2003) examines the implications of the ZLB on the ability of a central bank to contrast deflation. A credible commitment to the right sort of history-dependent policy can largely mitigate the distortions created by the ZLB. Jung et al. (2005) shows that at the ZLB, the optimal monetary policy response implies policy inertia, i.e., a zero interest rate policy should be continued for a while even after the natural rate returns to a positive level.[3] Adam and Billi (2007) study optimal monetary policy in a model where the ZLB on the nominal interest rate is an occasionally binding constraint. Rational agents anticipate the possibility of reaching the lower bound in the future, and this amplifies the effects of adverse shocks well before the bound is reached, which calls for a more aggressive response by the central bank. Bilbiie (2019) studies how long a central bank should keep interest rates low after a liquidity trap ends. The paper argues that the optimal duration is approximately half the time the economy spends in a liquidity trap. Nakata et al. (2019) show that in a framework where the stimulating ability of forward guidance is relatively muted, and the economy is in a liquidity trap, the monetary policy authority should commit to keeping the policy rate at zero for a significantly long time.[4]

The assumption of bounded rationality in our model follows Gabaix (2020) and is one of several approaches

[3] Hills and Nakata (2018) and Bonciani and Oh (2023a) show that monetary policy inertia reduces the size of government spending multipliers and removes the "Paradox of flexibility" when the economy is in a liquidity trap.

[4] A non-exhaustive list of papers dealing with monetary policy at the ZLB is Nakov (2008), Christiano et al. (2011), Nakata (2017), Nakata and Schmidt (2019), Masolo and Winant (2019), and Bonciani and Oh (2023b).

proposed to mitigate the excessive effectiveness of forward guidance under rational expectations (Del Negro et al., 2015; Werning, 2015). A large literature has explored alternative mechanisms that dampen the sensitivity of current output and inflation to distant policy commitments. Del Negro et al. (2015) solve the forward guidance puzzle by incorporating a perpetual-youth structure into an otherwise standard medium-scale NK model.McKay et al. (2016) show that incomplete markets and limited consumption smoothing can naturally attenuate forward guidance even under rational expectations. However, Ravn and Sterk (2021) highlight that this result arises only when idiosyncratic income risk is procyclical. When income risk is countercyclical, as in our model, the puzzle becomes more severe. Angeletos and Lian (2018) show how information frictions and dispersed beliefs can help resolve the forward guidance puzzle and offer a rationale for the front-loading of fiscal stimuli. Andrade et al. (2019); Campbell et al. (2019) propose an explanation based on imperfect policy credibility and communication. Dong et al. (2024) demonstrate that heterogeneous beliefs regarding inflation targets can weaken the efficacy of both forward guidance and conventional interest rate policies. Our approach based on bounded rationality offers a complementary and parsimonious way to capture this empirically relevant attenuation within a model that already features endogenous unemployment risk. By modelling cognitive myopia directly at the household level, we can study how imperfect foresight interacts with precautionary savings and labour-market frictions.

The remainder of the paper is structured as follows. In Section 2, we derive a stylised version of the model to provide analytical insights on how incomplete markets and bounded rationality affect the monetary policy transmission mechanism. In Section 3, we describe the fully-fledged model. Section 4 sets out our numerical analysis. In Section 5, we acknowledge potential limitations of our analysis. Finally, Section 6 provides some concluding remarks.

2 Analytical Insights

Before presenting the full model and our numerical results, we first highlight key analytical insights using a simplified framework. This stylised analysis clarifies how uninsurable unemployment risk and bounded rationality shape the response to demand changes under different monetary policies.

2.1 Stylised Model

In this setting, workers are either employed or unemployed. Unemployed workers consume a fraction $\delta \in [0, 1]$ of employed workers' consumption:

$$c_{u,t} = \delta c_{e,t}. \tag{1}$$

Employed workers choose consumption/savings according to the Euler equation:

$$c_{e,t}{}^{-1} = \beta E_t^{BR} \left[(1 - s_{t+1})\, c_{e,t+1}{}^{-1} + s_{t+1} c_{u,t+1}{}^{-1} \right] \frac{(1 + i_t)\, z_t}{1 + \pi_{t+1}}, \tag{2}$$

where E_t^{BR} denotes boundedly rational expectations, β the employed workers' discount factor, s_{t+1} is the probability of becoming unemployed, z_t a demand shock, i_t the nominal interest rate, and π_t inflation. Following Bilbiie et al. (2023), we assume that s_{t+1} depends on the state of the economy (output deviations from steady state):[5]

$$\frac{s_t}{s} = \left(\frac{y_t}{y} \right)^{-\alpha}, \tag{3}$$

implying countercyclical unemployment risk for $\alpha > 0$. The resource constraint is:

$$y_t = (1 - \omega_u)\, c_{e,t} + \omega_u c_{u,t}. \tag{4}$$

assuming a constant unemployment share $\omega_u \in (0, 1)$, as in Bilbiie et al. (2023).[6]

2.1.1 Bounded Rationality

Standard rational expectations models are afflicted by the forward guidance puzzle (Del Negro et al., 2015): agents tend to overreact to distant events, such as future interest rate changes. To solve this issue, we follow Gabaix (2020) and assume cognitive myopia. Then the Euler Equation (2) becomes:

$$1 = \beta E_t \frac{\left((1 - s_{t+1})\, c_{e,t+1}{}^{-1} + s_{t+1} c_{u,t+1}{}^{-1} \right)^{\zeta}}{\left((1 - s)\, c_e^{-1} + s c_u{}^{-1} \right)^{\zeta - 1} w_t{}^{-1}} \frac{(1 + i_t)\, z_t}{1 + \pi_{t+1}}. \tag{5}$$

where $\zeta \in [0, 1]$ captures the degree of bounded rationality, such that $\zeta = 1$ implies full rationality. Details are in Appendix A.

2.1.2 Log-Linear Three Equation NK Model

The log-linear model can be written as:

$$\hat{y}_t = \eta E_t \hat{y}_{t+1} - \hat{i}_t + E_t \hat{\pi}_{t+1} - \hat{z}_t, \tag{6}$$

[5] In the baseline model, Section 3, this is micro-founded with a search-and-matching mechanism.

[6] In line with Bilbiie et al. (2023), in this stylised model, we assume that the probability of switching from unemployed to employed is such that the shares of employed and unemployed households remain constant.

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \varphi \hat{y}_t. \tag{7}$$

Equation (6) is the IS equation, obtained by log-linearising Equation (5) around the deterministic steady-state. The second equation (7) is the canonical New Keynesian Phillips curve (NKPC). The coefficient η is given by:

$$\eta \equiv \zeta \left(1 + \frac{\alpha s \left(\delta^{-1} - 1\right)}{s\left(\delta^{-1} - 1\right) + 1}\right), \tag{8}$$

whereas φ is the slope of NKPC, as in McKay et al. (2017) and Bilbiie (2021). Hatted variables denote log-deviations from steady state. With this model, we can derive a set of analytical results.

Result 1 More countercyclical unemployment risk (i.e., a larger α) amplifies precautionary savings and increases the coefficient η:

$$\frac{d\eta}{d\alpha} = \frac{\zeta s \left(\delta^{-1} - 1\right)}{s\left(\delta^{-1} - 1\right) + 1} > 0. \tag{9}$$

An expected decline in $\hat{y}_{t+1}$ increases more significantly the expected job-loss probability (s_{t+1}), which amplifies the fall in $\hat{y}_t$. Similarly, an expected future interest rate cut ($\hat{i}_{t+1} < 0$), boosting $\hat{y}_{t+1}$, reduces s_{t+1} and has more expansionary effects on $\hat{y}_t$.

Result 2 Lower consumption loss due to unemployment (i.e., a larger δ) reduces η, mitigating the precautionary savings motive:

$$\frac{d\eta}{d\delta} = -\frac{\zeta \alpha s}{\left(s + (1-s)\,\delta\right)^2} < 0. \tag{10}$$

A higher δ lowers the risk associated with being unemployed $s_{t+1} {c_{u,t+1}}^{-1}$. Hence, employed workers will adjust today's consumption $c_{e,t}$ less to expected changes in s_{t+1}. Therefore, $\hat{y}_t$ will fall (increase) less in response to an expected fall (increase) in $\hat{y}_{t+1}$.

Result 3 An increase in the cognitive discounting parameter ζ increases η, strengthening forward-looking effects:

$$\frac{d\eta}{d\zeta} = 1 + \frac{\alpha s \left(\delta^{-1} - 1\right)}{s\left(\delta^{-1} - 1\right) + 1} > 0. \tag{11}$$

As a result, if $\hat{y}_{t+1}$ is expected to fall and s_{t+1} to rise, more rational workers will increase their precautionary savings more significantly, leading to a larger fall in $\hat{y}_t$.

2.2 Two-Period Analysis

To illustrate the impact of uninsurable unemployment risk and bounded rationality on the monetary policy transmission at the ZLB. Following Eggertsson and Garga (2019), we make the following simplifying assumptions: (i) Shock: $\hat{z}_0 = \hat{z} > \frac{i}{1+i}$ and $\hat{z}_1 = 0$ such that $\hat{i}_0 = -\frac{i}{1+i}$ and $-\frac{i}{1+i} < \hat{i}_1 < 0$ and (ii) Perfect foresight: $E_t \hat{x}_{t+1} = \hat{x}_{t+1}$, $\forall t$.

2.2.1 Strict Inflation Targeting

Under strict inflation targeting, the central bank sets the nominal policy rate according to:

$$\hat{\pi}_t = 0, \quad \text{s.t.} \quad \hat{i}_t \geq -\frac{i}{1+i}. \tag{12}$$

The outcomes on output and inflation (detailed derivations are in Appendix D.1) are:

$$\hat{y}_0 = -\left(\hat{z} - \frac{i}{1+i}\right) < 0, \quad \hat{\pi}_0 = -\varphi\left(\hat{z} - \frac{i}{1+i}\right) < 0, \quad \hat{i}_1 = \hat{y}_1 = \hat{\pi}_1 = 0. \tag{13}$$

First of all, since $\hat{i}_1 = 0$, $\hat{i}_1$ does not depend on $\hat{\pi}_0$ and $\hat{y}_0$ (i.e., the policy rate is not history dependent). Second, since $\hat{y}_1 = \hat{\pi}_1 = 0$, we have that $\hat{y}_0$ and $\hat{\pi}_0$ are independent of η (hence, independent of δ and ζ). It bears noting that this result relies on the ZLB constraint binding for only one quarter. With a longer binding ZLB, smaller η would mitigate the initial drop in output and inflation (as shown numerically in Section 4).

2.2.2 Optimal Monetary Policy

Under the optimal policy with commitment, the central bank minimises the following loss function:[7]

$$\frac{1}{2}\left(\hat{\pi}_0^2 + \vartheta \hat{y}_0^2 + \beta\left(\hat{\pi}_1^2 + \vartheta \hat{y}_1^2\right)\right), \tag{14}$$

subject to Equations (6) and (7). Thus, under the optimal policy with commitment, we obtain the following results (detailed derivations are in Appendix D.2):

$$\hat{i}_1 = \frac{\eta}{\beta}\hat{y}_0 + \frac{\varphi}{\vartheta}\left(\frac{\eta + \beta}{\beta}\right)\hat{\pi}_0, \tag{15}$$

$$\hat{y}_0 < 0, \quad \hat{\pi}_0 < 0, \quad \hat{y}_1 > 0, \quad \hat{\pi}_1 > 0, \tag{16}$$

$$\frac{d\hat{y}_0}{d\eta} > 0, \quad \frac{d\hat{\pi}_0}{d\eta} > 0. \tag{17}$$

Equation (15) shows that $\hat{i}_1$ is a function $\hat{y}_0$ and $\hat{\pi}_0$ (history dependence). Moreover, given the same fall in $\hat{y}_0$ and $\hat{\pi}_0$, the optimal reaction of $\hat{i}_1$ becomes stronger when η is large (equivalently, small δ or large ζ). In other words, a large η strengthens the commitment to keeping the interest rate lower at time $t = 1$ following

[7] The welfare loss function can be written as the canonical quadratic function of inflation and output if we focus on shocks that do not drive a wedge between inequality and output (see e.g., Bilbiie, 2021).

a macroeconomic contraction at time $t = 0$.

Equation (17) says that output and inflation decline less when η is larger (equivalently, larger α, smaller δ or larger ζ). The reason is that, when monetary policy is conducted optimally, the central bank commits to keeping the nominal interest rate in period 1 relatively low in response to the adverse demand shock ($\hat{z}$) in period 0. From Equation (15), it easy to see that $\hat{i}_1 < 0$, given $\hat{y}_0 < 0$ and $\hat{\pi}_0 < 0$. It follows that $\hat{y}_1 > 0$ and $\pi_1 > 0$, which has a positive impact on y_0 and π_0, as mentioned in Equation (16). The larger η, the stronger the impact of future output on current output.

2.2.3 Alternative Policy Rules

Next, we consider three implementable policy rules that, like the optimal policy, imply history dependence in the policy rate.

Strict Price Level Targeting Under strict price level targeting, the central bank stabilises the price level when the ZLB is not binding:

$$\hat{p}_t = 0 \quad \text{s.t.} \quad \hat{i}_t \geq -\frac{i}{1+i}, \quad \text{with} \quad \frac{p_t}{p_{t-1}} = \pi_t + 1. \tag{18}$$

Shadow Rate Smoothing The second policy is the following inertial policy rule (see e.g., Hills and Nakata, 2018 and Bonciani and Oh, 2023c):

$$\hat{i}_t = \max\left(\hat{i}_t^{\star}, -\frac{i}{1+i}\right), \tag{19}$$

$$\hat{i}_t^{\star} = \rho_i \hat{i}_{t-1}^{\star} + (1-\rho_i)\,\phi_\pi \hat{\pi}_t. \tag{20}$$

While the actual nominal rate, i_t, is bounded from below, the shadow (or notional) rate $i_t^{\star}$ is not. The shadow rate represents the theoretical rate that would prevail in the absence of a ZLB constraint. The central bank sets its shadow rate according to a Taylor-type rule with an autoregressive component. The parameter ρ_i controls the degree of policy inertia.

Average Inflation Targeting Finally, under average inflation targeting (see e.g., Budianto et al., 2020), the policy rate stabilises an exponentially weighted average inflation rate:

$$\hat{\pi}_t^{avg} = 0 \quad \text{s.t.} \quad \hat{i}_t > -\frac{i}{1+i}, \quad \text{with} \quad \hat{\pi}_t^{avg} = \omega\hat{\pi}_t + (1-\omega)\hat{\pi}_{t-1}^{avg}, \quad \omega \in (0,1). \tag{21}$$

with $\omega \in (0,1)$. In other words, the central bank aims to stabilise an exponential moving average inflation rate $\hat{\pi}_t^{avg}$. When $\omega = 0$, this reduces to strict inflation targeting; when $\omega = 1$, it matches price level targeting.

Results under the Three Policy Rules Under all three alternative policies, we obtain the following results:

$$\hat{i}_1 = \Gamma \hat{\pi}_0, \tag{22}$$

$$\hat{y}_0 < 0, \quad \hat{\pi}_0 < 0, \quad \hat{y}_1 > 0, \quad \hat{\pi}_1 > 0, \tag{23}$$

$$\frac{d\hat{y}_0}{d\eta} > 0, \quad \frac{d\hat{\pi}_0}{d\eta} > 0. \tag{24}$$

First of all, under all three policies, the future rate can be written as $\hat{i}_1 = \Gamma \hat{\pi}_0$, where $\Gamma = \frac{1}{\varphi}$ under price level targeting, $\Gamma = \frac{\rho_i(1-\rho_i)\phi_\pi}{1+(1-\rho_i)\phi_\pi\varphi}$ under the inertial rule[8], and $\Gamma = \left(\frac{1-\omega}{\varphi}\right)\hat{\pi}_0$ under average inflation targeting. Hence, these policies are history-dependent, like the optimal policy. This results in output and inflation responses to the demand shock z, which are qualitative in line with the optimal policy (i.e. future output and inflation increase, which mitigates the fall in current output and inflation).

However, it is important to note that, unlike the optimal policy, Γ does not depend on η. Therefore, the optimal policy delivers stronger commitment when unemployment insurance is imperfect or when agents are less myopic. Last, a larger η (i.e., smaller δ or larger ζ) mitigates the fall in output and inflation, because agents internalise more strongly the future boost to demand implied by the policy rule.

3 The Fully-Fledged Model

Given our interest in studying the implications of uninsurable unemployment risk on optimal monetary policy at the ZLB, we consider a relatively stylised framework that mostly abstracts from distributional issues and focuses instead on the optimal stabilisation of aggregate demand. More specifically, following Ravn and Sterk (2017) and Challe (2020), the economy consists of two types of households, workers and firm owners. Workers can be either employed or unemployed, and their wages result from a Nash bargaining process. Unlike the original model, workers exhibit bounded rationality, thus reacting myopically to distant events, such as anticipated changes in monetary policy. On the production side, the economy includes three types of firms, producing intermediate, wholesale, and final goods. In particular, intermediate-goods firms hire workers in a frictional labour market to produce their output. These firms sell the intermediate goods

[8] When $\phi_\pi \to +\infty$, the coefficient can be written as $\Gamma = \frac{\rho_i}{\varphi}$. When $\rho_i = 1$, this is equivalent to the coefficient under price level targeting.

to wholesale firms, which operate in a monopolistically competitive market and face price adjustment costs. Last, final-goods firms produce their output using wholesale goods as input.

3.1 Working Households

Working household $i \in [0,1]$ can be employed or unemployed, and maximises its lifetime utility (25) subject to a budget constraint (26) and a zero-debt-limit constraint (27). The optimisation problem of a working household is as follows:

$$\max_{c_{i,t},a_{i,t}} E_0^{BR} \sum_{t=0}^{\infty} \beta^t \log c_{i,t}, \tag{25}$$

subject to

$$\frac{a_{i,t}}{z_t} + c_{i,t} = e_{i,t} w_t + (1 - e_{i,t})\,\delta_t + \frac{1+i_{t-1}}{1+\pi_t} a_{i,t-1}, \tag{26}$$

$$a_{i,t} \geq 0, \tag{27}$$

$$\log z_t = \rho_z \log z_{t-1} + \sigma_z \varepsilon_t^z, \quad \epsilon_t^z \sim \mathcal{N}(0,1), \tag{28}$$

where E_0^{BR} is the boundedly-rational expectation operator. The parameter β is the subjective discount factor. The household derives utility from its consumption $c_{i,t}$. The dummy variable $e_{i,t}$ defines the employment status of the household. If $e_{i,t} = 1$, the household is employed, works full-time without any associated disutility, and earns a wage income $w_t > 0$. If $e_{i,t} = 0$, the household is unemployed and only gets an exogenous home-production income $\delta_t \in (0, w_t)$. The employment status of the workers is random and the associated income risk is uninsured, i.e., there is no compensation for the income loss. $a_{i,t}$ represents risk-free bonds issued by the workers. z_t is an aggregate demand shock with persistence $\rho_z \in [0,1)$ and volatility σ_z. Shock z_t is also commonly defined as a risk-premium shock (Smets and Wouters, 2007), which affects the intertemporal margin.[9] The net nominal interest rate is represented by i_t, whereas π_t is the inflation rate. At the beginning of time, workers are assumed to hold no assets $a_{-1} = 0$.

3.2 Firm Owners

There is a unit mass of households, who own the various firms in the economy. These households choose consumption c_t^F to maximise their lifetime utility (29) subject to their budget constraint (30) and a zero-debt-limit constraint (31). Unlike workers, firm owners do not face any idiosyncratic income risk and have

[9] Fisher (2015) provides a structural interpretation of the risk-premium shock as a disturbance to the demand for safe and liquid assets.

fully rational expectations.[10] Their optimisation problem looks as follows:

$$\max_{c_t^F, a_t^F} E_0 \sum_{t=0}^{\infty} \beta^t \log c_t^F, \tag{29}$$

subject to

$$\frac{a_t^F}{z_t} + c_t^F = \Pi_t^W + \Pi_t^I + \varpi + \tau_t + \frac{1+i_{t-1}}{1+\pi_t} a_{t-1}^F, \tag{30}$$

$$a_t^F \geq 0, \tag{31}$$

where E_0 is the rational expectation operator. a_t^F represents the bonds issued by the firm owners that pay the risk-free nominal interest rate i_t. Π_t^W and Π_t^I are the dividends the firm owners receive from the ownership of wholesale and intermediate-goods firms, whereas $\varpi \geq 0$ and τ_t are respectively a home-production income and a lump-sum fiscal transfer. Just like for the workers, firm owners hold no assets at the beginning of time $a_{-1} = 0$.

3.3 Final Goods Firms

The final good y_t is produced by aggregating wholesale inputs $y_t(h)$ with a constant elasticity of substitution technology:

$$y_t = \left(\int_0^1 y_t(h)^{\frac{\theta-1}{\theta}} dh \right)^{\frac{\theta}{\theta-1}}, \tag{32}$$

where θ is the elasticity of substitution of wholesale goods. The cost-minimisation problem for the final good firm implies that the demand for the wholesale good h is given by:

$$y_t(h) = \left(\frac{p_t(h)}{p_t} \right)^{-\theta} y_t, \tag{33}$$

where $p_t(h)$ is the price of the wholesale good. Finally, the zero-profit condition implies that the price index is expressed as:

$$p_t = \left(\int_0^1 p_t(h)^{1-\theta} dh \right)^{\frac{1}{1-\theta}}. \tag{34}$$

[10] In Section 3.11, we explain that firm owners have a binding debt limit and their Euler equation, therefore, only holds with a strict inequality. As a result, assuming that firm owners feature boundedly rational expectations would not help attenuate the forward guidance puzzle.

3.4 Wholesale Firms

There is a continuum of wholesale firms, indexed by $h \in [0, 1]$, that produce a differentiated product using a homogeneous intermediate good as input. The production function of a wholesale good h is given by:

$$y_t(h) = x_t(h), \tag{35}$$

where $x_t(h)$ is the input of intermediate goods demanded by the wholesale firm h, purchased at price q_t. $y_t(h)$ represents the output of firm h. These wholesale firms act in a monopolistically competitive market and set their price $p_t(h)$ facing quadratic adjustment costs à la Rotemberg (1982). Since these firms are owned by the firm owners, the stream of profits $\Pi^W_{t+j}(i)$ is discounted by pricing kernel $M^F_{t,t+j}$. The optimisation problem of these firms is given by:

$$\max_{p_t(h)} E_t \sum_{j=0}^{\infty} M^F_{t,t+j} \Pi^W_{t+j}(h), \tag{36}$$

$$\Pi^W_t(h) = \left(\frac{p_t(h)}{p_t}\right)^{1-\theta} y_t - \left(1 - \tau^W\right) \varphi_t \left(\frac{p_t(h)}{p_t}\right)^{-\theta} y_t - \frac{\psi}{2}\left(\frac{p_t(h)}{p_{t-1}(h)} - 1\right)^2 y_t, \tag{37}$$

where Equations (36) and (37) represent the stream of lifetime profits, φ_t is the price of intermediate goods relative to the final good's price, and τ^W is a production subsidy. In a symmetric equilibrium, the maximisation problem delivers the following New Keynesian Phillips curve (NKPC):

$$\psi (1 + \pi_t) \pi_t = \psi E_t M^F_{t+1} (1 + \pi_{t+1}) \pi_{t+1} \frac{y_{t+1}}{y_t} + 1 - \theta + \theta \left(1 - \tau^W\right) q_t. \tag{38}$$

The profits of the wholesale firm, which are returned to the firm owners in the form of dividends, are given by:

$$\Pi^W_t = \left(1 - \left(1 - \tau^W\right) \varphi_t - \frac{\psi}{2}\pi_t^2\right) y_t. \tag{39}$$

3.5 The Labour Market

At the beginning of each period t, firms post v_t vacancies and u_t unemployed workers look for a job. The matching technology takes the form of a Cobb-Douglas function:

$$m_t = \mu u_t^{\gamma} v_t^{1-\gamma}, \tag{40}$$

where m_t represents the number of successful matches, $\gamma \in (0, 1)$ and $\mu > 0$ scales the matching efficiency. The job-filling rate, i.e., the probability that a vacancy is matched with a worker searching for a job, is defined as:

$$\lambda_t = \frac{m_t}{v_t}. \tag{41}$$

The job-finding rate, i.e., the probability that an unemployed searching for a job is matched with an open vacancy, is given by:

$$f_t = \frac{m_t}{u_t}. \tag{42}$$

At the beginning of each period, there are n_{t-1} workers, with a fraction ρ being laid off. Thus, the number of workers who keep their jobs is $(1-\rho)\, n_{t-1}$. At the same time, m_t new matches are formed. Assuming that new hires start working immediately when they are hired, aggregate employment evolves according to the following law of motion:

$$n_t = (1-\rho)\, n_{t-1} + m_t, \tag{43}$$

while the number of unemployed workers seeking a job is given by:

$$u_t = 1 - (1-\rho)\, n_{t-1}. \tag{44}$$

3.6 Intermediate Goods Firms

If an intermediate-good firm successfully hires a worker, it produces one unit ($x_t = 1$) of its good with its only employee. If a firm finds a match, it obtains a flow profit in the current period after paying the worker. In the next period, if the match survives (with probability $1-\rho$), the firm continues its operations. If the match breaks down (with probability ρ), the firm posts a new job vacancy at a fixed cost κ with the value J_t^v. The value of a firm with a match (denoted by J_t^F) is therefore given by the Bellman equation:

$$J_t^F = \left(1-\tau^I\right)(q_t - w_t + T) + E_t M_{t,t+1}^F \left((1-\rho)\, J_{t+1}^F + \rho J_{t+1}^v\right), \tag{45}$$

where $\tau^I \in [0,1]$ is a corporate tax rate and T a wage subsidy. If the firm posts a new vacancy in period t, it costs κ units of final goods. The vacancy can be filled with probability λ_t, in which case the firm obtains the value of the match. Otherwise, the vacancy remains unfilled and the firm goes into the next period with the value J_{t+1}. Thus, the value of an open vacancy is given by:

$$J_t^v = -\kappa + \lambda_t J_t^F + (1-\lambda_t)\, E_t M_{t,t+1}^F J_{t+1}^v. \tag{46}$$

Free entry implies that $J_t^v = 0$, so that:

$$\frac{\kappa}{\lambda_t} = J_t^F. \tag{47}$$

This relation describes the optimal job creation decisions. The benefit of creating a new job is the match value J_t^F. The expected cost of creating a new job is the flow cost of posting a vacancy κ multiplied by the expected duration of an unfilled vacancy $1/\lambda_t$. Finally, the aggregate period profits of intermediate-goods firms are given by:

$$\Pi_t^I = n_t \left(1 - \tau^I\right)(q_t - w_t + T) - \kappa v_t. \tag{48}$$

3.7 Workers' Value Function

If a worker is employed, he obtains wage income w_t. At time $t+1$, the worker is laid off with probability ρ and may find a new job with probability f_{t+1}. A separated worker may fail to find a new match in period $t+1$, thereby entering the unemployment pool, with probability $s_{t+1} = \rho(1 - f_{t+1})$. The worker continues to be employed with probability $1 - s_{t+1}$. The value of an employed worker, V_t^e, can be written as follows:

$$V_t^e = \log w_t + \beta E_t^{BR}\left((1 - s_{t+1}) V_{t+1}^e + s_{t+1} V_{t+1}^u\right), \tag{49}$$

where V_t^u denotes the value of an unemployed worker. They obtain the home-production income δ_t and have the chance, in period $t+1$, of finding a new job with probability f_{t+1}. Thus, the value of an unemployed worker satisfies the Bellman equation:

$$V_t^u = \log \delta_t + \beta E_t^{BR}\left(f_{t+1} V_{t+1}^e + (1 - f_{t+1}) V_{t+1}^u\right). \tag{50}$$

3.8 The Nash Bargaining Wage

Firms and workers bargain over wages. If we define $S_t^W \equiv V_t^e - V_t^u$, the Nash bargaining problem is given by:

$$w_t^N = \underset{w_t}{\operatorname{argmax}} \left(S_t^W\right)^{1-\alpha} \left(J_t^F\right)^{\alpha}, \tag{51}$$

where $\alpha \in (0,1)$. The first-order condition is then given by:

$$(1 - \alpha) J_t^F = \alpha \left(1 - \tau^I\right) S_t^W w_t^N. \tag{52}$$

3.9 Wage Rigidity

In practice, however, the equilibrium real wage may differ significantly from the Nash bargaining solution. To achieve empirically reasonable levels of volatility in both vacancies and unemployment, the literature often assumes some form of real wage rigidity (Hall, 2005). We assume, therefore, that the actual wage is obtained by weighing the Nash wage w_t^N against the (constrained-efficient) steady-state value w:

$$w_t = w^{\phi} {w_t^N}^{1-\phi}, \tag{53}$$

where the parameter $\phi \in (0, 1)$ represents the degree of wage inertia.

3.10 Government

Monetary Policy In our baseline specification, we assume that the monetary policy authority optimally sets the nominal interest rate in response to aggregate shocks. In other words, it maximises the following social welfare function subject to all equilibrium conditions and the ZLB constraint (i.e., $i_t \geq 0$):

$$\mathbb{W} = E_0 \sum_{t=0}^{\infty} \beta^t U_t, \tag{54}$$

where U_t is the sum of instantaneous utilities of all households: employed, unemployed, and firm owners. In Section 3.12, we explicitly define $\mathbb{W}$ and U_t, while we set up the problem and derive the first-order conditions in Appendix C. To highlight the benefits of the optimal policy, we also consider the implications of a simple strict inflation-targeting rule:[11]

$$\pi_t = 0 \quad \text{s.t.} \quad i_t \geq 0. \tag{55}$$

Fiscal Policy To achieve a constrained-efficient allocation in steady state, we assume that the fiscal authority sets constant taxes and subsidies τ^w, τ^I, and T, which are rebated lump-sum to firm owners:

$$\tau_t = \tau^I n_t \left(q_t - w_t\right) - \tau^W q_t y_t - n_t \left(1 - \tau^I\right) T. \tag{56}$$

The first term of the expression represents a corporate tax, the second is a production subsidy, and the last is a wage subsidy. In Section 3.13, we report the values of taxes and subsidies associated with the constrained-efficient allocation.

[11] In the model, the allocation under the simple strict inflation-targeting rule is the same to that under the optimal discretionary policy.

3.11 Market Clearing and Equilibrium

The model is closed by the following market-clearing conditions for bonds, final goods, and wholesale goods:

$$\int_{[0,1]} a_{i,t} di + a_t^F = 0, \tag{57}$$

$$\int_{[0,1]} c_{i,t} di + c_t^F + \kappa v_t = y_t + (1 - n_t) \delta_t - \frac{\psi}{2} {\pi_t}^2 y_t + \varpi, \tag{58}$$

$$y_t = n_t. \tag{59}$$

We report the full set of equilibrium conditions in Appendix B. It bears noting that, as in Ravn and Sterk (2017, 2021) and Challe (2020), the model does not give rise to a distribution of wealth across workers. The reason for this is that with a zero debt limit (Equations (27) and (31)), no one is issuing the assets that the precautionary savers would be willing to purchase for self-insurance. In other words, the precautionary-savings motive of employed workers puts downward pressure on the real interest rate. Given the low level of the real rate, unemployed workers and firm owners would prefer to borrow and face, therefore, a binding debt limit. For this reason, the equilibrium supply of assets ends up being zero, and all households consume their whole current income.[12] Thus, employed workers consume their wage, $c_{e,t} = w_t$, and their Euler equation holds with equality:

$$E_t^{BR} M_{t,t+1}^e \frac{(1 + i_t) z_t}{1 + \pi_{t+1}} = 1, \tag{60}$$

where their stochastic discount factor is given by:

$$M_{t,t+1}^e = \beta \frac{(1 - s_{t+1}) u'(w_{t+1}) + s_{t+1} u'(\delta_{t+1})}{u'(w_t)}. \tag{61}$$

The two conditions above determine the saving/consumption choice of the employed households. In particular, two forces drive this decision: (i) changes in w_t make agents want to save more when wages are temporarily high (aversion to intertemporal substitutions); (ii) in times of high unemployment risk, i.e., high job-loss probability s_t, employed households wish to self-insure against the possibility of becoming unemployed (precautionary savings).

Unemployed households consume their home-production income, $c_{u,t} = \delta_t$. Since $\delta_t < w_t$, they are relatively poor at time t and would like to borrow in expectation of a higher income at time $t+1$. As a result, they

[12] Because of the zero-debt limit, the risk-premium shock does not appear in the resource constraint. This would not be the case in a more general setting.

face a binding debt limit, and their Euler equation holds with strict inequality:

$$E_t^{BR} M_{t,t+1}^u \frac{(1+i_t)\, z_t}{1+\pi_{t+1}} < 1, \tag{62}$$

where the stochastic discount factor is given by:

$$M_{t,t+1}^u = \beta \frac{(1-f_{t+1})\, u'(\delta_{t+1}) + f_{t+1} u'(w_{t+1})}{u'(\delta_t)}. \tag{63}$$

Firm owners do not have any precautionary-savings motive, as they do not face any unemployment risk. For this reason, they face a binding debt limit and their Euler equation holds with strict inequality:

$$E_t M_{t,t+1}^F \frac{(1+i_t)\, z_t}{1+\pi_{t+1}} < 1, \tag{64}$$

where the firm owners' stochastic discount factor is given by:

$$M_{t,t+1}^F = \beta \frac{u'\left(c_{t+1}^F\right)}{u'\left(c_t^F\right)}. \tag{65}$$

The consumption of a firm owner can be derived by combining Equations (30), (39), (48), (56), and (58):

$$c_t^F = y_t - w_t n_t - \frac{\psi}{2}\pi_t^2 y_t - \kappa v_t + \varpi. \tag{66}$$

3.12 Social Welfare

Under the optimal policy, the central bank's objective is to maximise social welfare, given by the sum of value functions of all households. In particular, assuming the same welfare weight across working households, we have that:

$$\mathbb{W} = E_0 \sum_{t=0}^{\infty} \beta^t U_t, \tag{67}$$

where U_t in Equation (67) is the sum of instantaneous utilities:

$$\begin{aligned} U_t &= n_t \log c_{e,t} + (1-n_t) \log c_{u,t} + \Lambda \log c_t^F \\ &= n_t \log w_t + (1-n_t)\log \delta_t + \Lambda \log\left(y_t - w_t n_t - \frac{\psi}{2}\pi_t^2 y_t - \kappa v_t + \varpi\right), \end{aligned} \tag{68}$$

where $\Lambda \geq 0$ is the relative welfare weight on firm owners.

3.13 Constrained-Efficient Steady State

The economy features three distortions: monopolistic competition in the wholesale sector, congestion externalities in the labour market, and imperfect insurance against unemployment risk. To simplify the optimal policy analysis, we assume a constrained-efficient steady state. To this end, we consider the appropriate values of steady-state inflation (π) and the tax instruments (τ^W, τ^I, T) that eliminate the various distortions in steady state:[13]

$$\pi = 0, \quad \tau^W = \frac{1}{\theta}, \quad T = \frac{u(w^*) - u(\delta^*)}{u'(w^*)}, \quad \tau^I = 1 - \frac{(1-\gamma)(1-\beta(1-\rho))}{1-\beta(1-\rho)(1-\gamma f^*)}, \tag{69}$$

where f^* is given by:

$$f^* = \left(\frac{(1-\tau^I)\,\mu^{\frac{1}{1-\gamma}}}{\kappa(1-\beta(1-\rho))} \left(1 - w^* + \frac{u(w^*) - u(\delta^*)}{u'(w^*)} \right) \right)^{\frac{1-\gamma}{\gamma}}. \tag{70}$$

where w^*, the constrained-efficient wage in steady state, satisfies:

$$u'(w^*) = \Lambda u'(y - w^* n - \kappa v + \varpi), \tag{71}$$

recalling that $c^e = w^*$ and $c^F = y - w^* n - \kappa v + \varpi$, where c^e and c^F are the steady-state consumption levels of employed workers and firm owners, y the steady-state level of final output, n the steady-state level of employment and v steady-state vacancies. The production subsidy τ^W ensures that the price markup is 1 in steady state, thereby eliminating monopolistic competition. The hiring subsidy T corrects the lack of unemployment insurance, whereas the corporate tax τ^I corrects the congestion externalities in the labour market. Finally, to ensure the decentralised wage is constrained-efficient in the steady state, we also need to assume:

$$\alpha = \left(1 + \frac{(1-\tau^I)\, S^W w^*}{J^F} \right)^{-1}. \tag{72}$$

3.14 Bounded Rationality in the Baseline Model

Similarly as in Section 2.1.1 This type of expectation affects two equilibrium conditions in our model. First, the worker's Euler equation becomes:

$$1 = \beta E_t \frac{\left((1-s_{t+1})\, {w_{t+1}}^{-1} + s_{t+1} {\delta_{t+1}}^{-1}\right)^{\zeta}}{\left((1-s)\, w^{-1} + s\delta^{-1}\right)^{\zeta-1} {w_t}^{-1}} \frac{(1+i_t)\, z_t}{1+\pi_{t+1}}. \tag{73}$$

[13] For a detailed derivation and discussion of the constrained-efficient allocation, please refer to Section 3 in Challe (2020).

Table 1: Calibration

Parameters		II	PI	Targets/Sources		II	PI
Sym.	Description	Value	Value	Sym.	Description	Value	Value
β	Discount factor	0.989	0.995	$4i$	Annual interest rate	2%	-
ζ	Cognitive discounting	0.750	-	-	Gabaix (2020)	-	-
θ	Monopoly power	6.000	-	$\frac{1}{\theta-1}$	Markup rate	20%	-
ψ	Price stickiness	1088.6	1119.2	-	Calvo stickiness	0.84	-
γ	Elasticity of matching	2/3	-	-	Shimer (2005)	-	-
κ	Vacancy cost	0.044	0.040	κ/w	% of wage	4.5%	-
w	Real wage	0.979	0.888	f	Job-finding rate	80%	-
μ	Matching efficiency	0.765	-	λ	Vacancy-filling rate	70%	-
ρ	Job-destruction rate	0.250	-	s	Job-loss rate	5%	-
δ	Workers' home prod.	0.882	0.888	$1-\frac{\delta}{w}$	Cons. loss upon unemp.	10%	0%
ϖ	Firm owners' home prod.	0.484	0.351	$\frac{wn}{c^F+wn}$	Labour share	65%	-
ϕ	Wage inertia	0.948	-	-	Challe (2020)	-	-
ρ_z	RP shock persistence	0.920	-	PI & SIT: ZLB for around 16 quarters			
σ_z	RP shock volatility	0.0187	-	PI & SIT: 10% output drop & 1.8%p infl. drop			

Note: The tables presents the calibrated value of our baseline model with imperfect insurance (II) and a version of the model with perfect insurance (PI). SIT stands for strict inflation targeting.

Second, the value of being employed is given by:

$$S_t^W = \log w_t - \log \delta_t + \beta E_t \frac{\left(\left(1 - s_{t+1} - f_{t+1}\right) S_{t+1}^W\right)^\zeta}{\left(\left(1-s-f\right) S^W\right)^{\zeta-1}}. \tag{74}$$

4 Numerical Exercises

4.1 Solution and Calibration

For the numerical analysis in Section 4.2, the fully-fledged model discussed in Section 3 is solved via a piecewise linear approximation using the approach suggested by Guerrieri and Iacoviello (2015), to consider the effects of the occasionally binding ZLB. In our numerical exercises, we compare the baseline model with imperfect unemployment insurance (II), i.e., $w_t > \delta_t$, to a version of the model with perfect insurance (PI), i.e., $w_t = \delta_t$. It is important to note that, in the II model, we assume that the home-production income δ_t varies such that δ_t/w_t is constant. This assumption implies that the income risk, faced by employed workers, depends on variations in the job-loss rate s_{t+1} and not on changes in δ_t/w_t.

Table 1 lists the model parameters and the empirical moments we aim to target. It is important to note that the calibration of some parameters differs between the II and PI models to match the steady-state target values. The discount factor β is set to 0.989 (II) or 0.995 (PI), targeting an average annualised nominal interest rate of 2%. We calibrate our cognitive discounting parameter to 0.75, which is consistent with the empirical evidence presented in Pfäuti and Seyrich (2022). They provide evidence from household survey expectations, specifically drawing from the Survey of Consumers from the University of Michigan. By analysing forecast errors and revisions, they estimate the cognitive discounting parameter for different income groups across various economic variables (e.g., unemployment expectations, inflation expectations). Their findings suggest that these estimated parameters generally fall within the range of approximately 0.6 to 0.85, supporting our chosen value of 0.75.[14] The elasticity of substitution between intermediate goods θ is set to 6, which is standard in the literature and implies an average markup rate of 20%. We set the Rotemberg price stickiness parameter to 1088.58 (1119.18), which, in a Calvo setting, would imply firms do not readjust their price with a probability of 0.84, consistent with Nakata et al. (2019). Regarding the labour market parameters, we set the matching function parameter $\gamma = 2/3$, in line with Shimer (2005). Following Challe (2020), the flow cost of a vacancy κ is set to 0.044 (0.04) to match an average vacancy cost-to-wage ratio of 4.5%. The steady-state real wage is 0.979 (0.888) to match an average job-finding rate of 80%. The average matching efficiency μ is 0.765, targeting a vacancy-filling rate of 70%. The job-separation rate ρ is set to 0.25, implying a 5% job-loss rate. The average home-production income δ is set to 0.882 (0.888), such that the average proportional consumption loss upon unemployment $1 - \frac{\delta}{w} = 0.1$. In the three-period model, we consider two additional counterfactual scenarios where $1 - \frac{\delta}{w}$ is set equal to 0.2 or 0.3. The steady-state level of the firm owners' home-production income is set to 0.484 (0.351) to match a 65% labour share. The real wage rigidity parameter is set to $\phi = 0.948$ as in Challe (2020).

Finally, we calibrate the exogenous risk-premium shock process to $\rho_z = 0.925$ and $\sigma_z = 0.0167$. This calibration induces a 10 per cent drop in output, a 1.8 percentage-point fall in inflation, and the ZLB constraint to bind for 16 quarters when the central bank conducts a strict inflation-targeting rule in the PI version of the model.

4.2 Infinite-Horizon Model

In this section, we analyse the impact of an adverse risk-premium shock that causes the ZLB constraint to bind for 16 quarters when the central bank follows a strict inflation-targeting rule. In line with the previous section, the shock causes a decline in output, wages and inflation. As displayed in Figure 1, under a strict inflation-targeting rule, the central bank cannot react to the fall in demand, which causes a significant decline in inflation expectations and an increase in the real interest rate. The latter further amplifies the initial

[14] Other empirical evidence is provided in Angeletos et al. (2021), who use consensus expectations rather than consumer expectations. Based on their estimates, the cognitive discounting parameter would lie between 0.73 and 0.92 for inflation and 0.82 to 0.83 for unemployment.

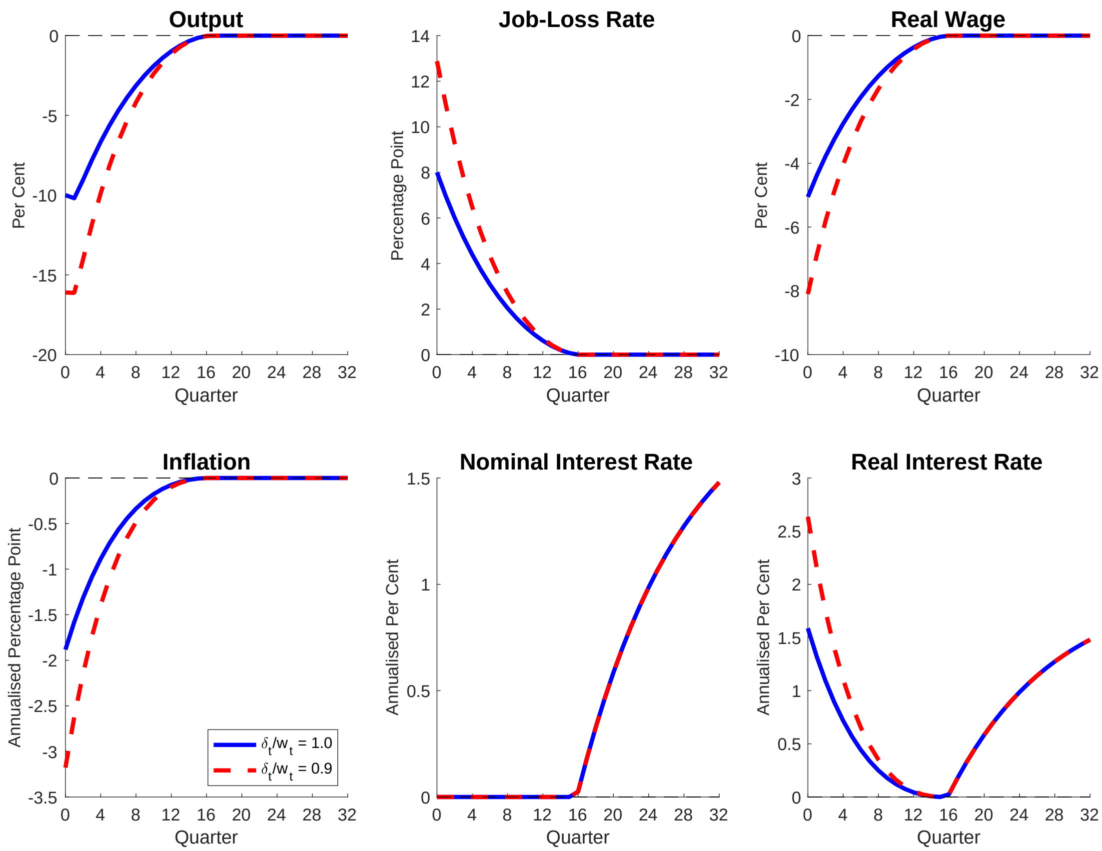

Figure 1: Strict Inflation Targeting in the Infinite-Horizon Model

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind for 16 quarters under strict inflation targeting. Each line represents a different degree of unemployment risk sharing.

drop in real activity and inflation. In the II case (red-dashed line), a worsening in labour market conditions (rise in the job-loss rate) induces employed workers to increase their savings for precautionary reasons, which causes inflation to fall even more substantially on impact. Because of the binding ZLB constraint on the policy rate, inflation expectations decline more severely under imperfect insurance, causing a larger increase in the real rate. Consequently, the fall in output is about 7 percentage points larger than under PI.

When the central bank commits to an optimal interest rate path, as shown in Figure 2, the effects of an adverse risk-premium shock are significantly milder than with a strict inflation targeting policy rule. By keeping the interest rate at zero for 7 quarters longer, the central bank boosts inflation expectations, reduces the real rate and substantially mitigates the drop in output. In the presence of imperfect insurance, the optimal path of the policy rate is nearly the same as in the PI case.[15] Because the nominal rate is kept low for an extended period, households expect labour market conditions to improve, which attenuates the

[15] For lower δ_t/w_t, the central bank tends to lift off the interest rate earlier.

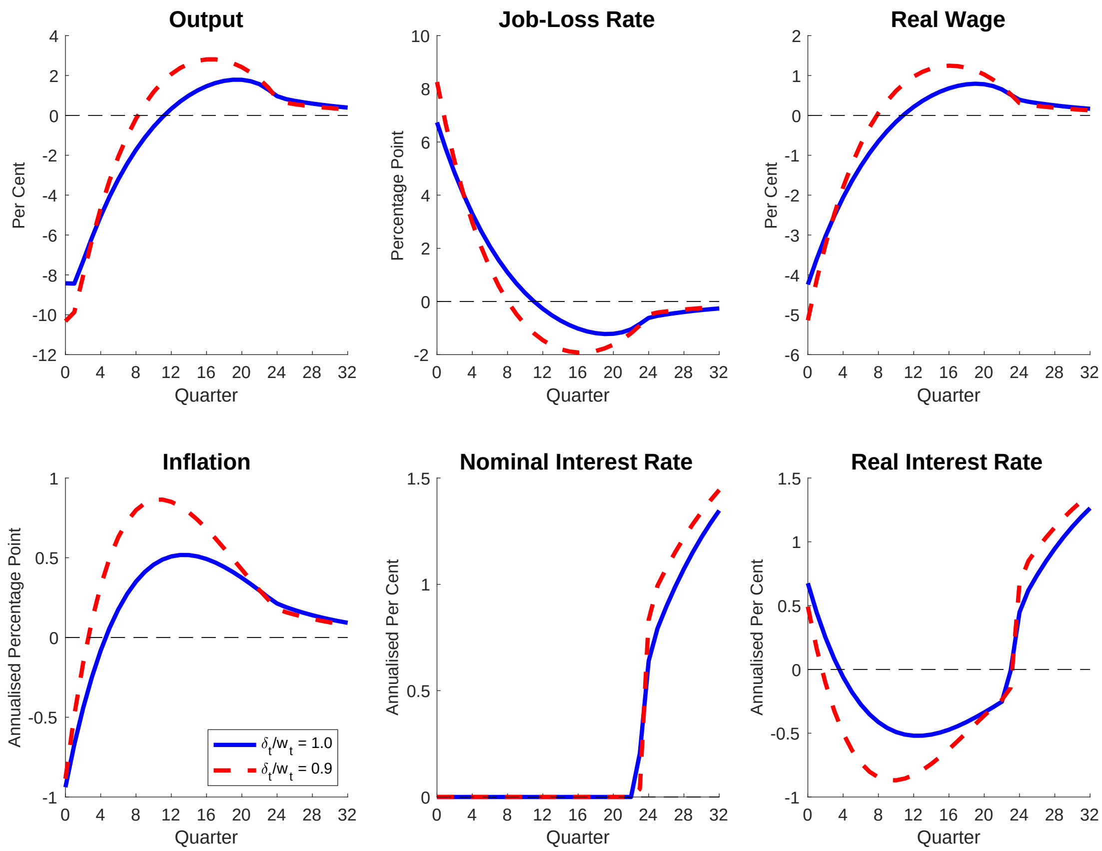

Figure 2: Optimal Monetary Policy in the Infinite-Horizon Model

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind for 16 quarters under strict inflation targeting. Each line represents a different degree of unemployment risk sharing.

employed workers' precautionary savings motive. Inflation declines less and overshoots more than in the PI case. As a result, the decline in real activity and real wages, as well as the rise in the job-loss rate, is nearly the same under PI and II. In other words, under the optimal policy, the central bank can almost fully neutralise the deflationary spiral caused by the precautionary-savings behaviour and the ZLB. In terms of output stabilisation, the benefits from reducing market incompleteness (e.g., via unemployment insurance policies) are significantly smaller under the optimal monetary policy than under strict inflation targeting. It bears noting, however, that although the optimal policy can significantly mitigate the initial demand contraction under II, the overall responses of output and inflation are more volatile than under PI.

4.3 The Power of Forward Guidance

In this section, we study how the power of forward guidance affects the optimal monetary policy by varying the workers' cognitive discounting parameter. First, we consider how changing the cognitive parameter affects the economy's response to a negative demand shock when monetary policy follows a strict inflation-targeting policy (i.e., the absence of forward guidance). Figure 3 displays the results for some key variables under $\zeta = 1$ (rational expectations, above the range of empirically plausible values discussed in Section 4.1), $\zeta = 0.75$ (the benchmark value of myopia), and $\zeta = 0.5$ (below the range of empirically plausible values). The shock is calibrated such that output and inflation fall respectively by 10 per cent and 1.8 percentage points, and the ZLB constraint binds for 16 quarters.[16] In Appendix F, we consider the alternative exercise of varying the degree of bounded rationality while hitting the economy with the same-sized shock (i.e. without recalibrating the shock conditional on ζ).

When working households are more myopic, the costs of a liquidity trap under II become significantly less severe. The reason is that workers do not internalise as much that the future interest rate will be stuck at the ZLB, which leads to a smaller fall in inflation expectations and a more muted rise in the real rate. Furthermore, agents do not fully anticipate that future labour market conditions are going to worsen, which significantly mitigates the precautionary savings motive under II. Hence, the difference between II and PI is reduced and for $\zeta = 0.5$, the II drop in output is only 2 percentage points larger than under PI, compared to 20 percentage points under fully rational expectations. The II fall in inflation is about 0.8 percentage points larger than under PI, compared to a 3 percentage points difference in the presence of fully rational agents.

Second, we analyse how the model economy responds under the optimal policy under commitment (Figure 4). The shock process is calibrated using the same values as for the strict inflation-targeting case. Under rational expectations, forward guidance is very effective, as workers fully anticipate that the central bank is keeping the interest rate lower for longer. This leads to a much smaller fall in output and inflation compared to the case with strict inflation targeting, both under PI and II. Furthermore, as workers expect labour market improvements, the precautionary savings motive under II is strongly muted, and, as a result, inflation expectations rise more substantially and output declines even less than under PI. When we reduce the cognitive discounting parameter, forward guidance becomes less effective, which is reflected in a stronger decline in output and inflation both under PI and II. The reduction in the power of forward guidance implies a stronger precautionary motive than the $\zeta = 1$ case. As a result, when $\zeta = 0.75$ or $\zeta = 0.5$, output tends to fall more under II than under PI. However, the gap between PI and II does not widen substantially when we go from $\zeta = 0.75$ to 0.5, as the reduction in the power of forward guidance is partially offset by the fact that agents internalise less future labour market developments, which eases the precautionary savings behaviour.

[16] The approach of keeping the severity of the recession constant as one varies the model's parameter values is adopted by Boneva et al. (2016), Hills and Nakata (2018), and Nakata et al. (2019).

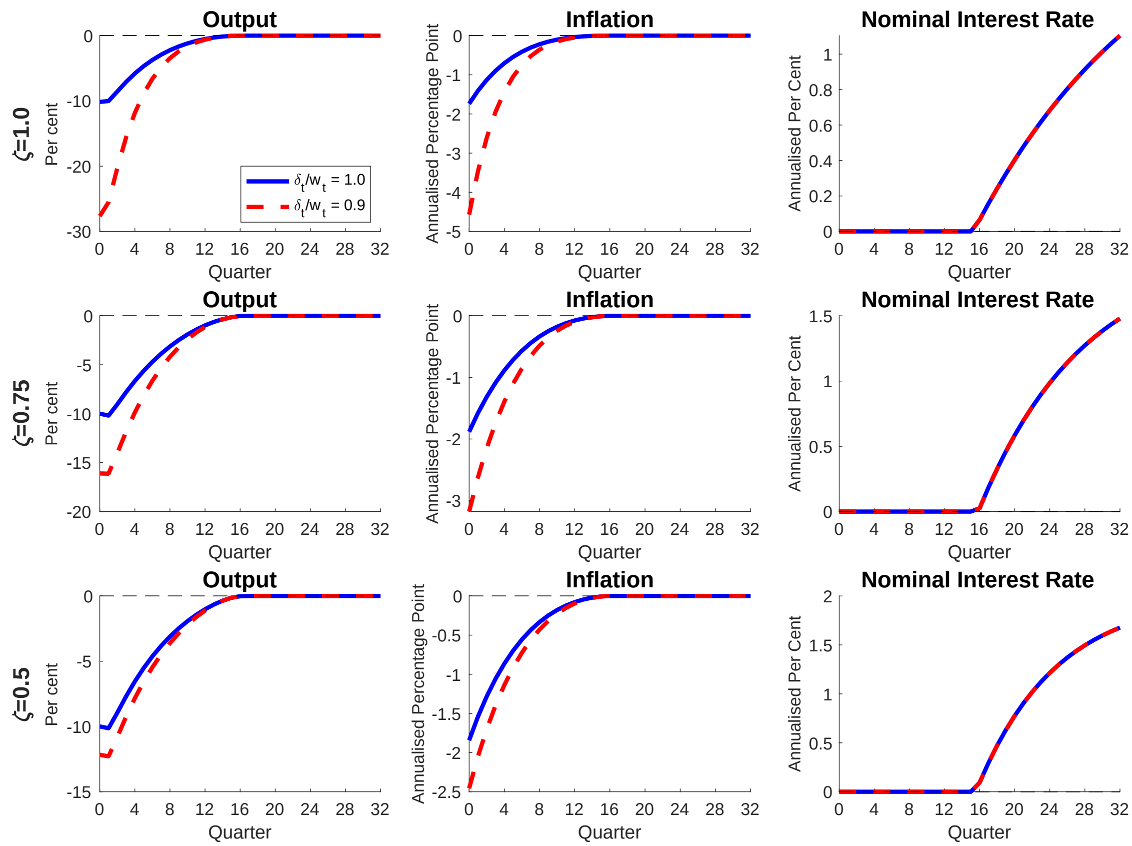

Figure 3: Strict Inflation Targeting and Cognitive Discounting

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind for 16 quarters under strict inflation targeting. Each line represents a different degree of unemployment risk sharing.

4.4 Alternative Policy Rules

In this section, we perform numerical simulations assuming the central bank follows the alternative policy rules discussed in Section 2.2.3. In particular, we consider a strict price-level-targeting rule, an inertial Taylor-type rule, and an average inflation-targeting rule. As discussed above, these rules attenuate the negative impact of demand shocks, both under perfect and imperfect unemployment insurance, and can deliver results closer to those found under the optimal policy. Unlike the optimal policy case, under these simple monetary policy rules, market incompleteness amplifies output contractions in response to negative demand shocks. Therefore, at the ZLB, unemployment insurance policies remain useful tools to stabilise output.

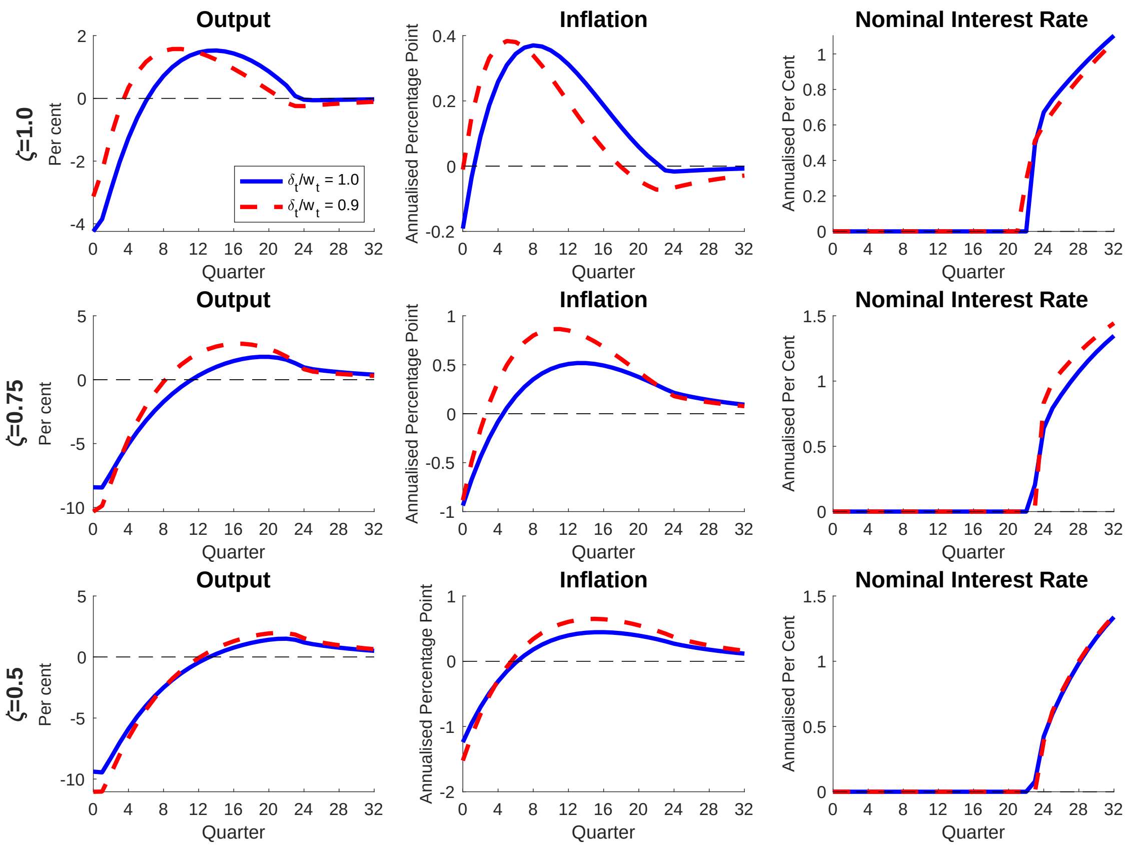

Figure 4: Optimal Monetary Policy and Cognitive Discounting

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind for 16 quarters under strict inflation targeting. Each line represents a different degree of unemployment risk sharing.

4.4.1 Price Level Targeting

Figure 5 displays the results under this policy specification. Since price-level targeting implies history dependence in the policy rate, the nominal policy rate is kept at zero for longer than implied by contemporaneous macroeconomic variables. As a result, inflation and output overshoot after the initial decline. Also in this case, the gap between the economies with PI and II narrows. However, the initial fall in output and inflation remains significantly larger under II.

We notice that price-level targeting is less effective than the optimal policy at closing the gap between PI and II. The reason is that, as we showed in Section 2.2, the optimal monetary policy implies a stronger commitment when markets are incomplete or agents are less cognitively myopic. On the other hand, simple policy rules, by definition, apply the same level of commitment irrespective of market incompleteness or cognitive myopia.

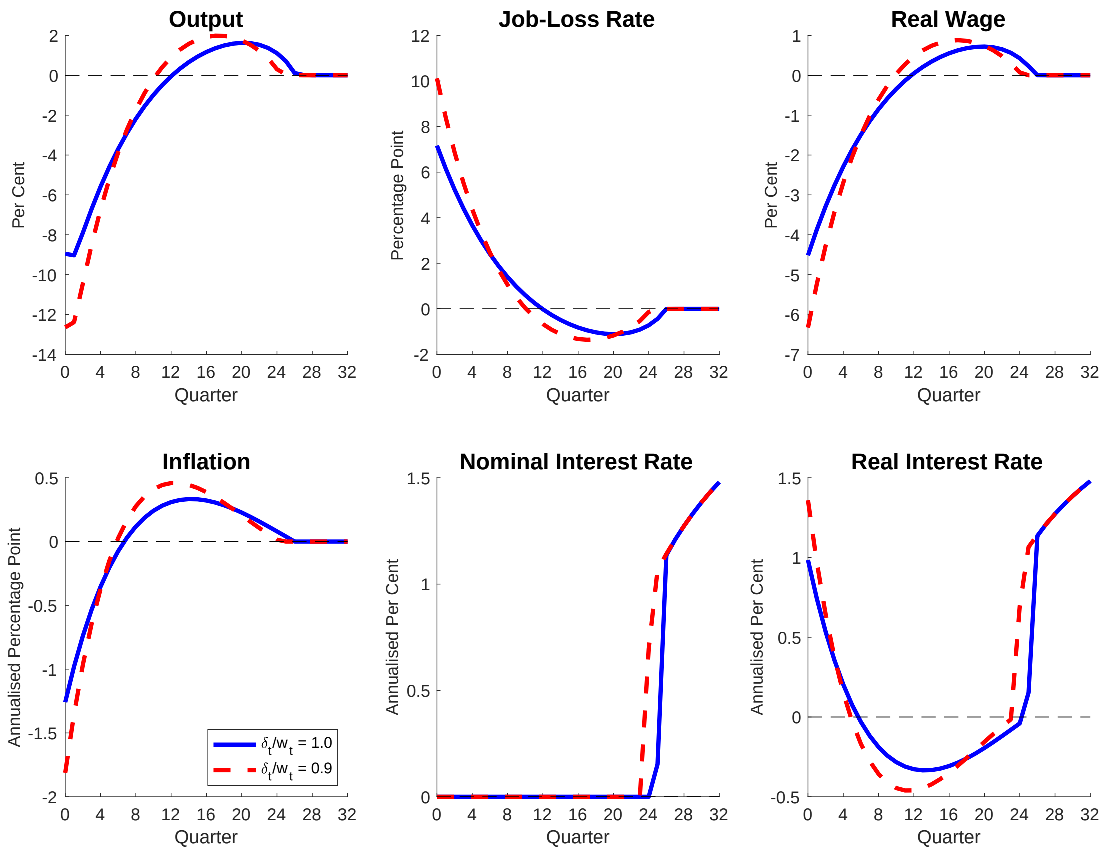

Figure 5: Price Level Targeting

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind for 16 quarters under strict inflation targeting. Each line represents a different degree of unemployment risk sharing.

4.4.2 Shadow Rate Smoothing

The second alternative policy is the Taylor-type rule with shadow-rate smoothing. Figure 6 displays the responses of our model variables under this policy. First, comparing these results with those in Figure 1, one can see how the inertial policy significantly mitigates the drop in output, wages, inflation, and the rise in the job-loss rate. Second, the inertial policy is more effective at reducing the decline in real activity under imperfect insurance. Specifically, in the PI case, output falls by 9 percent under an inertial policy, compared to a 10 percent drop in the absence of inertia. When there is II and employed workers feature a precautionary savings motive, the decline in output is about three percentage points smaller under the inertial policy compared to strict inflation targeting.

Intuitively, in the absence of inertia, a decrease in the shadow rate does not have any implications for the future path of the actual policy rate. Consequently, as displayed in Figure 1, the policy rate lifts off after 16

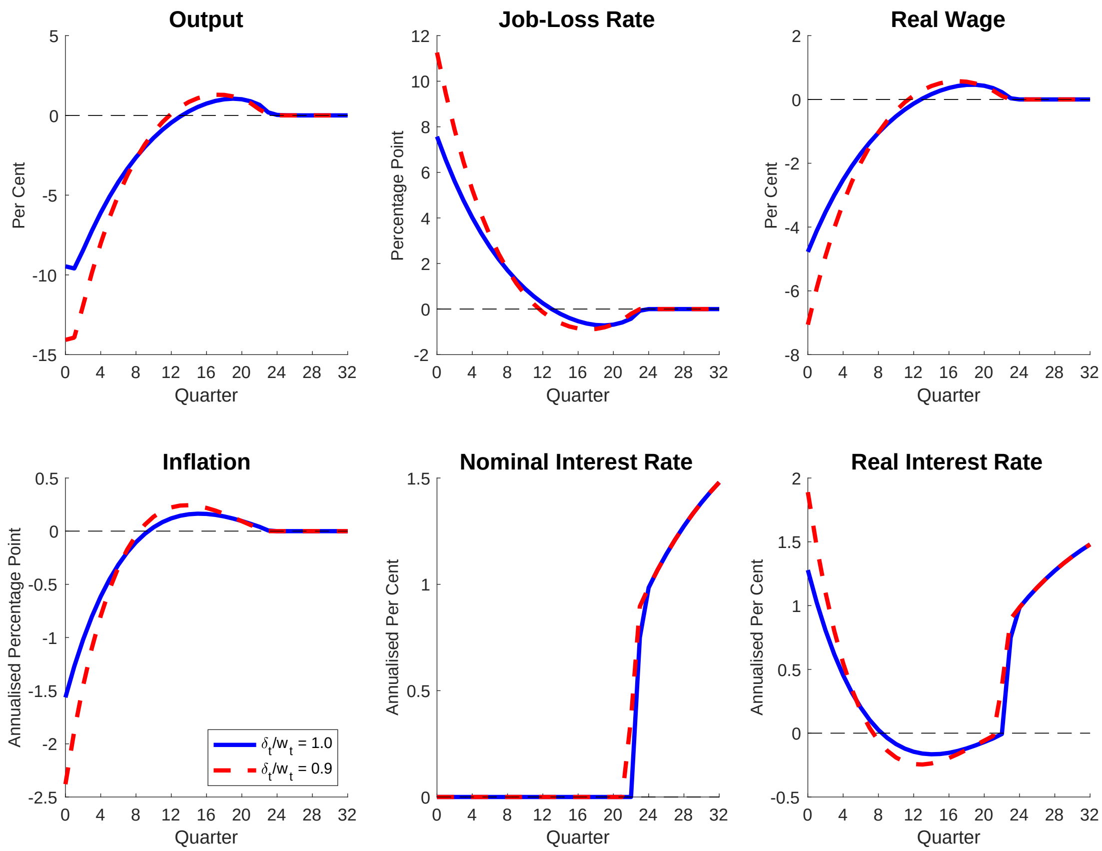

Figure 6: Inertial Policy Rule

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind for 16 quarters under strict inflation targeting. Each line represents a different degree of unemployment risk sharing. The inertial policy rule assumes $\rho_i = 0.9$.

quarters, as soon as the ZLB constraint is not binding anymore. With the inertial policy instead, a reduction in the shadow rate implies that the actual policy rate will remain lower for longer. Indeed, as shown in Figure 6, the nominal interest rate is kept at zero for 22 quarters under PI (21 under II), as long as the shadow rate is negative. By keeping the nominal rate lower for longer, the central bank boosts expectations about future inflation, output, and employment. The rise in inflation expectations leads to a smaller initial increase in the real rate, which undershoots after a few quarters. As a result, the declines in output and real wages are significantly more muted. However, the inertial monetary policy is not as effective as the optimal policy at offsetting the deflationary spiral caused by market incompleteness.

4.4.3 Average Inflation Targeting

The last policy specification is an average inflation-targeting rule with averaging parameter $\omega = 0.2$ as in Budianto et al. (2020). As mentioned in the analytical section, this policy rule is equivalent to strict inflation

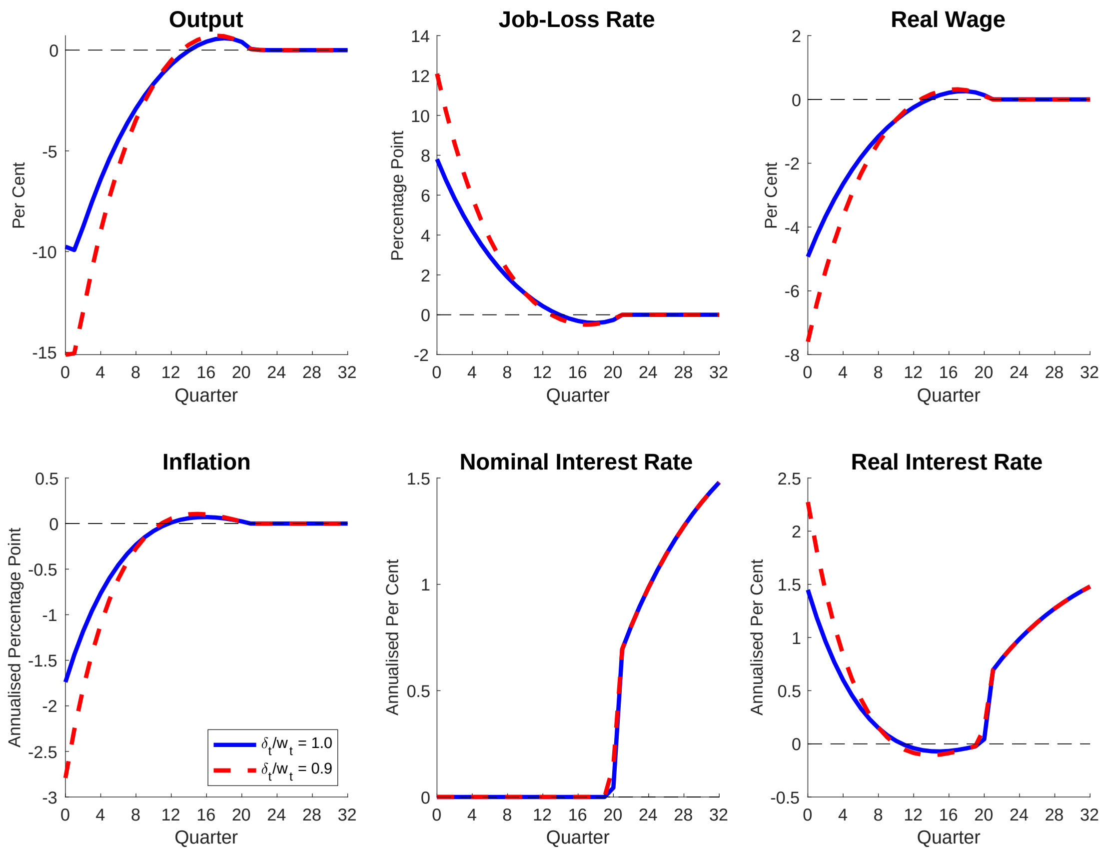

Figure 7: Average Inflation Targeting

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind for 16 quarters under strict inflation targeting. Each line represents a different degree of unemployment risk sharing. The averaging window parameter is set to $\omega = 0.2$.

targeting when $\omega = 1$ and equal to strict price level targeting when $\omega = 0$.

Figure 7 displays the results under the average inflation-targeting policy. Following a negative demand shock, the nominal policy rate is kept at zero for longer than implied by contemporaneous macroeconomic variables. Since the policy represents an average between the strict price-level-targeting and strict inflation-targeting policies, the rate is kept at zero for a shorter duration compared to price-level targeting. As a result, the policy results in larger impact declines in inflation and output relative to strict price-level targeting. Additionally, similar to previous cases, the gap between the economies with PI and II is narrower than under strict inflation targeting.

To sum up, all three alternative (and more realistic) policy specifications can ease the deflationary spiral caused by market incompleteness. However, they are less effective than the optimal policy at offsetting this spiral. Therefore, in practice, unemployment insurance policies remain important to stabilise output at the ZLB.

5 Model Limitations

Our analysis provides insights into the interaction between unemployment risk, the zero lower bound (ZLB), and optimal monetary policy. However, it is important to acknowledge a few limitations of our model, which could be addressed in future research.

The Zero-Liquidity Assumption A key simplifying assumption in our model, following Ravn and Sterk (2017) and Challe (2020), is the "zero-liquidity" setup. This implies that households face a zero-debt limit, leading to a situation where all households consume their entire current income. As a result, the equilibrium supply of assets is zero, and the model abstracts from any potential effects of monetary policy on the wealth distribution. Furthermore, a significant stylisation of our model is the assumption of a fixed zero debt limit. This fixed limit rules out the possibility of debt-deflation cycles, which can significantly exacerbate economic downturns in a ZLB environment (see e.g., Neri and Notarpietro, 2019). If the central bank credibly commits to the optimal zero-rate policy for longer, this will raise inflation expectations and lower the real interest rate. In a model with an endogenous debt limit, such as a collateral constraint as in Iacoviello (2005) and Gerali et al. (2010), a higher expected inflation raises the expected value of the collateral (e.g. physical capital or housing), increasing households' borrowing capacity, thereby further strengthening the expansionary effects of the optimal monetary policy. Consequently, in such a framework, the central bank might not need to commit to the zero-rate policy for as long a period as would be required in a case with a fixed debt limit, as the endogenous increase in borrowing capacity provides additional stimulus. However, it is important to highlight that there is theoretical support for the zero-liquidity assumption, which can be interpreted as a case of constrained debt issuance. In particular, Bassetto and Cui (2024) show that when distortionary tax revenues are insufficient to sustain the desired level of safe asset issuance, the optimal equilibrium features a limited supply of government debt, positive capital taxation, a positive liquidity premium, and a lower natural interest rate. This result provides direct support for studying the effects of monetary policy in a low-interest-rate environment under a zero-debt limit.

Absence of Explicit Fiscal Policy Analysis Our paper primarily focuses on the role of monetary policy, particularly optimal monetary policy, in mitigating the effects of unemployment risk at the ZLB. For this reason, our model abstracts from a detailed analysis of fiscal policy tools, such as government spending or tax adjustments, as active stabilisation instruments at the ZLB. However, a growing body of literature has shown that fiscal policy can be a particularly potent tool when monetary policy is constrained by the ZLB. Indeed, some studies (e.g., Christiano et al., 2011; Eggertsson, 2011; Woodford, 2011) suggest that fiscal policy can be a perfect substitute for monetary policy in such environments, with government spending multipliers potentially being much larger than in normal times. Correia et al. (2013) highlights that at the ZLB, the appropriate taxation mix can provide the necessary stimulus, without the need to use wasteful government spending or commitment to keeping policy rates lower for longer. In the presence of a more realistic fiscal policy, the central bank may need to keep the rate at zero for a shorter period than implied by our analysis. Our results should be seen as a benchmark of what an optimal commitment monetary policy at the ZLB can achieve, absent an endogenous debt limit and fiscal policy measures.

All the simplifications mentioned above are necessary to derive a tractable HANK model as in Ravn and Sterk (2021). Nevertheless, understanding how the inclusion of different fiscal policy instruments and an endogenous debt limit would affect our results is important from both a theoretical and policy perspective and should be addressed in future research.

6 Conclusion

In this paper, we study optimal monetary policy in response to adverse demand shocks when the short-term rate is at the ZLB and there is countercyclical uninsurable unemployment risk. Imperfect insurance gives rise to a precautionary-savings motive, which may significantly amplify the drop in inflation and inflation expectations, depending on the monetary policy response. Under a strict inflation-targeting policy rule, the central bank cannot respond to the fall in inflation, and, for this reason, the real rate rises. As a result, the decline in real activity is substantially larger than in the perfect-unemployment-insurance case.

The central bank's optimal response is to commit to keeping the interest rate at zero for an extended period after exiting the liquidity trap. The policy increases inflation expectations and reduces the real rate, sustaining current economic conditions both under complete and incomplete markets. The policy also has the additional benefit of improving the future economic outlook and expected labour market conditions, attenuating the precautionary-savings motive of households under imperfect unemployment insurance. As a result, we find that, in response to a negative demand shock, the contraction in real activity is almost the same under incomplete markets and under perfect risk sharing.

Assuming that (working) households are relatively myopic (i.e., boundedly rational) does not significantly affect the main conclusions above. On the one hand, making workers more myopic mitigates the power of forward guidance and hence the effectiveness of optimal monetary policy at the ZLB. On the other hand, bounded rationality has the additional effect of making agents less responsive to future developments in the labour market, which significantly attenuates the importance of the precautionary savings behaviour under incomplete markets. Therefore, even when agents are myopic and the power of forward guidance is relatively muted, incomplete markets do not substantially amplify the fall in demand when monetary policy is conducted optimally.

Finally, we consider the impact of alternative policy rules that introduce history dependence in the policy rate and could, therefore, operationalise the optimal policy prescriptions. In particular, we consider a price-level-targeting rule, an inertial rule, including the lagged shadow policy rate, and an average inflation-targeting rule. We find that these simple (and more realistic) policies ease but do not fully neutralise the deflationary spiral caused by the ZLB and the precautionary-savings behaviour. Therefore, we conclude that, in practice, unemployment insurance policies are desirable tools, alongside monetary policy, to stabilise output at the ZLB.

We acknowledge some caveats of our analysis. To concentrate on the role of countercyclical unemployment risk, the model relies on a zero-liquidity assumption, therefore abstracting from any potential effects of monetary policy on the wealth distribution, which is an important transmission channel in standard HANK models. Our model also abstracts from a detailed analysis of fiscal policy tools. Understanding the optimal mix of monetary and fiscal policies at the ZLB in a HANK model remains an open question for future research.

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