Optimal Policy Implications of Financial Uncertainty

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15 August 2019

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Abstract

In addition to the stabilization of inflation and output gap, the responsibility of preventing financial crises and providing stable financial system is assumed by the central banks. In the aftermath of the Great Recession, the policymakers gave financial stability mandate more prominence to preemptively obliterate the fluctuations in the financial market. New models with alternative policy tools have emerged during this period to analyze the impact of financial shocks, and their linkages with the real economy. However, for the policymaker, it might not be possible to verify these models with existing information, which leads to uncertainty. This paper proposes robust optimal policy under uncertainty in response to financial and inflation shocks by acknowledging financial stability as an explicit objective of monetary policy. To do so, we extend the framework of De Paoli and Paustian (2017) by introducing model misspecification. We show that model ambiguity in the financial side requires a passive monetary policy stance. However, if the uncertainty originates from the supply side of the economy, an aggressive response of interest rate is required. We also show the contribution of an additional tool to the dynamics of the economy.

JEL classification: D81, E44, E52, E58

Keywords: Financial Uncertainty, Financial Stability, Optimal Monetary Policy, Robust Control

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1. Introduction

The interaction between uncertainty and financial shocks is toxic not only for the financial sector but also for the real economy by leading to a profound welfare reduction in the society. The most notable and acute example for this situation is the *Great Recession*. After the global crisis, sustaining financial stability and preventing financial fragility came to prominence besides inflation and output gap stabilization. However, there is considerable *uncertainty* about the correct specification of the financial markets. Furthermore, uncertainty may have profound effects on the conduct of monetary policy, leading policymakers to purposefully deviate from *certainty equivalence*. Some sources of uncertainty suggest that monetary policy should be more aggressive, while others can justify a cautious approach. Quantifying how best to respond to economic developments under uncertainty requires knowledge of the type and degree of uncertainty.

The literature characterizes two broad definitions of uncertainty. The first one where decision makers assign probability distribution over possible outcomes is known as *risk*. However, the second one is *Knightian uncertainty* in which the probability distribution cannot be correctly specified. In the aftermath of the Great Recession, the standard New Keynesian model has been proven to be inadequate to account for the linkages between financial sector and the real economy. Accordingly, several models has emerged to include the financial block. However, for the policymaker, it might not be possible to verify these models with existing data which is relevant to the second type of uncertainty. The type of uncertainty that we are interested is pertinent to our aim and motivation is the latter one.

Naturally, sound intervention to financial imbalances calls for a coherent understanding of the practice and the influence of the tool(s) available to the policymaker, especially under uncertainty. Specifically, this paper aims to suggest a robust optimal policy by evaluating the impact of financial shocks to the real economy under financial uncertainty. The response of monetary policy to financial shock is extensively studied by many authors such as Carlstrom et al. (2010), Fiore et al. (2011), Huang and Davis (2013), and Angelini et al. (2014). Since responses to innovations are triggered by uncertainty, putting shock(s) and misspecification together gives more than the sum of the two. Kantur and Özcan (2018) investigate the impact of financial uncertainty on the optimal monetary policy in which the source of financial instability is asset price fluctuations. In this paper, while contributing to the literature by examining the impact of financial shocks under financial uncertainty with a detailed description of the financial market and financial friction, we also extend the analysis to focus on robust optimal policy in the presence of inflation uncertainty.

Following the above-mentioned objectives, we use the model of De Paoli and Paustian (2017) by extending the optimal policy solution by incorporating model uncertainty. Main intention of De Paoli and Paustian (2017) is to focus on the strategic interaction between monetary and macroprudential authorities, while we assume that the central bank is the only institution to conduct policy using the available tool(s). The model utilized in this paper is a dynamic general equilibrium model with a financial sector which is subject to moral hazard problem a lá Gertler and Karadi (2011). The policymaker targets the stability of inflation, output gap and financial markets.[1] Furthermore,under full commitment we propose optimal monetary policy when the policymaker faces model uncertainty. The model uncertainty is handled by the *robust control* methodology to design robust policies which performs well even under the worst case. . In this approach, the policymaker seeks policies that can reasonably guard against catastrophic outcomes. The augmented model of De Paoli and Paustian (2017) provides us the appropriate environment to study the interaction between uncertainty and concomitant shocks, and to propose necessary policy suggestions to countervail any deviation from targets which leads to a reduction in the society's welfare.

Our main findings are as follows: First, we show that interest rates should remain on hold amid financial uncertainty. Since financial uncertainty causes the policymaker to overestimate the strength of the moral hazard problem, robust central bank guards herself against model misspecification stemming from the financial side of the economy by initially dampening the policy rate. Consequently, model ambiguity in the financial side requires a *passive monetary policy* stance. We also show that even under uncertainty the first best solution is achieved if the central bank uses macroprudential tool. This result coincides with the findings of the De Paoli and Paustian (2017) when monetary and macroprudential policymaker is in full coordination and cooperation.

Second, we evaluate the impact of inflation uncertainty. Since the impact of the

[1]In the literature there are awash descriptions of financial stability. In a theoretical context, the policymaker targets the volatility of the financial variable since it is considered as the source of financial instability with the presence financial frictions. (Ueda and Valencia, 2014; Rubio and Carrasco-Gallego, 2014; Nistico, 2016; Curdia and Woodford, 2016; Verona et al., 2017)

supply shock is more prolonged due to uncertainty, we observe an *aggressive* response in the policy rate. Moreover, as suggested by Tinbergen's principle, the introduction of a second tool helps to reduce the trade-off between monetary and financial stability goals. Similar to the one-tool case, inflation uncertainty worsens the financial market conditions. Nevertheless, macroprudential instrument suppresses the transmission of the credit distortions into the real economy. However, interest rate response is still aggressive since the source of uncertainty is the dynamics of inflation. Previous studies, such as Tillmann (2009) show that monetary policy should be cautious due to the presence of the cost channel in the determination of inflation. In contrast, our model shows a more active policymaking. The intuition for this result is closely linked to the specification of the spread between the policy rate and the borrowing rate. In particular, endogenous nature of the spread in our model undermines the impact of the cost channel. Also, our analysis implies that, as the importance of the cost channel increases, the impact of uncertainty is proliferated in case of a supply shock but weakened in case of a financial shock.

Our paper proceeds as follows. Section 2 describes the model. Section 3 analyzes the effects of financial and cost-push shocks in the presence of uncertainty and under alternative assumptions regarding the availability of the tools of policymaker. Meanwhile, this section also provides a discussion on the significance of the cost channel. Section 4 concludes.

2. The Model

We adopt the model of De Paoli and Paustian (2017) as a baseline, and extend it by introducing uncertainty to the model. The core framework is a standard New Keynesian model with costly enforcement problem of Gertler and Karadi (2011). The economy consists of households, firms, financial intermediaries, and the policymaker. In this section, we describe the framework underlying the analysis in the rest of the paper.

2.1. Household

In the spirit of Gertler and Karadi (2011) —within each family—there are workers and bankers. Within the family, the ratio of bankers to workers is constant in each period. All family members transfer their earnings to the household, therefore there is perfect consumption insurance. This assumption enables us to study financial frictions in a representative agent framework.

The representative household consumes final good, c_t, and provides labor, L_t, and capital utilization services, u_t, to the intermediate good producers. Households save in terms of lending to the banks as deposits, A_t, and earn interest income $R_t A_t$ on their deposits at time $t+1$. Utility function of household is given by

$$U(c_t, L_t, u_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\theta}}{1+\theta} - \frac{u_t^{1+\theta}}{1+\theta}$$

where σ and θ refer to degree of risk aversion and (inverse) labor supply elasticity of the household, respectively. Real wage level is w_t and r_t is the price of capital utilization services. The period budget constraint of household in real terms is

$$c_t + A_t = \Omega_w w_t L_t + \Omega_r r_t u_t + \frac{R_{t-1}}{\pi_t} A_{t-1} + T_t + \Pi_t$$

where π_t is the inflation rate. Π_t is the payment to the households from exiting bankers. Ω_w and Ω_r are the steady state subsidies that are financed by the lump-sum taxes T_t.[2]

2.2. Firms

The supply side of the economy is modeled as the basic New Keynesian framework following Clarida et al. (1999). There are two types of firms, which are intermediate and final good producers. Different from the standard New Keynesian model, the introduction of price stickiness is at the final good production step. Intermediate good sector is perfectly competitive and uses labor and capital utilization services.

2.2.1. Intermediate Good Producers

Intermediate goods are produced in a perfectly competitive industry by using labor and capital utilization supplied by the households. Production function of the intermediate good, x_t, is

$$x_t = L_t^{\alpha} u_t^{1-\alpha}$$

[2]These steady state subsidies are necessary to derive welfare-based loss function. See De Paoli and Paustian (2017) for more detailed explanation and derivation.

where the parameter α controls the ratio of credit constrained input, that is the level of *financial friction* in the production process. When $\alpha = 0$, the model will collapse to the standard New Keynesian setup without financial friction. On the other hand, if $\alpha = 1$, the sole input will be the credit-constrained labor however the distortion originated from the resource allocation between L_t and u_t disappears.

Profit function of the intermediate firms is:

$$profits_t = p_t x_t - R_t^B b_t - r_t u_t$$

where p_t is the (relative) price of the intermediate good x_t at time t. To pay the wage cost, $b_t = w_t L_t$, intermediate firms have to borrow loans from banks at the rate R_t^B.

2.2.2. Final Good Producers

The final goods sector is monopolistically competitive and the firms are indexed by $i \in [0, 1]$. They produce differentiated goods by utilizing an identical technology, and use the intermediate goods as inputs. The production function of the final good producer is given by $y_{i,t} = x_{t,i}$. The differentiated goods are aggregated by CES technology,

$$y_t = \left[\int_0^1 y_{t,i}^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}$$

where ϵ is the mark-up parameter.

Rotemberg type price stickiness is introduced with quadratic cost of price adjustment. It enters firms' profit function i as $\frac{\phi}{2}[(p_{t,i} - p_{t-1,i})/p_{t-1,j}]^2 y_t$, with $\phi > 0$. Since the steady inflation rate is assumed to be zero, the quadratic cost disappears in the linearized model.

2.3. Financial Intermediaries

Banks collect deposits from households at a rate R_t, and provide loans to the intermediate good producers at a nominal interest rate, R_t^B. Banks receive direct subsidy, S_t, from the policymaker which controls the leverage and hence the loan supply at a given time period. Net worth of a bank j is given by

$$N_{jt} = R_{t-1}^B B_{jt-1} - R_{t-1}(1 - S_{t-1})A_{jt-1}$$

where $B_t = P_t b_t$ is the nominal loan value. Banks maximize their lifetime wealth:

$$V_{jt} = \max\left\{E_t \sum_{i=0}^{\infty}(1-\gamma)\gamma^i \beta^i \Lambda_{t,t+1+i} N_{jt+1+i}.\right\}$$

where γ is the probability of staying as a banker. This can be written recursively as

$$V_{jt} = \max\{E_t(1-\gamma)\Lambda_{t,t+1}N_{jt+1} + E_t \gamma\beta\Lambda_{t,t+1}V_{jt+1}\}$$

where $\Lambda_{t,t+1+i}$ is the bankers' discount rate.

Similar to Gertler and Karadi (2011), we have costly enforcement problem which controls the capacity of banks to get loans from the households. Financial intermediaries have the possibility to divert a certain fraction of assets. This generates an endogenous market-based leverage constraint which suggests that the households will only provide deposits if the incentive compatibility constraint (ICC) binds:

$$V_{jt} \geq \lambda_t B_{jt}$$

There may be exogenous shock ε_t^{λ} to the fraction $\lambda_t = \lambda\varepsilon_t^{\lambda}$. We suppose that the ICC is always binding, thus the leverage is

$$\delta_t = \frac{\upsilon_{n,t}}{\lambda_t - \upsilon_{b,t}}$$

and a positive shock to λ_t reduces the leverage and tightens the credit conditions in the economy. The incentive compatibility and in-advance borrowing constraints are the *credit frictions* in the model.

2.4. System of Equations

With the optimal monetary policy the following system of equations fully characterize the model:

$$\hat{\pi}_t = \beta E_t\hat{\pi}_{t+1} + \kappa[(\sigma+\theta)\hat{y}_t + \alpha\hat{f}_t] + \varepsilon_t^m \tag{1}$$

$$\hat{y}_t = E_t\hat{y}_{t+1} - \frac{1}{\sigma}(\hat{R}_t - E_t\hat{\pi}_{t+1}) \tag{2}$$

$$\hat{n}_t = \hat{n}_{t-1} + \hat{R}_{t-1} - \hat{\pi}_t + \frac{1}{\phi\delta+1}[\phi\delta\hat{\delta}_{t-1} + \delta\hat{\phi}_{t-1} + (\delta-1)\hat{S}_{t-1}] \tag{3}$$

$$\hat{\delta}_t + \hat{n}_t = (1+\sigma+\theta)\hat{y}_t - (1-\alpha)\hat{f}_t \tag{4}$$

$$\hat{\delta}_t + \hat{\varepsilon}_t^{\lambda} = \delta\hat{\phi}_t + (\delta-1)\hat{S}_t + \beta E_t[(\phi\delta+1)\hat{\delta}_{t+1} + \hat{\varepsilon}_{t+1}^{\lambda}] \tag{5}$$

Equation (1) is the Phillips equation with exogenous cost-push shock ϵ_t^m. Different from the conventional New Keynesian Phillips equation, we observe financial market related variables in the marginal cost component of the equation. Since the firms has to borrow from banks to finance their labor cost, the effective interest rate, $f_t = (\hat{R}_t + b\hat{\phi}_t)$, appears in the Phillips relation. The parameter α controls the significance of the cost channel on price developments. Equation (2) is the IS equation derived from combination of Euler equation and market clearing condition. The dynamic net worth equation is expressed in equation (3). Equation (4) illustrates the relation between real economy and the banking sector. Finally, equation (5) is derived from the ICC which controls the tightness of the credit conditions in the economy. A positive exogenous shock, $\hat{\varepsilon}_t^{\lambda}$, can be interpreted as tighter credit conditions.

Shocks are assumed to follow stationary autoregressive processes:

$$\varepsilon_{t+1}^m = \rho_m \varepsilon_t^m + \nu_{t+1}^m \tag{6}$$
$$\varepsilon_{t+1}^{\lambda} = \rho_{\lambda} \varepsilon_t^{\lambda} + \nu_{t+1}^{\lambda} \tag{7}$$

where ρ_m and ρ_{λ} are the persistence of the inflation and leverage shocks, respectively.

3. Robust Macroeconomic Policy Analysis

De Paoli and Paustian (2017) derives the model-consistent welfare criterion as follows:

$$\mathcal{L}_t = \frac{1}{2}(\hat{\pi}_t)^2 + \chi_y(\hat{y}_t)^2 + \chi_f(\hat{f}_t)^2 \tag{8}$$

where $\chi_y \equiv \frac{\sigma+\theta}{\varphi}$ and $\chi_f \equiv \frac{\alpha(1-\alpha)}{\varphi(1+\theta)}$ are relative weights of the output and financial stability.

The quadratic welfare criterion reflects the inefficiencies due to relative price distortions, exogenous cost-push shocks, and credit frictions. In this model, the credit spread also distorts the allocation of resources between inputs. This is because firms require loans to finance only the labor input. This distortion assigns a fundamental role to financial stability. Therefore, financial stability appears as an explicit target in addition to output and inflation stabilization.

3.1. Model Uncertainty

The aim of this paper is to study the optimal behavior of the policymaker when there is uncertainty about the structure of the economy. Model uncertainty is handled by the worst-case analysis. The idea is to construct policy to hedge against catastrophic outcomes. We focus only on commitment policies since the robust control has a significant impact on expectation formation in the economy. Therefore, persistent shocks generate richer model dynamics.

Model uncertainty is introduced by a second type of disturbance in the mark-up and financial shocks:

$$\varepsilon^i_{t+1} = \rho_m \varepsilon^i_t + [\nu^i_{t+1} + w^i_{t+1}], \quad i \in \{m, \lambda\} \tag{9}$$

When equation (9) is the true shock process, the error terms in (6) and (7) are distributed as $N(w^i_t, 1)$ rather than as $N(0,1)$.

To ensure that the distorted model is close to the reference model, the misspecification for each shock is controlled by parameters η^i_0 and bounded as follows:[3]

$$E_t \sum_{\tau=0}^{\infty} [w^i_{t+\tau}]^2 \leq \eta^i_0, \quad \eta^i_0 > 0, \quad i \in \{m, \lambda\}. \tag{10}$$

3.2. Formulation of Robust Policies

To specify the policymaker's problem with concerns about model ambiguity, we define an evil agent. The introduction of this fictitious agent sets a ground for obtaining the worst-case scenario. The evil agent maximizes the social objective function, (8), to distort the model as much as possible. Meanwhile, the policymaker solves the optimization problem to design an optimal policy to function well in the worst-case scenario. Therefore, we can describe this sequence of events as a Stackelberg game by the following max-min problem:

$$\min_{\{\hat{R}_t, \hat{S}_t\}_{t=0}^{\infty}} \max_{\{w^i_{t+1}\}_{t=0}^{\infty}} E_t \sum_{t=t_0}^{\infty} \beta^t \left[\mathcal{L}_t - \beta \left(\Theta^i (w^i_{t+1}))^2 \right) \right], \quad i \in \{m, \lambda\}$$

[3]One can model same degree of model uncertainty for all types of shocks by assuming $E_t \sum_{\tau=0}^{\infty} [w^m_{t+\tau} + w^{\lambda}_{t+1}]^2 \leq \eta_0$.

subject to (1), (2), (3), (4), (5), and (9). Central bank's uncertainty aversion is symbolized by the parameter $0 < \Theta^m(\Theta^\lambda) < \infty$.[4]

When the policymaker has access to two instruments, the welfare maximizing policy under credible commitment requires the joint choice of the nominal interest rate and the macroprudential subsidy, $\{\hat{R}_t, \hat{S}_t\}_{j=0}^{\infty}$, which minimizes the present value of the model-consistent welfare criterion (8) subject to equilibrium conditions.

The first-order conditions for the optimal commitment policy are as follows:

$$\hat{\pi}_t + s_{1t} - s_{1t-1} - \frac{1}{\beta}s_{2t-1} + s_{3t} = 0 \tag{11}$$

$$2\chi_y \hat{x}_t - \kappa(\sigma + \theta)s_{1t} + \sigma s_{2t} - \frac{\sigma}{\beta}s_{2t-1} - (1 + \sigma + \theta)s_{4t} = 0 \tag{12}$$

$$2\chi_f \hat{f}_t - \kappa\alpha s_{1t} + s_{2t} - \beta s_{3t+1} + (1 - \alpha)s_{4t} = 0 \tag{13}$$

$$-\frac{(\delta - 1)\beta}{\phi\delta + 1}s_{3t+1} - (\delta - 1)s_{5t} = 0 \tag{14}$$

$$2\chi_f b\hat{f}_t - \kappa\alpha b s_{1t} - \frac{\delta\beta}{\phi\delta + 1}s_{3t+1} + (1 - \alpha)bs_{4t} - \delta s_{5t} = 0 \tag{15}$$

$$s_{3t} - \beta s_{3t+1} + s_{4t} = 0 \tag{16}$$

$$-\frac{\phi\delta\beta}{\phi\delta + 1}s_{3t+1} + s_{4t} + s_{5t} - (\phi\delta + 1)s_{5t-1} = 0 \tag{17}$$

$$-s_{1t} + \rho_m s_{6t+1} - \frac{1}{\beta}s_{6t} = 0 \tag{18}$$

[4] Hansen and Sargent (2008) call this representation as *the multiplier version of the Stackelberg problem* since Θ^m (Θ^λ) can be interpreted as a Lagrange multiplier on the entropy constraint (10).

$$-\beta\Theta w^{m}_{t+1} + s_{6t+1} = 0 \tag{19}$$

$$-s_{5t} + \rho_{\lambda} s_{7t+1} - \frac{1}{\beta} s_{7t} = 0 \tag{20}$$

$$-\beta\Theta w^{\lambda}_{t+1} + s_{7t+1} = 0 \tag{21}$$

These conditions characterize robust optimal policy solution of the policymaker. When the central bank uses the conventional tool, $\hat{R}_t$, equation (14) is replaced by the identity $\hat{S}_t = 0$, meaning that credit subsidy remains at its steady state value. In the next section, we analyze the implications of these first-order conditions under different sources of model misspecification and shocks considering alternative tools.

4. Results and Discussion

4.1. Calibration and Results

The calibration of the model follows De Paoli and Paustian (2017). We set the discount factor, β to 0.99. The elasticity of substitution between the differentiated goods, ϵ, is calibrated to 10. The Rotemberg price adjustment cost, φ, is set to 211 —suggesting that prices stay fixed for an average of four quarters. The labor share, α —or the share of intermediate goods that are credit constrained—is 0.5. We suppose that the Frisch elasticity of labor supply is $\theta = 0.47$. We set the elasticity of intertemporal substitution, σ, to 1. Steady state levels for the leverage and credit spread are $\delta = 9$ and $\phi = 2\%$ respectively. Shocks follow an AR(1) process for autoregressive coefficient 0.9.

We get three possible equilibria in this framework: (i) rational expectations, (ii) worst-case and (iii) approximating. *Rational expectations equilibrium* is the baseline outcome when the policymaker has no uncertainty aversion and the model is not distorted. *Worst-case equilibrium* is the outcome in which the policymaker has uncertainty aversion and the policy is set under the distorted model. Finally, *approximating equilibrium* arises when the policmaker's uncertainty aversion still exists, so that the robust policy is conducted. However, the distortion is not realized. The shock process dynamics is similar under the rational expectations and the approximating equilibrium; however, their policy functions are different. In this setting, the approximating equilibrium is derived using the worst-case outcome. The policy is tailored to insure against the catastrophic outcomes.

The degree of uncertainty aversion is quantified with error detection probability (EDP). An EDP is the probability that the reference model and the worst-case model are statistically indistinguishable. We set Θ^{λ} to 0.008; Θ^{m} to 163.5 and 82 for the one-tool and two-tools cases respectively, which corresponds to a detection error probability of 20% in a sample of 142 observations.[5]

This section provides a comparison of the dynamics under model uncertainty. We have two sources of uncertainty originating from financial shock and the supply shock. In what follows, we study the optimal commitment macroeconomic policy under different assumptions for the availability of the monetary and macroprudential

[5]See Hansen and Sargent (2008) for the discussion of detection error probabilities. According to Hansen and Sargent (2008), a reasonable detection error probability should be between the range 10% and 20%. To calculate detection error probabilities, we use the algorithm provided by Giordani and Söderlind (2004). Our results are robust for different values of Θ^{i}, $i \in (\lambda, m)$.

instruments: $\hat{R}_t$ and $\hat{S}_t$.

4.1.1. Financial Uncertainty

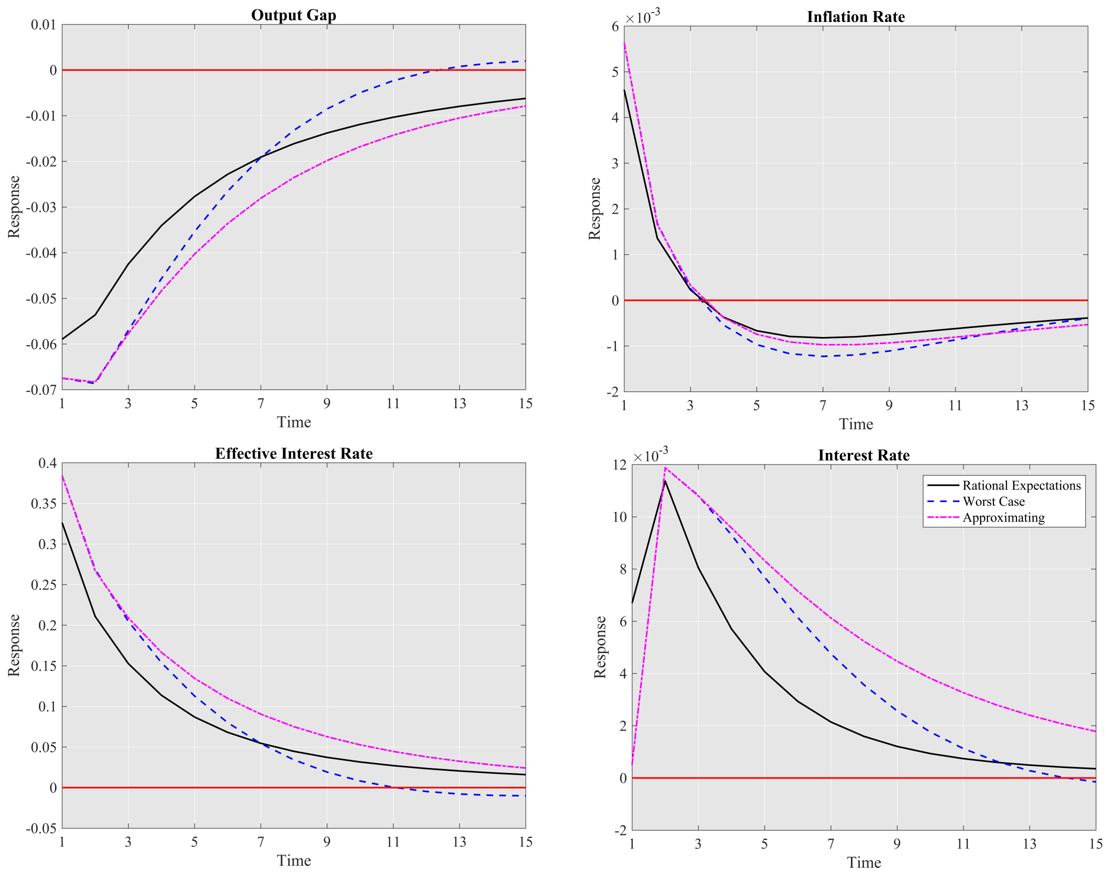

Figure 1: One Tool: Responses to Financial Shock

Figure 1 illustrates the responses to financial disturbances. A positive shock to the incentive-compatibility constraint leads to an increase in the gain from bankruptcy. Since the value of the bank, V_t, must be equal to this gain, the incentive constraint is tightened. Due to this effect, financial intermediaries begin a deleveraging process by cutting down loan supply, which leads to an increase in the cost of borrowing for the firms, $\hat{f}_t$, to finance their labor input. The presence of the cost channel results in an increase in the marginal cost and hence in inflation. The macroprudential tool would have prevented deleveraging process by decreasing credit subsidy, $\hat{S}_t$. In this case the shock will not be transmitted to the real economy and the macroeconomic targets will not deviate from their steady states. To counteract the fluctuations in the inflation, without a macroprudential instrument, central bank raises policy rate, $\hat{R}_t$. Output gap deteriorates.

Under financial uncertainty, policymaker overestimates the strength of the moral hazard problem. Because of the amplified moral hazard effect, which leads to even tighter credit conditions, the response of the effective interest rate and hence credit spread is magnified. Larger credit spread causes inefficient use of inputs in the production process. Thus, output declines more. Due to larger fluctuations in the output and the effective interest rate, robust central bank guards herself against model misspecification stemming from the financial side of the economy by initially dampening the policy rate. Hence, model ambiguity in the financial side requires a passive monetary policy stance. Moreover, the response of interest rate lasts longer compared to the rational expectations solution due to the endogenous persistence of the shock.

In order to observe the impact of financial uncertainty on the conduct of monetary policy, we further analyze the policy function of the interest rate. Table 1 shows the coefficient of the financial shock in the policy function of the interest rate which suggest 93% less responsiveness to the financial shock under financial uncertainty.

An analysis of the impact of additional tools is inevitable in a framework when the

Table 1: Policy function for the instruments

(a) Financial Uncertainty: Coefficient on ν^{λ}	
R_t-Rational Expectations	0.0067
R_t-Worst Case	-0.0005
Change	**93%**

policymaker is accountable for multiple mandates. The related literature is pioneered by Tinbergen (1952) suggesting that for a policy to be successful, the number of available policy tools should be enough to address multiple inefficiencies faced by the central banks. In a recent work by Davig and Gürkaynak (2015), a similar question is reexamined under welfare based optimal monetary policy framework.

We are also interested in the dynamics when the policymaker has an access to a second tool, namely the macroprudential tool. In this model, credit subsidy is used as the macroprudential policy tool. As De Paoli and Paustian (2017) discusses, credit subsidy fully eliminates the financial distortions. We show that this result is still preserved in the presence of financial uncertainty.

Proposition 1. *In this model, since the credit subsidy, S_t, directly targets financial frictions, there is no room for model uncertainty originating from financial side of the economy in the presence of the macroprudential policy instrument. Counter-cyclical credit subsidy immediately offsets the financial shock.*

PROOF. Solving the first-order conditions (11)-(17) and (20)-(21) under the fully optimal commitment policy yields that Lagrange multiplier for the dynamic net worth accumulation equation, s_{3t} to be zero.[6] In this case, financial shock and hence uncertainty associated with the shock is not transmitted into the real economy.

4.1.2. Inflation Uncertainty

In this section, we present the dynamics of the model under a mark-up shock.

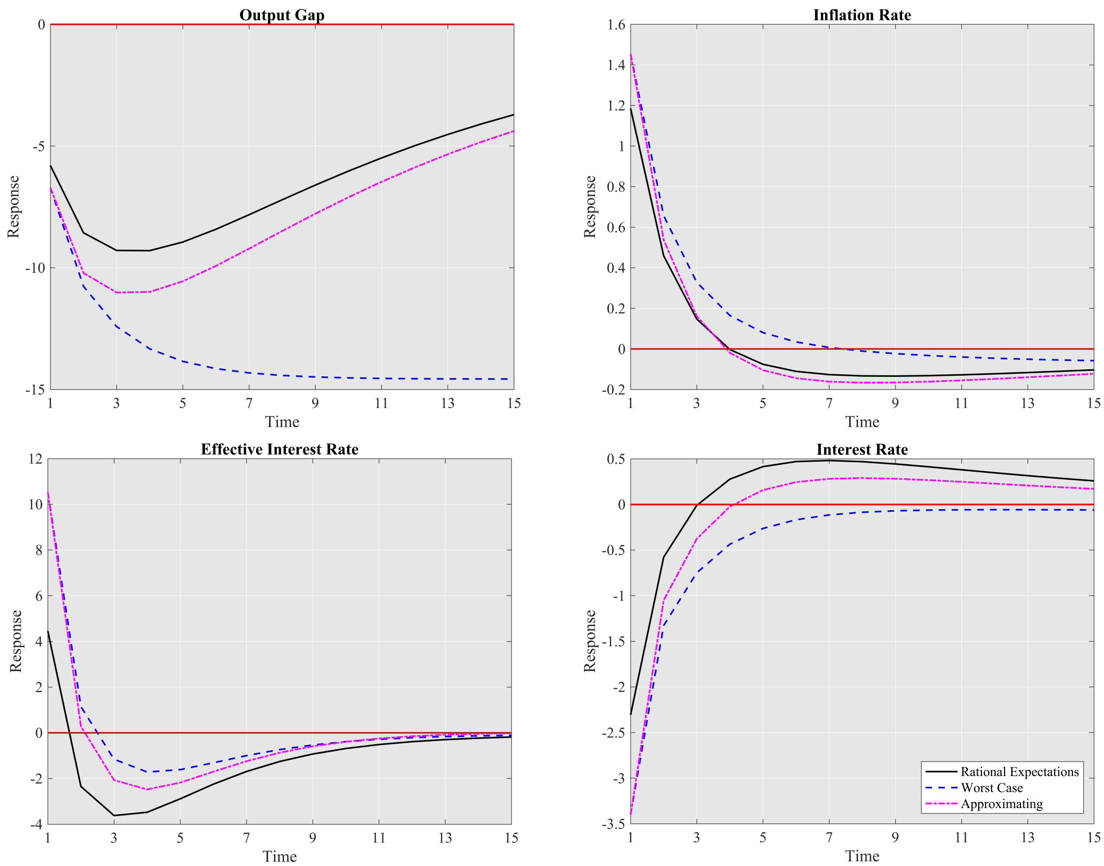

Figure 2: One Tool: Responses to Markup Shock

Figure 2 shows the dynamics of the model when the policymaker has access to one instrument only. A positive mark-up shock leads to an increase in inflation and

[6]Optimal commitment policy requires to set the multipliers $s_{1t-1} - s_{5t-1}$ to zero since there are no binding previous commitments in the first period.

a fall in the output. The optimal path of interest rate initially falls on impact to alleviate the negative response of output. However, current inflation also falls due to the commitment to higher future interest rates.

With lower output level, working capital need of intermediate firms causes a fall loan demand. At the same time, lower interest rate discourages saving behavior of the households. Thus, bank deposits and loan supply falls. Since decrease in loan supply dominates the fall in loan demand, the effective interest rate increases initially. As the net worth of the financial intermediaries increase —due to the increase in spread—loan supply recovers and effective rate falls below its steady state value. Eventually, the impact of the shock dissipates.

Evidently, the conventional monetary policy is not enough to ameliorate the tenacious fluctuations in credit conditions, which calls for an additional tool for this purpose. Below, we explore the impact of this tool on the financial stability.

Under inflation uncertainty, inflation and subsequently output fluctuates more. Furthermore, the impact of the shock is more prolonged due to uncertainty. This induces an aggressive response in the policy rate. Under commitment, central bank stabilizes the economy not only by controlling the current output but also by promising to keep them lower in the future. Due to the stronger response of the policy rate, the economy faces tighter credit conditions. By virtue of higher spread, the deterioration in the financial stability is more severe.

As discussed earlier, Tinbergen principle suggests that one policy instrument can only achieve one independent goal. Hence, when the central bank is equipped with the interest rate as the policy tool, targeting financial stability would increase the

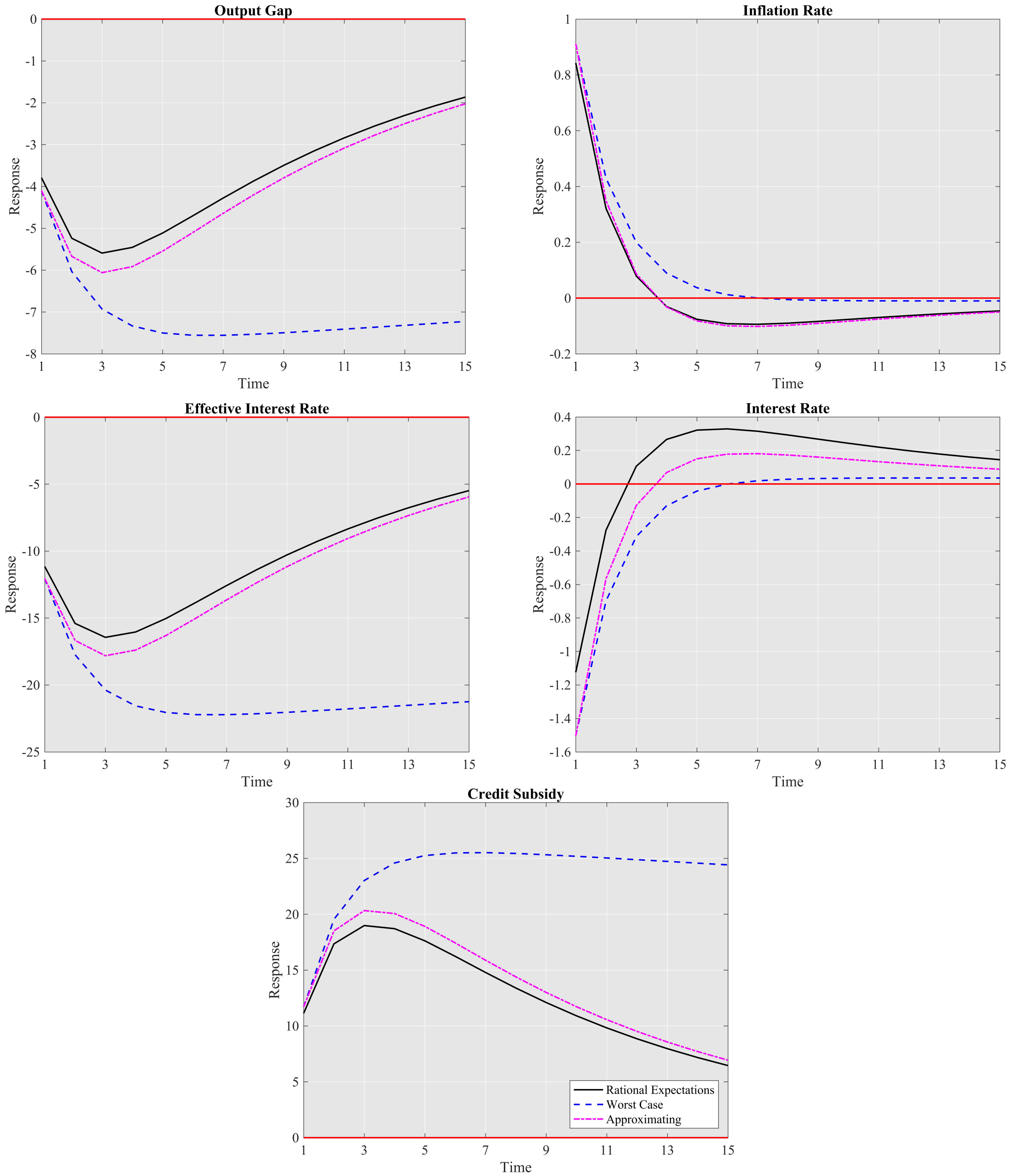

Figure 3: Two Tool: Responses to Markup Shock

volatility of inflation and output. An additional tool designed to fight for financial instability could help macroeconomic stability. Accordingly, Figure 3 shows the dynamics of the model when the policymaker has access to both monetary and macroprudential tools. Policymaker sets the interest rate and the macroprudential policy instruments simultaneously in order to pursue the objective of maximizing social welfare.

A positive mark-up shock leads to an increase in inflation and a fall in the output. As in the one-tool case, the nominal interest rate decreases. However, the presence of the macroprudential tool offsets the impact of the cost push shock on the financial market. Unlike one-tool case, the deterioration in the supply of loan is dampened, and decrease in loan demand results in lower effective interest rate.

After a cost-push shock, credit subsidy prevents effective interest rate to increase unlike in the one-tool case. Therefore, cost channel has a negative impact on the inflation. Similar to the one-tool case, inflation uncertainty deteriorates the financial market conditions. Nevertheless, macroprudential instrument countervails the decrease in the loan supply by responding aggressively. Therefore, the transmission of the credit distortions into the real economy is suppressed. However, interest response is still aggressive since the source of uncertainty is in the inflation equation. This discussion is summarized in the following proposition.

Proposition 2. *Credit subsidy dampens the impact of the cost channel.*

In order to evaluate the effect of inflation uncertainty on the policymaking, we further analyze the policy function of the interest rate and the credit subsidy. Table

Table 2: Policy function for the instruments

(a) Inflation Uncertainty (One Tool): Coefficient on ν^m	
R_t-Rational Expectations	-2.306
R_t-Worst Case	-3.4
Change	**47%**

(b) Inflation Uncertainty (Two Tools): Coefficient on ν^m	
R_t-Rational Expectations	-1.12
R_t-Worst Case	-1.5
Change	**33.9%**
S_t-Rational Expectations	11.13
S_t-Worst Case	11.7
Change	**5%**

2 summarizes the coefficient of the inflation shock in the policy functions of available policy tools. First, under certainty the principle of Tinbergen still exists. Next, uncertainty leads the interest rate to be more aggressive in both one-tool and two-tools cases. In the former, the responsiveness of the interest rate becomes 47% more aggressive under uncertainty. The corresponding value for the latter case is 33.9%. At the same time, the credit subsidy responds more aggressively by 5%. Therefore, the burden of uncertainty on the supply side of the economy is shared among available policy tools.

4.2. Discussion

In this model, α is the key parameter determining the importance of the cost channel in the model. Put differently, it is the interest rate pass-through from financial sector to the real economy. We discuss the sensitivity of our results for different levels of α under rational expectations as well as under uncertainty.

Table 3 (a) shows the coefficient of financial shock in the policy function of interest rate for $\alpha = 0.2$ and $\alpha = 0.8$ both for rational expectations and for the case under financial uncertainty.[7] The fluctuations in the financial market are carried to the real economy through the impact of the effective interest rate on inflation. Accordingly, as the weight of the cost channel increases, the response of the interest rate becomes stronger under rational expectations. Furthermore, due to the uncertainty in the financial side of the economy, the decrease in the loan supply is stronger. As a response, there is an upward pressure on interest rate to countervail the negative impact on loan supply by attracting deposits to fulfill the loan demanded by the firms. To sum up, the impact of uncertainty on the economy decreases as the strength of the cost channel increases.

Proposition 3. *As the importance of the cost channel increases, the impact of financial uncertainty decreases. Robust monetary becomes less passive (passiveness decreases).*

Table 3 (b) and 3 (c) illustrate the initial responses of policy tool(s) to inflation

[7]For consistency with the rest of the analysis, we choose $\alpha = 0.2$ and $\alpha = 0.8$ so that the relative weights of the targets in the social welfare function stay the same.

Table 3: Policy function for the instruments

(a) Financial Uncertainty: Coefficient on ε^{λ}		
Importance of financial frictions (α)	**0.2**	**0.8**
R_t-Rational Expectations	0.000727	0.0189
R_t-Worst Case	-0.0041	0.0171
Change	**664%**	**10%**

(b) Inflation Uncertainty (One Tool): Coefficient on ε^{m}		
Importance of financial frictions (α)	**0.2**	**0.8**
R_t-Rational Expectations	-2.36	-1.73
R_t-Worst Case	-2.99	-2.66
Change	**27%**	**54%**

(c) Inflation Uncertainty (Two Tools): Coefficient on ε^{m}		
Importance of financial frictions (α)	**0.2**	**0.8**
R_t-Rational Expectations	-1.79	-0.36
R_t-Worst Case	-2.2	-0.49
Change	**23%**	**36%**
S_t-Rational Expectations	8.02	16.73
S_t-Worst Case	8.33	17.17
Change	**3.9%**	**2.6%**

Note. To keep the detection error probability constant, we recalibrate Θ for each case.

shock for different values of α for the cases under rational expectations and inflation uncertainty. As the pass-through effect on inflation becomes more significant, fluctuations in the financial sector vehemently carried to the real economy, and leading to stronger response of inflation in return. Due to the cost-push shock, there is a downward pressure on interest rate to eliminate the negative impact of the shock on output. However, the fall in interest rate is suppressed by the increase in inflation. Under uncertainty, the response of the interest rate is more aggressive. Moreover, the impact of the uncertainty escalates as the importance of cost channel increases due to the fact that the uncertainty on the supply side of the economy triggers the fluctuations in the financial side; thus, we observe further inflation. Therefore, the interest rate decreases even more.

As the weight of cost channel in the Phillips equation increases, the response of robust policy becomes more aggressive which contradicts with the result of Tillmann (2009). In Tillmann (2009) spread is exogenous; however, in our framework the effective interest rate, hence spread, is determined in the loan market. The presence of the endogenous spread leads to an increase in the effective interest rate after a cost-push shock and contemporaneously effects the inflation rate. Therefore, the response of inflation becomes higher as the importance of cost channel increases. When the central bank has access to the macroprudential tool, responses of interest rate under rational expectation and uncertainty are identical to one-tool case: aggressiveness of the interest rate tool declines and the impact of uncertainty on interest rate rises. As the transitivity of financial sector on real economy strengthens, the macroprudential tool becomes more aggressive to control the fluctuations in the financial sector under rational expectations. However, the impact of uncertainty on the macroprudential tool is less observed because the considerable amount of uncertainty is treated by the interest rate. Therefore the role of credit subsidy to cope with uncertainty is limited.

Proposition 4. *As the importance of the cost channel increases, the impact of inflation uncertainty increases. Robust monetary becomes more aggressive (aggressiveness increases). Robust macroprudential policy becomes less aggressive (aggressiveness decreases).*

Our analysis indicates that the source of uncertainty matters and it has an imperative impact on the conduct of monetary policy. In our model, financial uncertainty originates from a shock to the loan market which highlights the severity of the moral hazard problem in the financial market. This type of uncertainty brings attenuation in monetary policy. Clearly, in a model where the source of financial uncertainty is related to the volatility of asset prices as in Kantur and Özcan (2018), optimal policy suggestion would be substantially different as discussed above. Policymakers should take these concerns into consideration in pursue of robust policies. Moreover, in this paper the responsibility of stabilization of inflation and output, and providing stable financial system is assumed by a *single* institution. It will be an interesting future area for research to explore the impact of strategic interaction between multiple robust policymakers especially when monetary and the macroprudential authorities have coordination failures.

5. Conclusions

In this paper, we propose robust optimal policy under uncertainty in response to financial and inflation shocks by acknowledging financial stability as an explicit objective of monetary policy in addition to inflation and output targets. To do so, we extend the framework of De Paoli and Paustian (2017) by incorporating model uncertainty in the spirit of Hansen and Sargent (2008). Our findings are as follows: If the model misspecification originates from the financial side of the economy, the policymaker should prefer to choose a passive monetary policy stance. However, an uncertainty associated with the supply side of the economy requires an aggressive reaction of the policymaker. We also assess the contribution of an additional —macroprudential—tool to the dynamics of the economy. Since macroprudential tool directly targets the inefficiencies in the financial market related variables, the uncertainty in the financial side of the economy is not transmitted to the real economy. On the other hand, an uncertainty which has a direct impact on the supply side of the economy requires more aggressive policy stance for both conventional and macroprudential tool. In two-tool environment, compared to one-tool case, the burden of uncertainty is shared among available policy instruments.

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6. Appendix

Households

The optimality conditions for labor supply, capital utilization, and riskless-bond holdings are as follows:

$$\frac{L_t^\theta}{c_t^{-\sigma}} = \Omega_w w_t \tag{22}$$

$$\frac{u_t^\theta}{c_t^{-\sigma}} = \Omega_r r_t \tag{23}$$

$$c_t^{-\sigma} = \beta E_t \left(c_{t+1}^{-\sigma} \frac{R_t}{\pi_{t+1}} \right) \tag{24}$$

Firms

The first order conditions are:

$$\alpha p_t x_t = (1+\phi_t) R_t w_t L_t \tag{25}$$

$$(1-\alpha) p_t x_t = r_t u_t \tag{26}$$

where ϕ_t refers to the spread between borrowing and the deposit rate. Especially, $\phi_{t-1} = (R_{t-1}^B - R_{t-1})/R_{t-1}$.

In equilibrium, the price-setting problem of Rotemberg yields the following Phillips equation:

$$0 = (1-\epsilon_t) + \epsilon_t p_t - \varphi(\pi_{t-1})\pi_t - \beta E_t \left[\frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \varphi(\pi_{t+1}-1)\pi_{t+1} \frac{y_{t+1}}{y_t} \right] \tag{27}$$

Due to monopolistic competition, firms can earn profits in equilibrium. Dividends are distributed to shareholders of the final good firms.

$$d_t = y_t(1-p_t) - \frac{\varphi}{2}(\pi_t - 1)^2 y_t \tag{28}$$

In symmetric equilibrium, where $y_{i,t} = y_t$, aggregate output is given by

$$y_t = L_t^\alpha u_t^{1-\alpha}. \tag{29}$$

Total output equals to the summation of consumption and price adjustment costs. Market clearing condition:

$$y_t = c_t + \frac{\varphi}{2}(\pi_t - 1)^2 y_t \tag{30}$$