Unemployment Risk, Liquidity Traps, and Monetary Policy*

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February 12, 2021

Abstract

When the economy is in a liquidity trap, and households have a precautionary motive to save against unemployment risk, adverse demand shocks cause a severe deflationary spiral and output contractions. We study the implications of optimal monetary policy, which consists of keeping the nominal rate at zero longer than implied by current macroeconomic conditions. Under such policy and incomplete markets, expected improvements in labour market conditions alleviate the rise in unemployment risk and decline in demand. As a result, market incompleteness may mitigate output contractions in a liquidity trap. However, reducing market incompleteness is welfare-improving under realistic monetary policy rules.

Keywords: Unemployment risk, Liquidity trap, Zero lower bound, Monetary policy

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

*We are grateful to Daeha Cho, ShinHyuck Kang, Mira Kim, Ricardo Reis, and Vincent Sterk for insightful discussions and helpful suggestions. All errors are our own. The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or its committees.

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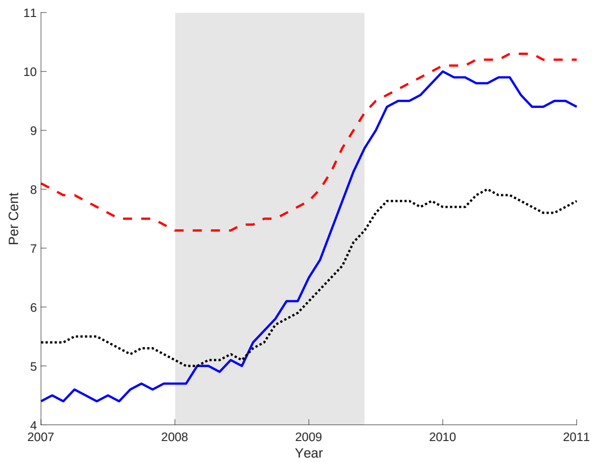
1 Introduction

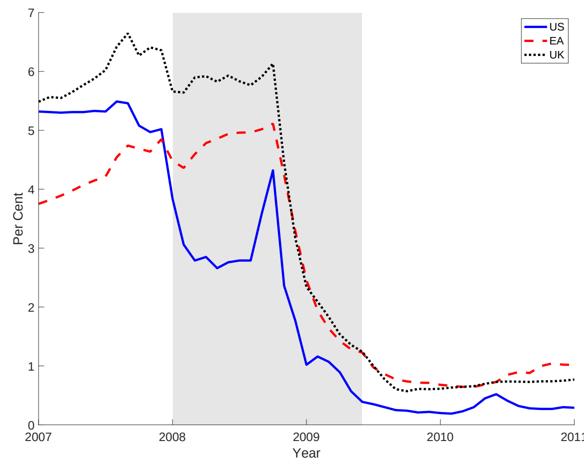
The Great Recession in 2008-2009 caused a significant and persistent increase in the unemployment rate across major advanced economies, as shown in the of Figure 1(a). The worsening in labour market conditions increased uncertainty about job prospects, which potentially gave rise to precautionary-saving behaviour, putting further downward pressure on real economic activity and prices (see, e.g., Den Haan et al., 2018 and Challe, 2020). Moreover, in response to the severe drop in demand, central banks worldwide cut short-term nominal interest rates that rapidly approached the zero lower bound (ZLB), where they remained for a prolonged time (see Figure 1(b)).

How effective is monetary policy at responding to a contraction in demand and increase in uninsurable unemployment risk when the nominal rate is at the ZLB? In this paper, we address this question through the lenses of 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, 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. Firm owners, instead, do not face any idiosyncratic risk. Households face a zero-debt limit and, as a result, end up consuming all their income. This ingredient of the model allows us to abstract from any distributional effects of monetary policy, and rather concentrate on the interaction between monetary policy and counter-cyclical 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 bank responds to aggregate demands shocks by setting the nominal policy rate, subject to a ZLB constraint.

In such a context, we compare the Ramsey optimal monetary policy to a simple strict-inflation-targeting rule in response to a negative demand shock that leads the economy into a liquidity trap. We find that, if the central bank only responds to current inflation, the adverse demand shock has significantly stronger effects under incomplete markets. This is because the fall in demand reduces job creation and raises unemployment risk, which induces households to increase their savings for precautionary reasons. The precautionary savings effect leads to a stronger fall in inflation and inflation expectations. Since the nominal rate is stuck at zero, the real rate rises, putting further downward pressure on consumption and output. In other words, when asset markets are incomplete, and the central bank is unable to cut the interest rate, an adverse demand shock gives rise to a deflationary spiral and a severe contraction in real activity due to a worsening in ex-



(a) Unemployment Rate



(b) Short-Term Rate

Figure 1: Unemployment Rates and Short-Term Interest Rates in the Great Recession

Note: The figure displays the unemployment rates and short-term interest rate for the United States (USA, blue-solid line), Euro Area (EA, red-dashed line), and United Kingdom (UK, black-dotted line). Grey shaded areas represent NBER recession dates. Source: OECD Main Economic Indicators, Volume 2021 Issue 1.

pected labour market conditions.

Under the optimal policy, instead, the central bank responds to the negative demand shock by committing to keep its nominal rate at zero longer than implied by current economic conditions. This policy has the effect of increasing inflation expectations and reducing the real rate. In this case, market incompleteness amplifies the rise in inflation expectations and the reduction in the real rate, thereby mitigating the decline in real activity. By keeping the interest rate lower for longer, agents expect improvements in labour market conditions, which reduces their precautionary-saving behaviour and further amplifies the positive effects of the optimal policy. Therefore, when the central bank sets an optimal path for the policy rate, an adverse demand shock causes smaller contractions in real economic activity under incomplete markets than under perfect risk sharing.

Finally, we show that a central bank can mitigate the deflationary spiral, caused by the ZLB and incomplete markets, by following a simple Taylor rule augmented with the lagged value of the shadow policy rate, i.e., the theoretical policy rate that would prevail in the absence of a ZLB constraint. In particular, smoothing the shadow rate introduces history dependence in the policy reaction function. As a result, in a liquidity trap, a fall in the shadow rate due to a negative demand shock implies that the future actual policy rate will remain relatively low compared to that in the absence of smoothing. Hence, the central bank is de facto committing to keep the actual policy rate lower for longer than implied by current economic conditions. Similarly as above, the presence of countercyclical uninsured unemployment risk leads to a rise in inflation expectations and a fall in the real rate. Therefore, an inertial Taylor rule is more effective at mitigating the fall in demand under imperfect insurance than under perfect unemployment-risk sharing. Unlike the optimal-policy case, it bears noting that, for realistic values of policy inertia, incomplete markets still amplify contractions in real activity in response to adverse demand shocks. Therefore, unemployment insurance policies, aimed at reducing market incompleteness, are desirable tools, alongside monetary policy, to respond to declines in output and rises in unemployment risk.

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 frictions in the labour market, our paper is particularly related to the literature on HANK (Heterogeneous Agents New Keynesian) 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.

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. Ravn and Sterk (2017) build a model where households face uninsured unemployment risk, sticky prices, and search-and-matching frictions. In such a framework, higher risk of job loss and worsening job finding prospects induce a precautionary-saving 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. 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. Den Haan et al. (2018) show that the combination of incomplete markets and sticky nominal wages increases business cycle volatility. Ravn and Sterk (2020) show that in a heterogeneous agents model with labour market frictions, the precautionary-saving 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 call for an accommodative monetary policy. Acharya et al. (2020) study optimal monetary policy in a

HANK framework, where the planner's objective function includes reducing consumption inequality, besides stabilising output and inflation. When income risk is countercyclical, they find that policy curtails the fall in output in recessions to mitigate the increase in inequality.[1] Our work extends the analysis in Challe (2020) to the liquidity trap case, where the deflationary spiral induced by countercyclical unemployment risk may be 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 mitigate the effects of forward guidance if idiosyncratic income risk is countercyclical. These two papers examine the sensitivity of aggregate demand to future monetary policy changes in models where the cyclicality of individual income risk is potentially 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.

This paper is also related to the strand of the macroeconomic literature studying the optimal conduct of monetary policy when the nominal 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 positive level.[2] 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. 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. Bilbiie (2019) studies how long a central bank should keep interest rates at a low level after a liquidity trap ends. The paper argues that the optimal duration is approximately half the time the economy spent in a liquidity trap.[3]

The remainder of the paper is structured as follows. In Section 2, we describe the model. Section 3 presents the main mechanisms at play, based on a three-period version of the model. In Section 4, we set out our numerical analysis. Finally, in Section 6, we provide some concluding remarks.

[1]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), and Oh and Rogantini Picco (2020).

[2]Hills and Nakata (2018) and Bonciani and Oh (2020a) 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.

[3]A non-exhaustive list of papers dealing with monetary policy at the ZLB are Nakov (2008), Christiano et al. (2011), Nakata (2017), Nakata and Schmidt (2019), Masolo and Winant (2019), and Bonciani and Oh (2020b).

2 The 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 rather focuses on the optimal stabilisation of aggregate demand. More specifically, following Challe (2020), the economy consists of two types of households, workers and firm owners. The latter own firms, producing either intermediate or final goods. Intermediate sector firms face price adjustment costs, which allow monetary policy to affect real economic activity. Workers can be either employed or unemployed, and their wage is the result of a Nash bargaining process.

2.1 Working Households

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

$$\max_{c_{i,t}, a_{i,t}} E_0 \sum_{t=0}^{\infty} \beta^t \log c_{i,t}, \tag{1}$$

subject to

$$\frac{a_{i,t}}{z_t} + c_{i,t} = e_{i,t} w_t + (1 - e_{i,t})\, \delta_t + \frac{1 + i_{t-1}}{1 + \pi_t} a_{i,t-1}, \tag{2}$$

$$a_{i,t} \geq 0, \tag{3}$$

$$\log z_t = \rho_z \log z_{t-1} + \sigma_z \varepsilon_t^z, \quad \epsilon_t^z \sim \mathcal{N}(0,1), \tag{4}$$

where Equation (2) is the budget constraint. 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 can be interpreted as a risk-premium shock (Smets and Wouters, 2007), $\rho_z \in [0,1)$ is its persistence, σ_z is its volatility. 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 $a_{-1} = 0$.

2.2 Firm Owners

There is a unit mass of households, who are firm owners and own the various firms in the economy. These households choose consumption c_t^F to maximise their lifetime utility (5). Unlike workers, firm owners do not face any idiosyncratic income risk. Their optimisation problem looks as follows:

$$\max_{c_t^F, a_t^F} E_0 \sum_{t=0}^{\infty} \beta^t \log c_t^F, \tag{5}$$

subject to

$$\frac{a_t^F}{z_t} + c_t^F = \Pi_t^W + \Pi_t^I + \varpi + \tau_t + \frac{1+i_{t-1}}{1+\pi_t} a_{t-1}^F, \tag{6}$$

$$a_t^F \geq 0, \tag{7}$$

where Equation (6) is the budget constraint. 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 firms, whereas $\varpi \geq 0$ and τ_t are respectively a home production income and a lump-sum fiscal transfer. Similarly as for the workers, firm owners hold no assets at the beginning of time $a_{-1} = 0$.

2.3 Final Goods Firms

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

$$y_t = \left(\int_0^1 y_t(h)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}, \tag{8}$$

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 intermediate good i is given by:

$$y_t(h) = \left(\frac{p_t(h)}{p_t} \right)^{-\theta} y_t, \tag{9}$$

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

$$p_t = \left(\int_0^1 p_t(h)^{1-\theta} dh \right)^{\frac{1}{1-\theta}}. \tag{10}$$

2.4 Wholesale Firms

There exists 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:

$$y_t(h) = x_t(h), \tag{11}$$

where $x_t(h)$ is the input of intermediate goods demanded by the wholesale firm h, purchased at price φ_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:

$$\max_{p_t(h)} E_t \sum_{j=0}^{\infty} M^F_{t,t+j} \Pi^W_{t+j}(h), \tag{12}$$

$$\Pi^W_t(h) = \left(\frac{p_t(h)}{p_t}\right)^{1-\theta} y_t - \left(1-\tau^W\right)\varphi_t \left(\frac{p_t(h)}{p_t}\right)^{-\theta} y_t - \frac{\psi}{2}\left(\frac{p_t(h)}{p_{t-1}(h)} - 1\right)^2 y_t, \tag{13}$$

where Equations (12) and (13) 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:

$$\psi(1+\pi_t)\pi_t = \psi E_t M^F_{t+1}(1+\pi_{t+1})\pi_{t+1}\frac{y_{t+1}}{y_t} + 1 - \theta + \theta\left(1-\tau^W\right)\varphi_t. \tag{14}$$

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

$$\Pi^W_t = \left(1 - \left(1-\tau^W\right)\varphi_t - \frac{\psi}{2}\pi_t^2\right) y_t. \tag{15}$$

2.5 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:

$$m_t = \mu u_t^{\gamma} v_t^{1-\gamma}, \tag{16}$$

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 a job, is defined as:

$$\lambda_t = \frac{m_t}{v_t}. \tag{17}$$

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

$$f_t = \frac{m_t}{u_t}. \tag{18}$$

At the beginning of every period, there are n_{t-1} workers and a fraction ρ are 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:

$$n_t = (1-\rho)\, n_{t-1} + m_t, \tag{19}$$

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

$$u_t = 1 - (1-\rho)\, n_{t-1}. \tag{20}$$

2.6 Intermediate Goods Firms

If an intermediate-good firm can successfully hire 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. 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:

$$J_t^F = \left(1-\tau^I\right)(\varphi_t - w_t + T) + E_t M_{t,t+1}^F \left((1-\rho)\, J_{t+1}^F + \rho J_{t+1}^v\right). \tag{21}$$

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:

$$J_t^v = -\kappa + \lambda_t J_t^F + (1-\lambda_t)\, E_t M_{t,t+1}^F J_{t+1}^v. \tag{22}$$

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

$$\frac{\kappa}{\lambda_t} = J_t^F. \tag{23}$$

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 firms are given by:

$$\Pi_t^I = n_t \left(1 - \tau^I\right) \left(\varphi_t - w_t + T\right) - \kappa v_t. \tag{24}$$

2.7 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 $s_{t+1} = \rho\left(1 - f_{t+1}\right)$. The worker continues to be employed with probability $1 - s_{t+1}$. The value of an employed worker, V_t^e, writes as:

$$V_t^e = \log w_t + \beta E_t \left(\left(1 - s_{t+1}\right) V_{t+1}^e + s_{t+1} V_{t+1}^u\right), \tag{25}$$

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

$$V_t^u = \log \delta_t + \beta E_t \left(f_{t+1} V_{t+1}^e + \left(1 - f_{t+1}\right) V_{t+1}^u\right). \tag{26}$$

2.8 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 writes as:

$$w_t^N = \underset{w_t}{\operatorname{argmax}} \left(S_t^W\right)^{1-\alpha} \left(J_t^F\right)^{\alpha}, \tag{27}$$

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

$$\left(1 - \alpha\right) J_t^F = \alpha S_t^W w_t^N. \tag{28}$$

2.9 Wage Rigidity

In practice, however, the equilibrium real wage may differ significantly from the Nash bargaining solution. For this reason, to generate empirically a reasonable volatility of vacancies and unemployment, the literature 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) long-run average w:

$$w_t = w^{\phi} {w_t^N}^{1-\phi}, \tag{29}$$

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

2.10 Government

Monetary Policy In our baseline specification, we assume that the monetary policy authority sets the nominal interest rate optimally 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., $i_t \geq 0$):

$$W_t = E_0 \sum_{t=0}^{\infty} \beta^t U_t, \tag{30}$$

where U_t is the sum of instantaneous utilities of all households: employed, unemployed and firm owners. In Section 2.12, we explicitly define W_t and U_t, while we leave the derivation of the Ramsey optimal policy problem to Appendix B. To highlight the benefits of the optimal policy, we also consider the implications of a simple strict inflation targeting rule:

$$\pi_t = 0 \;\; \text{s.t.} \;\; i_t \geq 0. \tag{31}$$

Fiscal Policy In order 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:

$$\tau_t = \tau^I n_t(\varphi_t - w_t) - \tau^W \varphi_t Y_t - n_t(1 - \tau^I)T. \tag{32}$$

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 2.13, we report the values taxes and subsidies associated with a constrained-efficient allocation.

2.11 Market Clearing and Equilibrium

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

$$\int_{[0,1]} a_{i,t} di + a_t^F = 0, \tag{33}$$

$$\int_{[0,1]} c_{i,t} di + c_t^F + \kappa v_t = y_t + (1 - n_t)\,\delta_t - \frac{\psi}{2}{\pi_t}^2 y_t + \varpi, \tag{34}$$

$$Y_t = n_t, \tag{35}$$

where the left-hand side of Equation (35) is the demand for intermediate goods defined as $y_t = \int_{[0,1]} y_{h,t} dh$.

For the sake of conciseness, we report the full set of equilibrium conditions in Appendix A. It bears noting that, as in Ravn and Sterk (2017, 2020) 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 (3) and (7)) no one is issuing the assets that the precautionary savers would be willing to purchase for self-insurance. In other words, the precautionary-saving 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 just consume their current income. Thus, employed workers consume their wage, $c_{e,t} = w_t$, and their Euler equation holds with equality:

$$E_t M^e_{t,t+1} \frac{(1 + i_t)\, z_t}{1 + \pi_{t+1}} = 1, \tag{36}$$

where their stochastic discount factor writes as:

$$M^e_{t,t+1} = \beta \frac{(1 - s_{t+1})\, u'(w_{t+1}) + s_{t+1} u'(\delta_{t+1})}{u'(w_t)}. \tag{37}$$

The two condition 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 face a binding debt limit and their Euler equation holds with strict inequality:

$$E_t M^u_{t,t+1} \frac{(1 + i_t)\, z_t}{1 + \pi_{t+1}} < 1, \tag{38}$$

where the stochastic discount factor is given by:

$$M^u_{t,t+1} = \beta \frac{(1 - f_{t+1})\, u'(\delta_{t+1}) + f_{t+1} u'(w_{t+1})}{u'(\delta_t)}. \tag{39}$$

Also 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:

$$E_t M^F_{t,t+1} \frac{(1 + i_t)\, z_t}{1 + \pi_{t+1}} < 1, \tag{40}$$

where the firm owners' stochastic discount factor is equal to:

$$M^F_{t,t+1} = \beta \frac{c^F_t}{c^F_{t+1}}. \tag{41}$$

The consumption of a firm owners can be derived by combining Equations (6), (15), (24), (32), (34), and the fact that assets-supply is zero in equilibrium ($a^F_t = 0$):

$$c^F_t = y_t - w_t n_t - \frac{\psi}{2}\pi^2_t y_t - \kappa v_t + \varpi. \tag{42}$$

2.12 Social Welfare

The objective of the central bank following an optimal policy is to maximise social welfare, given by the sum of value functions of all agents in the economy. In particular, assuming the same welfare weight across working households, we have that:

$$W_t = n_t V^e_t + (1 - n_t)\, V^u_t + \Lambda V^F_t = U_t + \beta E_t W_{t+1}, \tag{43}$$

where $\Lambda = \frac{c^F}{w}$ is the relative welfare weight on firm owners, V^e_t and V^u_t are defined by Equations (25) and (26), and the value of firm owners V^F_t is given by:

$$V^F_t = \log c^F_t + \beta V^F_{t+1}. \tag{44}$$

U_t in Equation (43) is the sum of instantaneous utilities:

$$U_t = n_t \log c_{e,t} + (1 - n_t) \log c_{u,t} + \Lambda \log c^F_t = n_t \log w_t + (1 - n_t) \log \delta_t + \Lambda \log \left(y_t - w_t n_t - \frac{\psi}{2}\pi^2_t y_t - \kappa v_t + \varpi \right), \tag{45}$$

where the last equality is a result of households consuming all their income each period. The Ramsey optimal policy is obtained by maximising the welfare function above subject to all the equilibrium conditions and the ZLB constraint. We set up the problem and derive the first-order conditions analytically in Appendix B.

2.13 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 analysis about optimal policy, we assume a constrained-efficient the 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:[4]

$$\pi = 0, \quad \tau^W = \frac{1}{\theta}, \quad T = \frac{u(w^*) - u(\delta^*)}{u(w^*)}, \quad \tau^I = 1 - \frac{(1-\gamma)(1-\beta(1-\rho))}{1-\beta(1-\rho)(1-\gamma f^*)}, \tag{46}$$

where f^* and w^* are given by:

$$f^* = \left(\frac{\left(1-\tau^I\right) \mu^{\frac{1}{1-\gamma}}}{\kappa(1-\beta(1-\rho))} \left(1 - w^* + \frac{u(w^*) - u(\delta^*)}{u'(w^*)}\right)\right)^{\frac{1-\gamma}{\gamma}}, \quad w^* = \frac{n^* - \kappa v^* + \varpi}{(1+n^*)}. \tag{47}$$

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, in order to ensure the decentralised wage to be constrained-efficient in steady state, we also need to assume:

$$\alpha = \left(1 + \frac{S^W w^*}{J^F}\right)^{-1}. \tag{48}$$

2.14 Solution and Calibration

The three-period version of the model considered in Section 3 is solved with a perfect foresight algorithm using Levenberg-Marquardt mixed complementarity problem solver (Adjemian et al., 2011). Our numerical analysis in Section 4, instead, the model is solved via a piecewise linear approximation using the approach suggested by Guerrieri and Iacoviello (2015), in order to consider the effects of the occasionally binding ZLB. In our numerical exercises, we compare the baseline model with imperfect unemployment insurance (I.I.) to a version of the model with steady-state perfect-insurance (P.I.), i.e., $\delta = w$. In the three-period model, we

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

consider two additional scenarios where the level of unemployment insurance is lower than the baseline.

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 I.I. and P.I. models to match the steady-state target values. The discount factor β is set to 0.989 (I.I.) or 0.995 (P.I.), targeting an average annualised nominal interest rate of 2%. We assume a logarithmic utility function, implying a risk aversion parameter $\sigma = 1$. 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 per cent. 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. Regarding the labour market parameters, the γ parameter in the matching function is equal to 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 per cent. 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 per cent. The job-separation rate ρ is equal to 0.25, implying a 5 per cent 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 $1 - \frac{\delta}{w} = 0.1$. 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 $\phi = 0.9$. In the three-period model, we also consider two additional counterfactual scenarios where the average proportional consumption loss upon unemployment is 0.2 or 0.3.

Finally, we calibrate the exogenous risk-premium shock process such that it induces a two percentage point drop in inflation when the central bank conducts a strict-inflation-targeting rule in the P.I. version of the model. In particular, for $\rho_z = 0.925$ and $\sigma_z = 0.017$, the risk-premium shock leads to a 10 per cent drop in output, a two per cent fall in inflation and the ZLB constraint to bind for 16 quarters.

3 Three-Period Model

Before discussing our main numerical results, based on the infinite-horizon model, we consider first a simple three-period version of the model, to highlight the key mechanism behind our results.[5] In particular, for this exercise we assume agents have perfect foresight and we consider the impact of a two per-cent increase in the period-0 risk premium ($z_0 = 1.02$). In the following periods, the risk-premium returns to its steady-state value ($z_1 = z_2 = 1.0$). The rise in the risk premium leads the nominal interest rate to hit

[5] In an infinite-horizon setting with a strict-inflation-targeting policy, the response of inflation becomes rapidly very large as we decrease the degree of unemployment insurance.

Table 1: Calibration

Parameters		I.I.	P.I	Targets/Sources		I.I.	P.I.
Sym.	Description	Value	Value	Sym.	Description	Value	Value
β	Discount factor	0.989	0.995	$4i$	Annual interest rate	2%	-
γ	Elasticity of matching	2/3	-	-	Shimer (2005)	-	-
θ	Monopoly power	6.000	-	$\frac{1}{\theta-1}$	Markup rate	20%	-
ψ	Price stickiness	1088.6	1119.2	-	Calvo stickiness	0.84	-
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	0.900	-	P.I.: 10% output drop & 2%p inflation drop			
ρ_z	RP shock persistence	0.925	-	(Same)			
σ_z	RP shock volatility	0.017	-	(Same)			

Note: The tables presents the calibrated value of our baseline model with imperfect insurance (I.I.) and a version of the model with steady-state perfect insurance (P.I.).

the ZLB on impact, i.e. $i_0 = 0$. We then compare how the responses depend on the degree of unemployment insurance under strict-inflation targeting and the optimal monetary policy. We consider four different possible levels of the ratio δ/w, such that a smaller value implies lower steady-state unemployment insurance.

Figure 2 displays the responses of the model variables to the rise in the risk-premium when the central bank follows a strict inflation targeting rule. The increase in the risk premium causes employed workers to reduce their consumption, via their Euler equation. Given that prices are sticky, firms reduce their production (y_0) and labour demand (n_0) to adjust to the falling demand, whereas inflation (π_0) declines more sluggishly. The fall in the firm's profits causes a decline in the firm owners' consumption (c_0^F). Furthermore, the fall in demand causes a tightening in labour market conditions, reducing vacancies v_0, the job-finding rate f_0, and wages, and increasing the job-loss rate s_0. Since the nominal rate is at zero, the central bank cannot reduce it to respond to the fall inflation. Hence, the real rate rises and the fall in demand is larger than away from the ZLB.

When there is perfect (steady-state) risk-sharing between working households ($\delta/w = 1$), a rise in the job-loss rate does not affect their saving behaviour. In the imperfect-insurance case (i.e., $\delta/w < 1$), instead, a tightening in labour-market conditions increases the stochastic discount factor of employed workers, who increase their savings for precautionary reasons. Precautionary savings further amplify the initial decline in inflation. Since in period 1 the ZLB constraint does not bind anymore, the monetary policy authority can

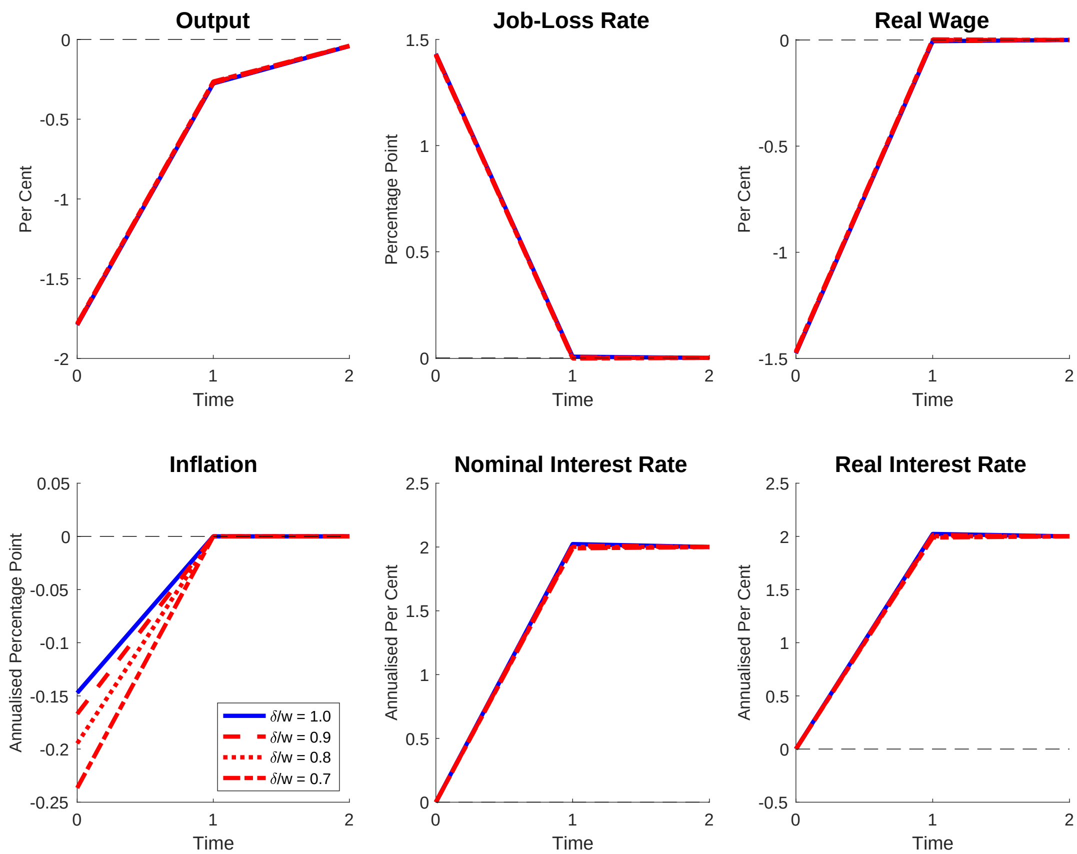


Figure 2: Strict Inflation Targeting in a Three-Period Model

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind in period 0. Each line represents a different degree of unemployment-risk-sharing.

adjust the interest rate to bring inflation back to zero ($\pi_1 = 0$). As a result, the real interest rate in period 0 is the same both under perfect or imperfect unemployment insurance ($r_0 \approx i_0 - \pi_1 = 0$). Similarly, the decline in output, employment and real wages are unaffected by the degree of unemployment insurance.

Under the optimal monetary policy, as displayed in Figure 3, the central bank can commit to a specific path for the nominal interest rate. In particular, the central bank keeps the rate at zero for one additional period. The lower interest rate (compared to the strict-inflation-targeting policy) has a positive effect on y_1 and π_1. The increase in inflation expectations reduces the period-0 real interest rate r_0, which mitigates the decline in real activity y_0 and inflation π_0 (standard of forward guidance channel). In the presence of incomplete markets, future improvements in labour market conditions further strengthen this mechanism. In other words, $i_1 = 0$ has a positive effect on the period-1 job finding rate f_1 and a negative one on the job-loss rate s_1. The latter decreases the stochastic discount factor of employed workers, hence mitigating their period-0

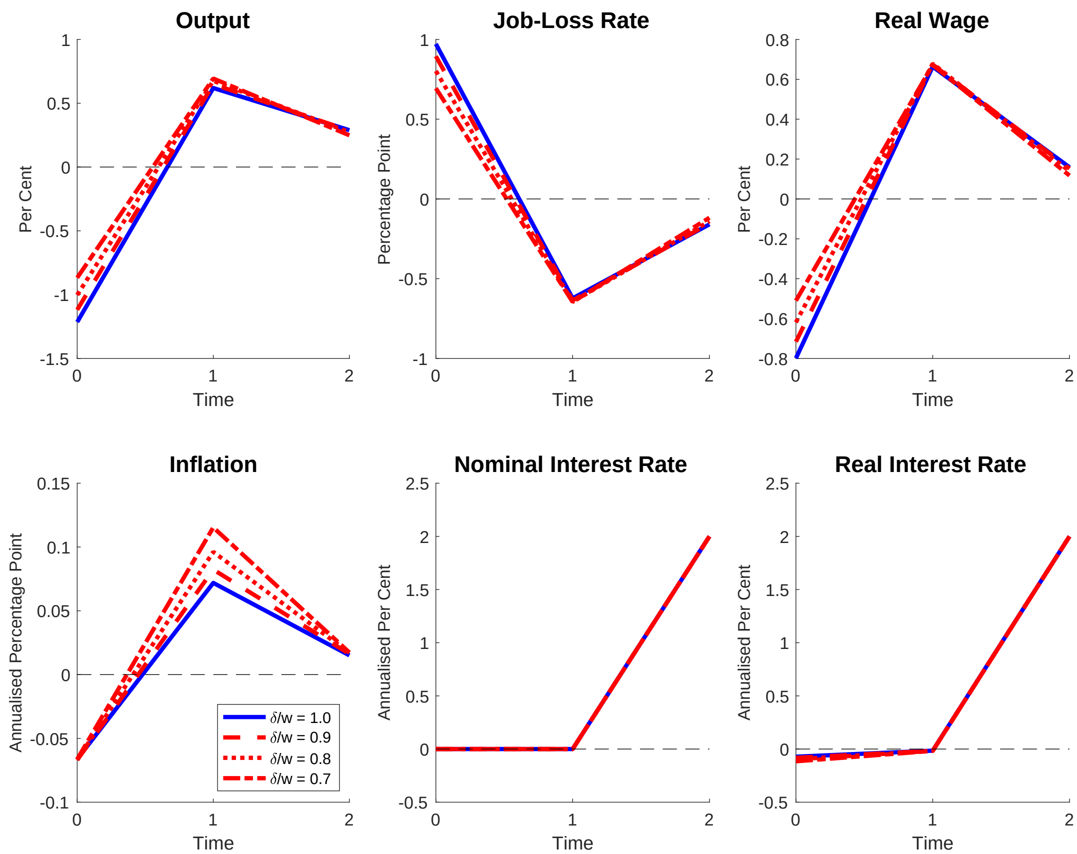


Figure 3: Optimal Monetary Policy in a Three-Period Model

Note: The figure displays the responses to an adverse risk-premium shock that leads the ZLB constraint to bind in period 0. Each line represents a different degree of unemployment-risk-sharing.

precautionary savings and fall in consumption $c_{e,0}$. As a result of the optimal policy, we see that the smaller the degree of unemployment-risk sharing, i.e., the smaller δ/w, the more muted is the response of output, employment and the real wage to a negative demand shock.

4 Infinite-Horizon Model

In this section, we analyse the impact of an adverse risk-premium shock, that cause 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, employment, wages and inflation. As displayed in Figure 4, under a strict-inflation-targeting rule, the central bank cannot react the fall in demand, which causes a significant decline in inflation expectations and increase in the real interest rate. The latter further amplifies the initial drop in real activity and inflation. In the imperfect-insurance case (red-dashed line), a worsening in labour market conditions induces employed workers to increase their savings for precautionary reasons,

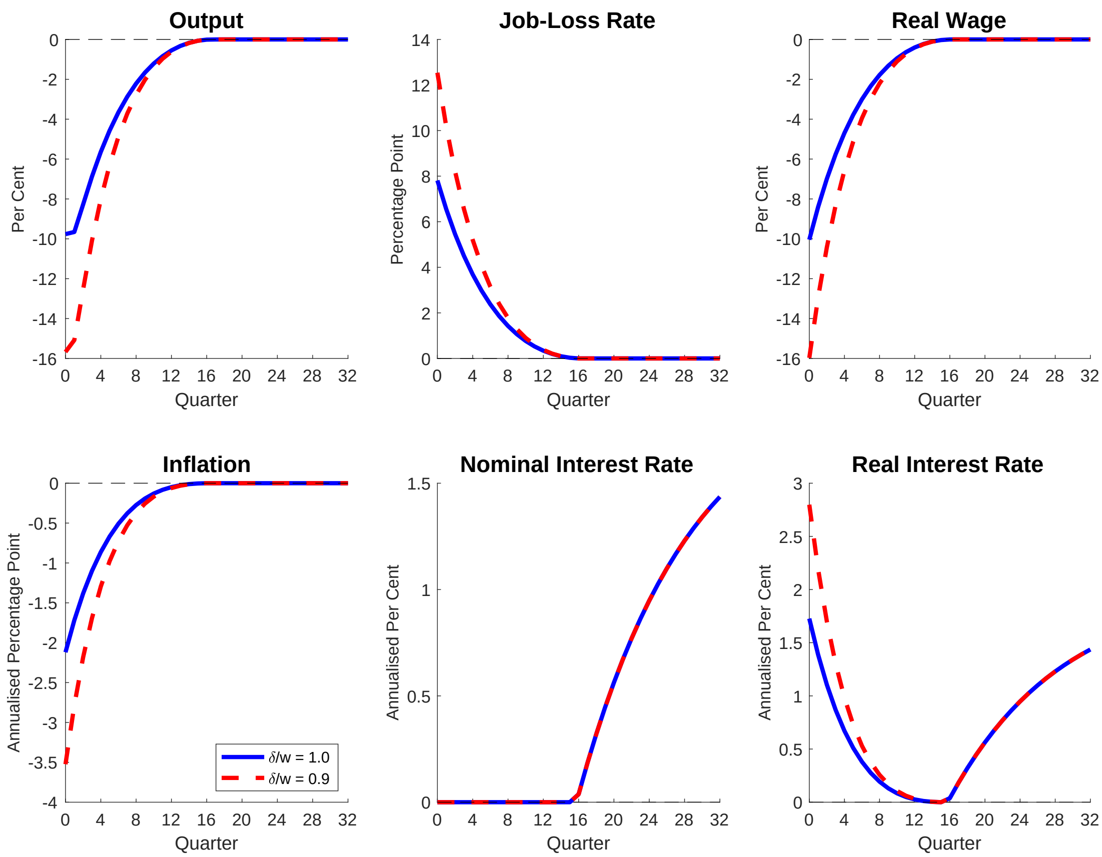


Figure 4: Strict Inflation Targeting in the Infinite-Horizon Model

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

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 and employment is six percentage points larger than under perfect unemployment-risk sharing.

When the central bank is able to commit to an optimal interest rate path, as shown in Figure 5, 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 12 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 unchanged compared to the perfect-insurance case.[6] Because the nominal rate is kept low for an extended period, households expect labour market conditions to improve, which mitigates the employed workers' precautionary-saving motive. Inflation declines less and overshoots

[6]For lower δ/w, the central bank tends to lift-off the interest rate earlier.

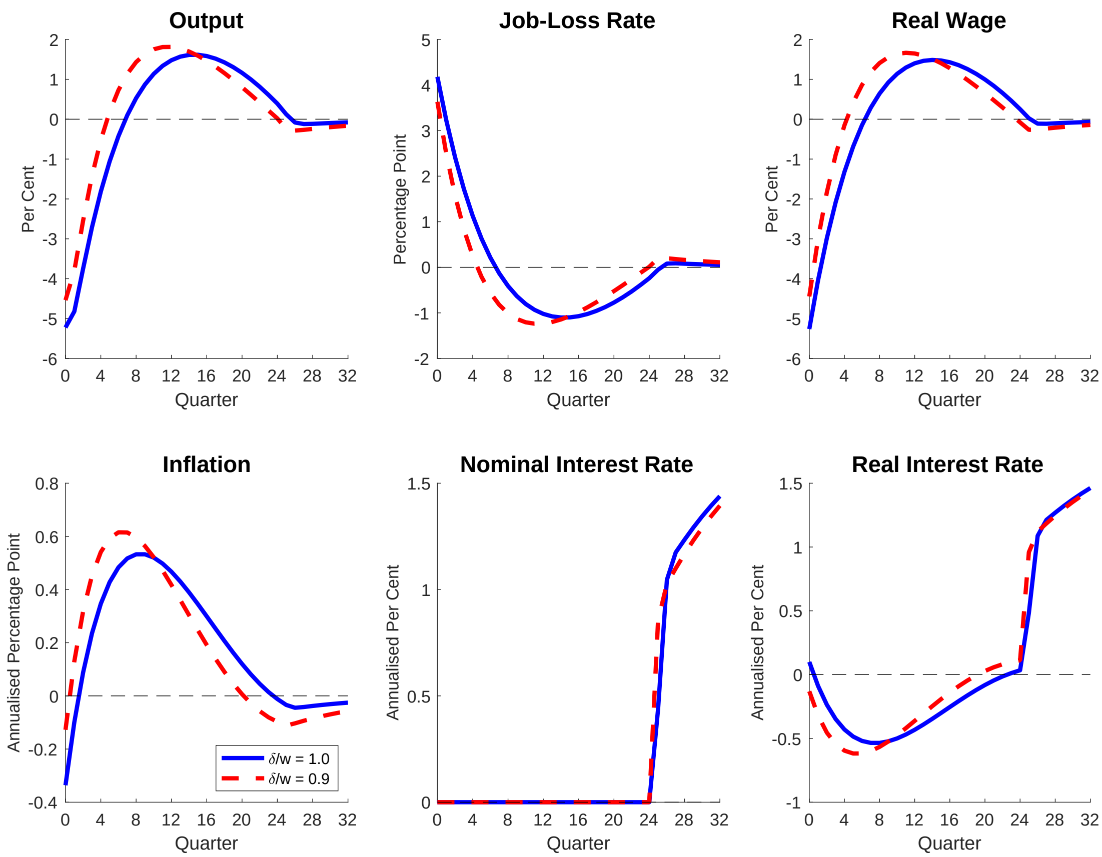


Figure 5: Optimal Monetary Policy in the Infinite-Horizon Model

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

more than in the case of perfect unemployment-risk sharing. As a result, the decline in real activity, employment and real wages is more muted than under perfect unemployment insurance. In other words, under the optimal policy, the central bank is able to neutralise the deflationary spiral caused by the ZLB and the precautionary-saving behaviour. Lower market incompleteness (e.g., via unemployment insurance policies), provided an optimal path of monetary policy, would not be beneficial in terms of output stabilisation.

Distributional Effects As shown in Figure 6, different monetary policy rules have different implications for the consumption and welfare of different households in the economy. When the central bank follows a strict-inflation-targeting rule, the fall in demand causes a severe decline in workers' consumption, whereas firm owners' consumption rises. More specifically, the fall in inflation expectations and rise in the real rate affects the employed workers, whose Euler equation holds with equality in equilibrium. As a result, these households significantly cut down their consumption. The decline in consumption is the same as that in their wage (see Figure 4). Unemployed households reduce their consumption in the same proportion following

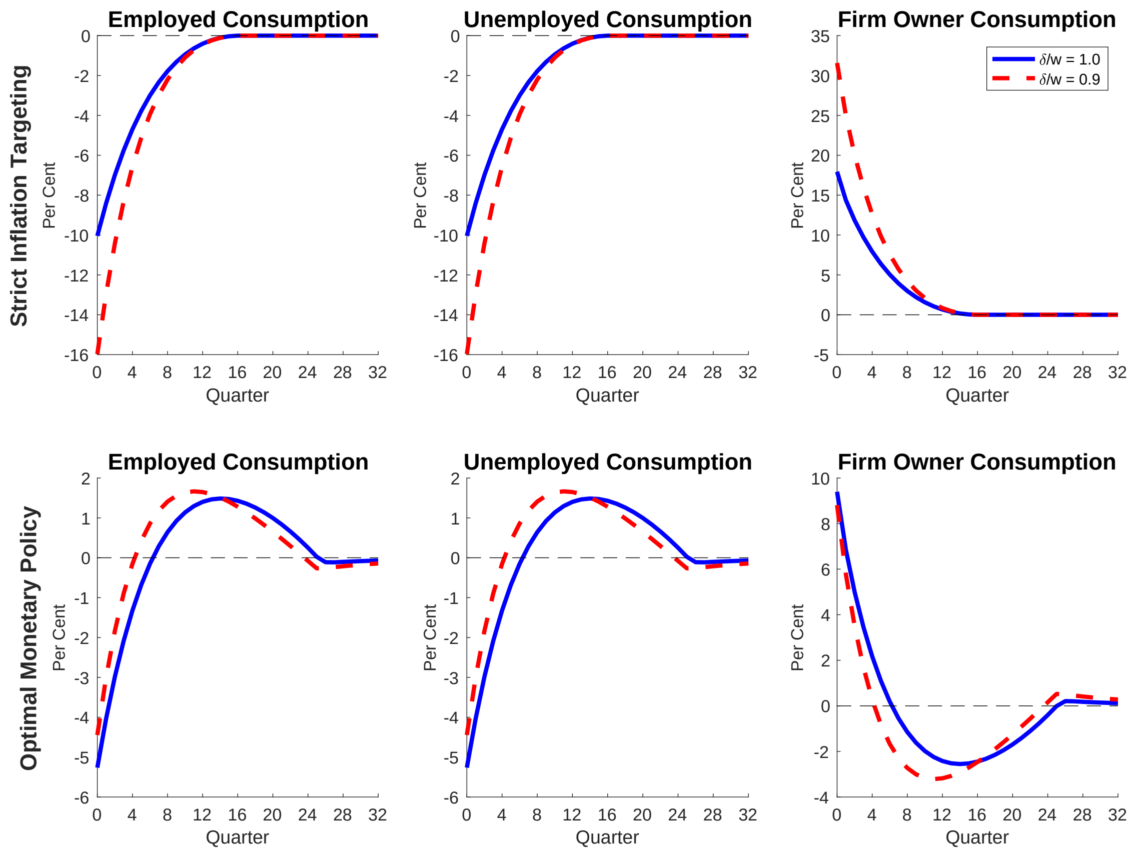


Figure 6: Households' Consumption and Monetary Policy

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

a decline in their home-production income. The drops in wages, the share of employed workers, and the number of posted vacancies reduce the costs paid by firm owners, who increase their consumption. These results are amplified in the imperfect-insurance case because the rise in unemployment risk and precautionary savings puts further downward pressure on employed workers' consumption.

Under the optimal policy, inflation expectations rise, and the real rate falls. The fall in the real rate mitigates the decline in the working households' consumption, which overshoots after some quarters. By contrast, firm owners' consumption first rises, following a decline in the wage bill and the costs of posting vacancies, and undershoots. In the imperfect-insurance case, the fall in worker's consumption is slightly mitigated on impact and overshoots earlier and more vigorously. Symmetrically, firm owners are worse off, as their consumption rises slightly less on impact and undershoots earlier and more strongly. In other words, optimal monetary policy has the effect of mitigating the welfare losses of employed workers at the expense of reducing firm owners' welfare gains.

5 Shadow Rate Smoothing

In this section, we show how a simple inertial Taylor rule can significantly mitigate the negative impact of demand shocks, both under perfect and imperfect unemployment insurance, and deliver results that are closer to those found under the optimal policy. To this end, we include the lagged shadow policy rate into the standard policy rule:

$$i_t = \max\left\{i_t^\star, 0\right\}, \tag{49}$$

$$i_t^\star = \rho_i i_{t-1}^\star + (1-\rho_i)\left(i + \phi_\pi \pi_t\right). \tag{50}$$

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 $i_t^\star$ in response to deviations of the inflation rate from its steady-state value. Moreover, we assume that the monetary authority has a preference for smoothing the shadow rate, which is given by the autoregressive component in Equation (50). The parameter ρ_i controls the degree of policy inertia, while ϕ_π indicates the responsiveness of the shadow rate to inflation. It bears noting that the strict-inflation-targeting rule considered above implies the parameter $\phi_\pi \to +\infty$ and $\rho_i = 0$. In this section, we assume that $\rho_i = 0.9$, which is broadly in line with the literature (see e.g., Hills and Nakata, 2018), and set ϕ_π to a large value (10^5).

Figure 7 displays the responses of our model variables under an inertial policy. First, comparing these results with those in Figure 4, one can see how the inertial policy significantly mitigate the drop in output, employment, wages and inflation. Second, in line with the optimal policy case, the inertial policy is more effective at reducing the decline in real activity under imperfect insurance. In particular, with perfect unemployment-risk sharing, output falls by eight per cent under an inertial policy, against a 10 per cent drop in the absence of inertia. When there is imperfect unemployment insurance, and employed workers feature a precautionary-saving motive, the decline in output is about six percentage points smaller under inertial policy compared to the standard strict-inflation-targeting rule.

Intuitively, in the absence of inertia, a fall in the shadow rate does not have any implications about the future path of the actual policy rate. Therefore, as displayed in Figure 4, the policy rate lifts off after 16 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

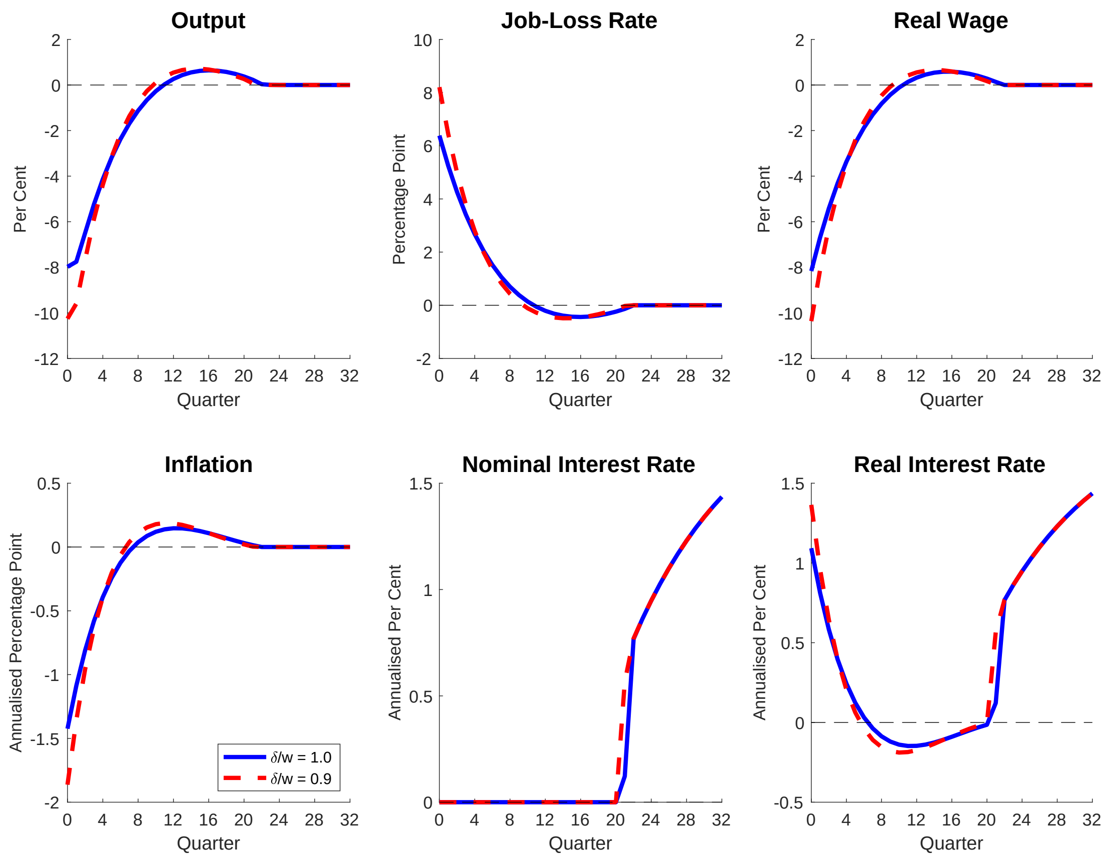


Figure 7: Inertial Policy Rule

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

Figure 7, the nominal interest rate is kept at zero for 20 quarters, as long as the shadow rate is negative. By keeping the nominal rate lower for longer, the central bank is boosting 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, employment and real wage are significantly more muted.

Unlike the optimal policy case, under an inertial monetary policy market incompleteness amplifies output contractions in response to negative demand shocks. Finally, it bears noting how the optimal policy discussed implies an even larger degree of policy inertia. To keep the policy rate at zero for 24 quarters, as with the optimal policy, we would need to raise the inertial parameter beyond 0.999, which is unreasonably large. Thus, for realistic values of policy inertia, unemployment insurance policies are desirable to stabilise output.

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-saving 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 is unable to 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, which sustains current economic conditions both under complete and incomplete markets. The policy has also the additional benefit of improving the future economic outlook and expected labour market conditions, which mitigate the precautionary-saving 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 milder under incomplete markets than under perfect risk sharing. Finally, we show that a simple policy rule, including the lagged shadow policy rate, can mitigate the deflationary spiral caused by the ZLB and the precautionary-saving behaviour. The inertial rule, therefore, represents a simple way to (partially) operationalise the optimal policy prescriptions. However, we point out that the optimal policy requires an unreasonably large degree of inertia. For realistic values of policy inertia, incomplete markets amplify contractions in real activity in response to negative demand shocks. Therefore, we conclude that, in practice, unemployment insurance (UI) policies are desirable tools, alongside monetary policy, to respond to declines in output and rises in unemployment risk.

Our analysis has two important limitations. First, in order to concentrate on the role of countercyclical unemployment risk, the model relies on a zero-liquidity assumption, therefore abstracting from potential effects of monetary policy on the wealth distribution, which is an important transmission channel in standard HANK models. Second, correcting for the "Forward Guidance puzzle" may mitigate the strength of optimal monetary policy. Despite these caveats, our results underscore that, in the face of recessions in times of low interest rates, monetary policy can be an effective tool alongside UI policies in mitigating the negative consequences of heightened unemployment risk. Understanding the optimal mix of monetary and UI policies is an important open question, which should be further investigated in future research.

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Appendices

A Equilibrium Conditions

- Workers
  - Home production
$$\delta_t = \frac{\delta}{w} w_t, \tag{A.1}$$
  - Euler equation
$$E_t M^e_{t+1} \frac{(1+i_t)\, a_t}{1+\pi_{t+1}} = 1, \tag{A.2}$$
  - IMRS of employed workers
$$M^e_t = \beta \frac{(1-s_t)\, w_t{}^{-1} + s_t \delta_t{}^{-1}}{w_{t-1}{}^{-1}}, \tag{A.3}$$
- Firm owners
  - Total consumption of firm owners
$$c^F_t = y_t - w_t n_t - \kappa v_t - \frac{\psi}{2} \pi_t{}^2 y_t + \varpi, \tag{A.4}$$
  - IMRS of firm owners
$$M^F_t = \beta \left(\frac{c^F_t}{c^F_{t-1}} \right)^{-1}, \tag{A.5}$$
- Labor market flows
  - Job finding rate
$$f_t{}^{\frac{\gamma}{1-\gamma}} = \left(1-\tau^I\right) (\varphi_t - w_t + T)\, \mu^{\frac{1}{1-\gamma}} / \kappa + (1-\rho)\, M^F_{t+1} f_{t+1}{}^{\frac{\gamma}{1-\gamma}}, \tag{A.6}$$
  - Period-to-period job-loss rate
$$s_t = \rho\,(1-f_t)\,, \tag{A.7}$$
  - Employment rate
$$n_t = (1-s_t)\, n_{t-1} + (1-n_{t-1})\, f_t, \tag{A.8}$$
  - Vacancies
$$v_t = \left(\frac{n_t - (1-\rho)\, n_{t-1}}{(1-(1-\rho)\, n_{t-1})^{\gamma}} \right)^{\frac{1}{1-\gamma}}, \tag{A.9}$$

- Wholesale firms

  - New Keynesian Phillips curve

$$\psi\left(1+\pi_t\right)\pi_t = \psi M_{t+1}^F\left(1+\pi_{t+1}\right)\pi_{t+1}\frac{y_{t+1}}{y_t} + 1 - \theta + \theta\left(1-\tau^W\right)\varphi_t, \tag{A.10}$$

- Nash wage

  - Value of being employed $(V^e - V^u)$

$$S_t^W = \log w_t - \log\delta_t + \beta\left(1 - s_{t+1} - f_{t+1}\right)S_{t+1}^W, \tag{A.11}$$

  - Job value (from free-entry condition)

$$J_t^F = \kappa\frac{f_t{}^{\frac{\gamma}{1-\gamma}}}{\mu^{\frac{1}{1-\gamma}}}, \tag{A.12}$$

  - Nash wage

$$\frac{S_t^W}{S^W} = \left(\frac{J_t^F}{J^F}\right)\left(\frac{w_t^N}{w}\right)^{-1}, \tag{A.13}$$

  - Nash-bargaining wage

$$w_t = w^\phi w_t^{N\,1-\phi}, \tag{A.14}$$

- Market clearing

$$y_t = n_t, \tag{A.15}$$

- Monetary authority

  - Ramsey optimal monetary policy

$$\max\sum_{t=0}^{\infty}\beta^t W_t, \tag{A.16}$$

$$W_t = n_t\log w_t + \left(1-n_t\right)\log\delta_t + \Lambda\log c_t^F + \beta W_{t+1}, \tag{A.17}$$

$$i_t \geq 0, \tag{A.18}$$

  - Simple Taylor rule

$$i_t = \max\left\{i_t^\star, 0\right\}, \tag{A.19}$$

$$i_t^\star = \rho_i i_{t-1}^\star + \left(1-\rho_i\right)\left(i + \phi_\pi\pi_t\right). \tag{A.20}$$

B Ramsey Optimal Policy Problem

The Ramsey problem under commitment can be described as follows. Let $\{\lambda_{1,t}, \lambda_{2,t}, \lambda_{3,t}, \lambda_{4,t}, \lambda_{5,t}, \lambda_{6,t}, \lambda_{7,t}, \lambda_{8,t}, \lambda_{9,t}, \lambda_{10,t}, \lambda_{11,t}, \lambda_{12,t}, \lambda_{13,t}, \lambda_{14,t}, \lambda_{15,t}\}_{t=0}^{\infty}$ represent sequences of Lagrange multipliers on the constraints XXXX. Given a set of stochastic processes $\{a_t, \sigma_t^a\}_{t=0}^{\infty}$, the allocation plans for the control variables $\{n_t, w_t, \delta_t, c_t^F, M_t^e, i_t, \pi_t, s_t, y_t, v_t, M_t^F, \varphi_t, f_t, S_t^W, J_t^F, w_t^N\}_{t=0}^{\infty}$, and for the co-state variables $\{\lambda_{1,t}, \lambda_{2,t}, \lambda_{3,t}, \lambda_{4,t}, \lambda_{5,t}, \lambda_{6,t}, \lambda_{7,t}, \lambda_{8,t}, \lambda_{9,t}, \lambda_{10,t}, \lambda_{11,t}, \lambda_{12,t}, \lambda_{13,t}, \lambda_{14,t}, \lambda_{15,t}\}_{t=0}^{\infty}$, represent an optimal allocation if they solve the following maximization problem:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left(n_t \log w_t + (1-n_t)\log \delta_t + \Lambda \log c_t^F\right), \tag{B.1}$$

subject to XXXX. The augmented Lagrangian for the optimal policy problem then reads as follows:

$$\begin{aligned}
L = \max E_0 \sum_{t=0}^{\infty} \beta^t \Bigg[& n_t \log w_t + (1-n_t)\log\delta_t + \Lambda \log c_t^F + \lambda_{1,t}\left(\delta_t - \frac{\delta}{w} w_t\right) \\
&+\lambda_{2,t}\left(1 - M_{t+1}^e \frac{(1+i_t)\,a_t}{1+\pi_{t+1}}\right) + \lambda_{3,t}\left(M_t^e {w_{t-1}}^{-1} - \beta\left((1-s_t)\,{w_t}^{-1} + s_t{\delta_t}^{-1}\right)\right) \\
&+\lambda_{4,t}\left(y_t - w_t n_t - \kappa v_t - \frac{\psi}{2}{\pi_t}^2 y_t + \varpi - c_t^F\right) + \lambda_{5,t}\left(\beta {c_t^F}^{-1} - M_t^F {c_{t-1}^F}^{-1}\right) \\
&+\lambda_{6,t}\left(\left(1-\tau^I\right)(\varphi_t - w_t + T)\frac{\mu^{\frac{1}{1-\gamma}}}{\kappa} + (1-\rho)\,M_{t+1}^F {f_{t+1}}^{\frac{\gamma}{1-\gamma}} - {f_t}^{\frac{\gamma}{1-\gamma}}\right) \\
&+\lambda_{7,t}\left(s_t - \rho\,(1-f_t)\right) + \lambda_{8,t}\left((1-s_t)\,n_{t-1} + (1-n_{t-1})\,f_t - n_t\right) \\
&+\lambda_{9,t}\left(v_t(1-(1-\rho)\,n_{t-1})^{\frac{\gamma}{1-\gamma}} - (n_t - (1-\rho)\,n_{t-1})^{\frac{1}{1-\gamma}}\right) \\
&+\lambda_{10,t}\left(\psi\,(1+\pi_t)\,\pi_t y_t - \psi M_{t+1}^F (1+\pi_{t+1})\,\pi_{t+1} y_{t+1} - (1-\theta)\,y_t - \theta\left(1-\tau^W\right)\varphi_t y_t\right) \\
&+\lambda_{11,t}\left(\log w_t - \log\delta_t + \beta\,(1-s_{t+1}-f_{t+1})\,S_{t+1}^W - S_t^W\right) + \lambda_{12,t}\left(J_t^F - \kappa\frac{{f_t}^{\frac{\gamma}{1-\gamma}}}{\mu^{\frac{1}{1-\gamma}}}\right) \\
&+\lambda_{13,t}\left(\frac{S_t^W}{S^W} - \left(\frac{J_t^F}{J^F}\right)\left(\frac{w_t^N}{w}\right)^{-1}\right) + \lambda_{14,t}\left(w_t - w^{\phi} {w_t^N}^{1-\phi}\right) + \lambda_{15,t}\,(n_t - y_t) + \lambda_{16,t} i_t \Bigg].
\end{aligned} \tag{B.2}$$

The first-order conditions are as follows:

$$\begin{aligned}
[n_t]: \quad & \log w_t - \log\delta_t - \lambda_{4,t} w_t - \lambda_{8,t} - \lambda_{9,t}\frac{1}{1-\gamma}(n_t - (1-\rho)\,n_{t-1})^{\frac{1}{1-\gamma}-1} + \lambda_{15,t} \\
&+\beta\lambda_{8,t+1}(1-s_{t+1}-f_{t+1}) \\
-\beta\lambda_{9,t+1}&\left(v_{t+1}\frac{\gamma}{1-\gamma}(1-(1-\rho)\,n_t)^{\frac{\gamma}{1-\gamma}-1}(1-\rho) - \frac{1}{1-\gamma}(n_{t+1} - (1-\rho)\,n_t)^{\frac{1}{1-\gamma}-1}(1-\rho)\right) = 0,
\end{aligned} \tag{B.3}$$

$$[w_t]: \quad \frac{n_t}{w_t} - \lambda_{1,t}\frac{\delta}{w} + \lambda_{3,t}\beta\left(1-s_t\right){w_t}^{-2} - \lambda_{4,t}n_t - \lambda_{6,t}\left(1-\tau^I\right)\frac{\mu^{\frac{1}{1-\gamma}}}{\kappa} + \lambda_{11,t}{w_t}^{-1} + \lambda_{14,t} - \beta\lambda_{3,t+1}M^e_{t+1}{w_t}^{-2} = 0, \tag{B.4}$$

$$[\delta_t]: \quad \frac{1-n_t}{\delta_t} + \lambda_{1,t} + \lambda_{3,t}\beta s_t{\delta_t}^{-2} - \lambda_{11,t}{\delta_t}^{-1} = 0, \tag{B.5}$$

$$\left[c^F_t\right]: \quad \frac{\Lambda}{c^F_t} - \lambda_{4,t} - \lambda_{5,t}\beta {c^F_t}^{-2} + \beta\lambda_{5,t+1}M^F_{t+1}{c^F_t}^{-2} = 0, \tag{B.6}$$

$$[M^e_t]: \quad \lambda_{3,t}{w_{t-1}}^{-1} - \frac{1}{\beta}\lambda_{2,t-1}\frac{\left(1+i_{t-1}\right)z_{t-1}}{1+\pi_t} = 0, \tag{B.7}$$

$$[i_t]: \quad \lambda_{2,t}M^e_{t+1}\frac{z_t}{1+\pi_{t+1}} + \lambda_{16,t} = 0, \tag{B.8}$$

$$[\pi_t]: \quad -\lambda_{4,t}\psi\pi_t y_t + \lambda_{10,t}\psi\left(1+2\pi_t\right)y_t + \frac{1}{\beta}\lambda_{2,t-1}M^e_t\frac{\left(1+i_{t-1}\right)z_{t-1}}{\left(1+\pi_t\right)^2} - \frac{1}{\beta}\lambda_{10,t-1}\psi M^F_t\left(1+2\pi\right)y_t = 0, \tag{B.9}$$

$$[s_t]: \quad \lambda_{3,t}\beta\left({w_t}^{-1} - {\delta_t}^{-1}\right) + \lambda_{7,t} - \lambda_{8,t}n_{t-1} - \frac{1}{\beta}\lambda_{11,t-1}\beta S^W_t = 0, \tag{B.10}$$

$$[y_t]: \quad \lambda_{4,t}\left(1-\frac{\psi}{2}{\pi_t}^2\right) + \lambda_{10,t}\left(\psi\left(1+\pi_t\right)\pi_t - 1 + \theta - \theta\left(1-\tau^W\right)\varphi_t\right) - \lambda_{15,t} - \frac{1}{\beta}\lambda_{10,t-1}\psi M^F_t\left(1+\pi_t\right)\pi_t = 0, \tag{B.11}$$

$$[v_t]: \quad -\lambda_{4,t}\kappa + \lambda_{9,t}\left(1-\left(1-\rho\right)n_{t-1}\right)^{\frac{\gamma}{1-\gamma}} = 0, \tag{B.12}$$

$$\left[M^F_t\right]: \quad -\lambda_{5,t}{c^F_t}^{-1} + \frac{1}{\beta}\lambda_{6,t-1}\left(1-\rho\right){f_t}^{\frac{\gamma}{1-\gamma}} - \frac{1}{\beta}\lambda_{10,t-1}\psi\left(1+\pi_t\right)\pi_t y_t = 0, \tag{B.13}$$

$$[\varphi_t]: \quad \lambda_{6,t}\left(1-\tau^I\right)\frac{\mu^{\frac{1}{1-\gamma}}}{\kappa} - \lambda_{10,t}\theta\left(1-\tau^W\right)y_t = 0, \tag{B.14}$$

$$[f_t]: \quad -\lambda_{6,t}\frac{\gamma}{1-\gamma}{f_t}^{\frac{\gamma}{1-\gamma}-1} + \lambda_{7,t}\rho + \lambda_{8,t}\left(1-n_{t-1}\right) - \lambda_{12,t}\kappa\frac{\gamma}{1-\gamma}\frac{{f_t}^{\frac{\gamma}{1-\gamma}-1}}{\mu^{\frac{1}{1-\gamma}}} + \frac{1}{\beta}\lambda_{6,t-1}\left(1-\rho\right)M^F_t\frac{\gamma}{1-\gamma}{f_t}^{\frac{\gamma}{1-\gamma}-1} - \frac{1}{\beta}\lambda_{11,t-1}\beta S^W_t = 0, \tag{B.15}$$

$$\left[S^W_t\right]: \quad -\lambda_{11,t} + \lambda_{13,t}\frac{1}{S^W} + \frac{1}{\beta}\lambda_{11,t-1}\beta\left(1-s_t-f_t\right) = 0, \tag{B.16}$$

$$\left[J^F_t\right]: \quad \lambda_{12,t} - \lambda_{13,t}\left(\frac{1}{J^F}\right)\left(\frac{w^N_t}{w}\right)^{-1} = 0, \tag{B.17}$$

$$\left[w^N_t\right]: \quad \lambda_{13,t}\left(\frac{J^F_t}{J^F}\right)\left(\frac{w^N_t}{w}\right)^{-2}\frac{1}{w} - \lambda_{14,t}\left(1-\phi\right)w^{\phi}{w^N_t}^{-\phi} = 0, \tag{B.18}$$

$$[\lambda_{1,t}]: \quad \delta_t - \frac{\delta}{w}w_t = 0, \tag{B.19}$$

$$[\lambda_{2,t}]: \quad 1 - M^e_{t+1}\frac{\left(1+i_t\right)z_t}{1+\pi_{t+1}} = 0, \tag{B.20}$$

$$[\lambda_{3,t}]: \quad M_t^e {w_{t-1}}^{-1} - \beta\left((1-s_t)\,{w_t}^{-1} + s_t{\delta_t}^{-1}\right) = 0, \tag{B.21}$$

$$[\lambda_{4,t}]: \quad y_t - w_t n_t - \kappa v_t - \frac{\psi}{2}{\pi_t}^2 y_t + \varpi - c_t^F = 0, \tag{B.22}$$

$$[\lambda_{5,t}]: \quad \beta {c_t^F}^{-1} - M_t^F {c_{t-1}^F}^{-1} = 0, \tag{B.23}$$

$$[\lambda_{6,t}]: \quad \left(1-\tau^I\right)(\varphi_t - w_t + T)\,\frac{\mu^{\frac{1}{1-\gamma}}}{\kappa} + (1-\rho)\,M_{t+1}^F {f_{t+1}}^{\frac{\gamma}{1-\gamma}} - {f_t}^{\frac{\gamma}{1-\gamma}} = 0, \tag{B.24}$$

$$[\lambda_{7,t}]: \quad s_t - \rho\,(1-f_t) = 0, \tag{B.25}$$

$$[\lambda_{8,t}]: \quad (1-s_t)\,n_{t-1} + (1-n_{t-1})\,f_t - n_t = 0, \tag{B.26}$$

$$[\lambda_{9,t}]: \quad v_t(1-(1-\rho)\,n_{t-1})^{\frac{\gamma}{1-\gamma}} - (n_t - (1-\rho)\,n_{t-1})^{\frac{1}{1-\gamma}} = 0, \tag{B.27}$$

$$[\lambda_{10,t}]: \quad \psi\,(1+\pi_t)\,\pi_t y_t - \psi M_{t+1}^F\,(1+\pi_{t+1})\,\pi_{t+1} y_{t+1} - (1-\theta)\,y_t - \theta\left(1-\tau^W\right)\varphi_t y_t = 0, \tag{B.28}$$

$$[\lambda_{11,t}]: \quad \log w_t - \log \delta_t + \beta\,(1-s_{t+1}-f_{t+1})\,S_{t+1}^W - S_t^W = 0, \tag{B.29}$$

$$[\lambda_{12,t}]: \quad J_t^F - \kappa\frac{{f_t}^{\frac{\gamma}{1-\gamma}}}{\mu^{\frac{1}{1-\gamma}}} = 0, \tag{B.30}$$

$$[\lambda_{13,t}]: \quad \frac{S_t^W}{S^W} - \left(\frac{J_t^F}{J^F}\right)\left(\frac{w_t^N}{w}\right)^{-1} = 0, \tag{B.31}$$

$$[\lambda_{14,t}]: \quad w_t - w^{\phi}\left(w_t^N\right)^{1-\phi} = 0, \tag{B.32}$$

$$[\lambda_{15,t}]: \quad n_t - y_t = 0, \tag{B.33}$$

$$[\lambda_{16,t}]: \quad i_t \geq 0. \tag{B.34}$$