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Financial friction, rare disaster, and recovery policy

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ABSTRACT

The paper introduces financial intermediation into the New Keynesian model with rare disasters, analyzes the impacts of rare disaster shock on the macro economy, and compares the effects of different economic recovery policies. Based on the numerical analysis, this study finds that: (1) rare disaster risk shock retains a negative relationship with consumption levels, and banks increase their leverage ratios to cause risk accumulation; (2) refinance policy and consumer coupon policy can alleviate economic fluctuations caused by disaster risks from various channels; (3) the consumer coupon policy is conducive to reducing the average social welfare loss caused by disaster risks. It is believed that the establishment of a sustainable economic stimulus mechanism to fundamentally reduce the impact of catastrophic events on the macro economy and achieve economic recovery in a short period are essential issues that should be urgently addressed by countries.

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1. Introduction

With the outbreak of COVID-19, people have rekindled interest in rare disasters and their economic impacts. A batch of research related to disaster risk has emerged, for example, on the impact of disaster risk on the macroeconomic and policy response (Benmelech & Tzur-Ilan, 2020; Bloom et al., 2022; Jinjarak et al., 2021), on how COVID-19 affects inequality in income, wealth, and health (Alfani, 2022; Beach et al., 2022), on rare disaster and financial intermediary and financial market (Falato et al., 2021; Gertler et al., 2020; Goodell, 2020; Zhang et al., 2020) and on the application and expansion of the epidemic model (Atkeson et al., 2020; Bisin & Moro, 2020; Ellison, 2020).

Gabaix (2011, 2012) and Gourio (2012) define rare disasters as events that may destroy a considerable proportion of capital stock and productivity, leading to a significant decline in the quality of life, like global wars, epidemics, and financial crises. Rare disasters are less likely to occur, but once they occur, they will incur extensive

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economic impact. Presently, the economic model with catastrophic risk has become the leading research framework for explaining specific facts about the overall market, interest rates, and financial derivatives (Tsai & Wachter, 2015), providing possible ideas for unraveling the mystery of stock premiums (Mehra & Prescott, 1985). For example, to characterize the scale of the risk premium, Rietz (1988), Barro (2006), and Barro and Ursua (2008) introduced a constant slight probability of rare disaster shock in endowment economies and considered the probability of rare disasters as the determinant of the asset risk premium. However, because the probability of a disaster is constant, it cannot explain the countercyclical characteristics of the risk premium. Gabaix (2008) introduced a time-varying disaster probability shock into the aforementioned endowment economy, and then Gabaix (2011, 2012) and Gourio (2012, 2013) further introduced the time-varying disaster probability into the real business cycle (RBC) model, which can not only solve the problem of countercyclical risk premium but also use additional financial frictions such as corporate leverage to match the scale of risk premium with volatility. However, the RBC model that introduces disaster shocks has two shortcomings: First, the increase in the probability of disaster risk will cause stock prices to fall and induce an economic recession, but at the same time increase consumption, which is contrary to substantial data. Second, the RBC-based disaster risk model needs to set the intertemporal elasticity of substitution (EIS) to be strictly greater than 1 to produce an economic recession, and if the EIS is less than 1, the result will be the opposite. For this reason, Isoré and Szczerbowicz (2017) introduced the time-varying disaster probability shock into the standard New Keynesian model for the first time to study the impact of the shock on the economy. They verified the negative relationship between rare disaster risk impact and consumption level and pointed out that the value of EIS should be less than 1. Petrosky-Nadeau et al. (2018) more extremely considered the endogenous disaster risk and balanced the endogenous disaster by combining wage inertia and trade externalities.

Rare disaster risks substantially affect the macroeconomic in two ways. One is the actual damage caused by the occurrence of disasters to the real economy. Another is the impact of catastrophe expectations on economic fluctuations. However, none of the previous models consider the effects of the financial intermediary sector on the economy. Shocks from financial intermediaries contribute more than 50% to overall volatility and have become the primary cause of economic volatility (Claessens et al., 2012; Iacoviello, 2015; Kollmann, 2013). The occurrence of disasters will cause considerable losses and uncertainties to the domestic and foreign economies and at the same time, will cause consumers to change their current consumption habits, leading to changes in the proportion of savings and investment in the economy, which in turn affects the leverage ratio of the banking sector. Gertler et al. (2020) believe that bank panic caused by excessive leverage remains the endogenous source of economic disaster.

Based on this fact, a significant number of studies embed financial intermediary as an independent sector in the DSGE framework to re-examine the relationship between economic fluctuations and financial factors, and the substantial impact of financial variables on the RBC. These studies have formed the critical emerging research field of financial economic cycle theory (Brunnermeier & Sannikov, 2014;

Gertler & Kiyotaki, 2010; Philippon, 2015; Woodford, 2010). The theory is based on the bank intermediation model with financial friction in Gertler and Karadi (2011). It draws on Kiyotaki and Moore (1997) to characterize liquidity risk.

However, due to information asymmetry and financial market defects, the debt financing contract is incomplete, and financial shocks are amplified through the endogenous mechanism of the financial market, which affects the financing conditions and investment levels of enterprises, leading to drastic fluctuations in the real economy (Christiano et al., 2005; Smets & Wouters, 2007). A large number of studies have proven that the DSGE model with financial frictions can explain China's economy well (Chang et al., 2015, 2019; Liu, Spiegel, et al., 2021; Liu, Wang, et al., 2021). The difference between our study and the existing literature is that we attempt to introduce the financial sector into the New Keynesian model with disaster risk to study the impact of disaster shocks on macroeconomics and analyze the implementation effects of different economic stimulus policies issued by the government after disaster events.

The rest of the paper is as follows. The benchmark model of this study is introduced in Section 2. Section 3 is the empirical analysis containing parameter calibration and numerical simulation results. Further analysis is given in section 4 and the summary of this study is presented in the final section.

2. Benchmark model

Based on the framework of Isoré and Szczerbowicz (2017), this study introduces the financial intermediary as Gertler and Kiyotaki (2015) described while analyzing the impact of rare disaster shocks on the macroeconomic. The model primarily includes household, bank, and firm sectors. The household includes workers and bankers. Workers only provide labor and receive wage returns. Bankers manage financial intermediaries and generate the bank's net profit to the household sector. Workers and bankers can flow between them. Each period has a $1-\sigma$ ratio of bankers to become workers, that is, the survival time of each banker is $1/(1-\sigma)$. After exiting, the banker transfers the retained earnings to the family and becomes a worker in the following stage. The firm includes intermediate product producers and final product producers. Intermediate goods are produced using the capital loaned by the bank, the labor is provided by the household, and final products are assembled from intermediate goods. The economy will be impacted by disasters. The probability of disaster θ_t itself is small, but it will affect the discount factor of the household. This discount factor, which changes over time, can capture the dynamic impact of changes in the probability of disaster on macroeconomic output and asset prices.

2.1. Household

The household obtains capital income through savings deposits and provides labor supply to the firm to obtain wage income. The household obtains utility from consumption C_t and labor L_t. The utility function can be expressed in the form of Epstein–Zin–Weil, namely:

$$\tilde{U}_t = \left\{ \left[C_t (1-L_t)^{\varpi} \right]^{1-\psi} + \beta_0 \left(E_t \tilde{U}_{t+1}^{1-\gamma} \right)^{\frac{1-\psi}{1-\gamma}} \right\}^{\frac{1}{1-\psi}} \tag{1}$$

where ϖ represents the leisure preference of the household, $1/\tilde{\psi}$ represents the elasticity of intertemporal substitution (EIS), where $\tilde{\psi} \equiv 1-(1+\varpi)(1-\psi)$. β_0 is the discount factor and γ is the risk aversion coefficient. To characterize the influence of changes in disaster risk by the household through its preferences, this model draws on the method of Gourio (2012) and follows a smoothing model to capture changes in household preferences, thereby characterizing the influence of changes in disaster risk. Further, $U_t \equiv \left(\tilde{U}_t/z_t\right)^{1-\psi}$, where z_t represents the productivity level, assuming that the growth of productivity level is affected by the disaster event. $z_{t+1}/z_t = e^{\mu+\varepsilon_{z,t+1}+x_{t+1}ln(1-\Delta)}$, where μ is exogenous technological trend, and $\varepsilon_{z,t+1}$ i.i.d. normally distributed innovations with zero mean. x_{t+1} is an indicator variable used to describe the occurrence of disasters. Specifically, the probability of $x_{t+1}=1$ is θ_t. In this case, the Δ part of the present capital stock will be destroyed, otherwise $x_{t+1}=0$. The probability of disaster θ_t is incredibly small (steady-state is 0.009), but changes with time, following the first-order autoregressive process:

$$\log\theta_t = (1-\rho_\theta)\log\overline{\theta} + \rho_\theta \log\theta_{t-1} + \sigma_\theta \varepsilon_{\theta_t} \tag{2}$$

In that, $\overline{\theta}$ represents the average of the probability of disaster occurrence, ρ_θ represents the persistent part of the probability of disaster occurrence, and the random variable ε_{θ_t} obeys the process of independent identical distribution. Therefore, Equation (1) can be rewritten as:

$$U_t = \left[\frac{C_t}{z_t} (1-L_t)^{\varpi} \right]^{1-\psi} + \beta(\theta) e^{(1-\psi)\mu} \left[E_t e^{(1-\gamma)\varepsilon_{z,t+1}} U_{t+1}^{1-\chi} \right]^{\frac{1}{1-\chi}} \tag{3}$$

In Equation (3), $\chi \equiv 1-(1-\gamma)/(1-\psi)$, $\beta(\theta)$ is the adjusted discount factor, which attends to a function of the probability θ of disaster occurrence (Gourio, 2012), through this time-varying discount factor to capture the dynamic impact of changes in the probability of catastrophe on macroeconomic output and asset prices. The change of disaster risk means that the preference of the agent has changed, similar to the standard preference shock in Smets and Wouters (2003) or the uncertainty shock in Basu and Bundick (2017), as shown in Equation. (4).

$$\beta(\theta) = \beta_0 \left[1 - \theta_t \left(1 - e^{(1-\gamma)ln(1-\Delta)} \right) \right]^{\frac{1}{1-\chi}} \tag{4}$$

The budget constraint of the household can be expressed as shown in Equation. (5),

$$C_t + \frac{D_t}{p_t} = \frac{W_t}{p_t} L_t + \frac{D_{t-1}R_{t-1}}{p_t} + \Pi_t \tag{5}$$

where D_t represents the savings of the household in each period, R_t is the unit return rate of savings, p_t is the price level, W_t is the nominal wage level of the household, and Π_t represents the monopoly profit obtained from the firm in each period. The household maximizes its utility by choosing current consumption, labor supply, and savings in the subsequent period.

2.2. Banks

According to the description of Gertler and Kiyotaki (2015), bankers mainly provide loans for firm by absorbing deposits from the household and accumulated net assets. To a certain extent, banks may face friction in the financial market and their ability to obtain deposits from household may be restricted. They will try to avoid financing constraints by accumulating wealth to achieve 100% equity financing. To limit bankers' unrestricted accumulation of wealth, the model allows bankers and workers to flow. Each period has a ratio of $1-\sigma$ bankers become workers. After exiting, bankers transfer the accumulated wealth to the family and become workers in the next stage. For the bank, capital flow constraints mean the value of loans Q_tS_t within a certain period must be equal to the sum of bank's net assets N_t and deposits D_t obtained from the household, where Q_t is the price of capital.

$$Q_tS_t = N_t + D_t \tag{6}$$

The accumulation formula of bank's net assets, that is, the difference between the total income of bank's assets and the cost of borrowing, is shown in Equation (7):

$$N_t = \left[\frac{p_t^K}{p_t} + (1-\delta)Q_t\right]S_{t-1}e^{x_t ln(1-\Delta)} - R_{t-1}D_{t-1} \tag{7}$$

where p_t^K represents the nominal capital income per unit obtained by the bank lending funds to the firm, and δ represents the physical depreciation rate of capital. Since bankers only consume net assets when they exit, when bankers exit, the present value of the bank's future combined net assets can be expressed as:

$$V_t = E_t\Lambda_{t,t+1}\left[(1-\sigma)N_{t+1} + \sigma V_{t+1}\right] \tag{8}$$

where, $\Lambda_{t,t+1}$ represents the random discount factor, which is determined by the ratio of the marginal consumption of the following period of the household sector to the marginal consumption of the current period. Concerning the processing method of Gertler and Kiyotaki (2015), to impose endogenous constraints on the ability of bankers to obtain funds in the deposit market, this study introduces the following simple agency problem: assuming that after the bank obtains funds, the banker may change the proportion of ω and the bank's total assets, thus, become his/her private property. If a banker transfers assets for personal gain, it will go bankrupt due to debt default. Creditors of the bank can obtain total assets in the ratio of $1-\omega$. Since its creditors recognize the bank's motives for transferring funds, they will limit the amount they lend, so that lending constraints may arise. To ensure that bankers will not transfer assets, the following incentive conditions must be met:

$$V_t \geq \omega Q_t S_t \tag{9}$$

Therefore, for the bankers, the optimization problem is to maximize the combined, total amount of assets at the time of withdrawal by selecting the number of loans S_t in each period under the constraints of Equations (6) and (7), that is,

$$\max E_t \Lambda_{t,t+1}\left[(1-\sigma)N_{t+1} + \sigma V_{t+1}\right] \tag{10}$$

2.3. Firm

2.3.1. Intermediate product manufacturers

Intermediate product producers invest capital and labor and adjust their prices to maximize their profits. Therefore, we divide the optimization problem of intermediate product manufacturers into two aspects. One is to consider the problem of minimizing cost input and the other is to consider the problem of maximizing profit after adjusting prices.

Intermediate product producers minimize the production cost in each period by selecting the optimal number of production factors. The production function of the intermediate product producer satisfies the Cobb Douglas form. $Y_{j,t}$ is the number of j intermediate product, the given nominal wage price is W_t, the unit nominal cost of capital is p_t^K, and the intermediate product producer j will minimize its cost by selecting the number of workers $L_{j,t}$ and the number of capital inputs $K_{j,t}$. Therefore, the problems encountered by intermediate product manufacturers can be expressed as:

$$\min_{L_{j,t}, K_{j,t}} W_t L_{j,t} + p_t^K K_{j,t} \tag{11}$$

$$K_{j,t}^{\alpha}(z_t L_{j,t})^{1-\alpha} \geq Y_{j,t} \tag{12}$$

This model introduces sticky prices. Intermediate product producers can adjust the price of intermediate goods to maximize the present value of potential profits. According to the assumption of Calvo (1983), in each period, the producer of intermediate products will adjust the price with a fixed probability ζ, that is to say, among all the producers of intermediate products, the manufacturers of the proportion of ζ are randomly selected to adjust prices. The enterprise will discount the potential profits, and the random discount factor is $\Lambda_{t,t+s}$, that is, the problem of maximizing profits faced by intermediate commodity producers is,

$$\max_{p_{j,t}} E_t \sum_{s=0}^{\infty} \zeta^s \Lambda_{t,t+s}\left(p_{j,t} Y_{j,t} - W_t L_{j,t} - p_t^K K_{j,t}\right) \tag{13}$$

The first-order derivation can be implemented to obtain the optimal intermediate commodity price $p_{j,t}^*$. The optimal price of the j-th intermediate commodity applies to all intermediate producers, so the optimal commodity price at the overall level is

p_t^*. Consistent with $p_{j,t}^*$, that is, $p_t^* = p_{j,t}^*$, the corresponding optimal inflation rate can be expressed as:

$$1 + \pi_t^* = \frac{\nu}{\nu - 1} \frac{\Xi_{1t}}{\Xi_{2t}} (1 + \pi_t) \tag{14}$$

where, Ξ_{1t} and Ξ_{2t} are recursive auxiliary variables, which can be expressed as:

$$\Xi_{1t} = Y_t mc_t^* + \zeta E_t \left[\Lambda_{t,t+1} (1 + \pi_{t+1})^{\nu} \Xi_{1t+1} \right] \tag{15}$$

$$\Xi_{2t} = Y_t + \zeta E_t \left[\Lambda_{t,t+1} (1 + \pi_{t+1})^{\nu-1} \Xi_{2t+1} \right] \tag{16}$$

and mc_t^* represents the actual marginal production cost.

2.3.2. Final product manufacturer

The final product manufacturer obtains the final product by assembling intermediate products. The production function of the final product is expressed by Eq. (17):

$$Y_t = \left(\int_0^1 Y_{j,t}^{\frac{\nu-1}{\nu}} dj \right)^{\frac{\nu}{\nu-1}} \tag{17}$$

where Y_t is the number of final products, and ν is the elasticity of substitution between intermediate products. The profit of the final product manufacturer can be expressed as:

$$\max_{Y_{j,t}} p_t \left(\int_0^1 Y_{j,t}^{\frac{\nu-1}{\nu}} dj \right)^{\frac{\nu}{\nu-1}} - \int_0^1 p_{j,t} Y_{j,t} dj \tag{18}$$

where $p_{j,t}$ is the price of intermediate commodity j at time t. The first-order derivative of the profit of the final product manufacturer can obtain the optimal number of intermediate products selected by the final product, namely:

$$Y_{j,t} = \left(\frac{p_{j,t}}{p_t} \right)^{-\nu} Y_t \tag{19}$$

2.4. Rate setting

The central bank sets deposit interest rates based on the Taylor rule, which depends on the difference between inflation and its target and trending output and its steady-state level.

$$R_t = \rho_r R_{t-1} + (1 - \rho_r) \left[\varphi_\pi (\pi_t - \overline{\pi}) + \varphi_Y \left(\frac{Y_t}{z_t} - \frac{\overline{Y}}{\overline{z}} \right) + \overline{R} \right] \tag{20}$$

where an overbar stands for the steady-state value of a variable. Policy objectives are the gap between current inflation and its steady-state (target) value $\overline{\pi}$, on the one hand, and the gap between current output and its steady-state $\overline{Y}$ value, both adjusted by the level of productivity.

2.5. Market clearing

The capital accumulation equation of the intermediate product is shown in equation (21):

$$K_{t+1} = \left[f\left(\frac{I_t}{K_t}\right) K_t + (1-\delta) K_t \right] e^{x_{t+1} ln(1-\Delta)} \tag{21}$$

where, K_t represents capital, I_t represents investment, δ is the depreciation rate of capital, $f\left(\frac{I_t}{K_t}\right)$ represents capital adjustment cost, which can be expressed as:

$$f\left(\frac{I_t}{K_t}\right) = \frac{I_t}{K_t} - \frac{\tau}{2}\left(\frac{I_t}{K_t} - \frac{\overline{I}}{\overline{K}}\right)^2 \tag{22}$$

The total assets of the bank are used to produce the intermediate productions, therefore:

$$S_t = K_{t+1} \tag{23}$$

In the commodity market, total output is used for consumption and investment. Therefore, in equilibrium, the condition for clearing the commodity market is:

$$Y_t = C_t + I_t + f\left(\frac{I_t}{K_t}\right) \tag{24}$$

3. Empirical analysis

3.1. Parameter calibration

The theoretical model established in this study expresses no explicit solution. Thus, the paper will utilize numerical algorithms to solve the model. This section will calibrate the model parameters. Table 1 is a summary of the calibration of the model parameters.

The parameters of the model primarily include five parts. The first is to calibrate the parameters of the household. The discount factor of the household sector is 0.9925, and the corresponding annual interest rate is 3%; the intertemporal substitution elasticity of the household, that is, the EIS is 0.5, which is consistent with Isoré and Szczerbowicz (2017). Isoré and Szczerbowicz (2017) proved that when the intertemporal elasticity of substitution in the household sector is less than one, it matches the actual data; for consumers' leisure preference coefficient and risk aversion

Table 1. Baseline calibration values (quarterly).

Notation	Parameter	Estimate	Notation	Parameter	Estimate
β_0	Discount factor	0.9925	α	Capital share of production	0.45
ψ	Inverse of EIS	2	ν	Elasticity of substitution among goods	21
ϖ	Leisure preference	2.33	ζ	Calvo probability	0.75
γ	Risk aversion coefficient	3.8	μ	Trend growth of productivity	0.005
$\bar{\theta}$	Mean probability of disaster	0.009	δ	Capital depreciation rate	0.025
Δ	Size of disaster	0.22	τ	Capital adjustment cost	2
ρ_θ	Persistence of disaster risk	0.9	φ_π	Taylor rule inflation weight	1.6
σ_θ	Std. of innovations to disaster risk	0.6	φ_Y	Taylor rule output weight	0.5
σ	Bankers survival probability	0.95	ρ_r	Interest rate smoothing parameter	0.8
ω	Seizure rate	0.19	$\bar{\pi}$	Target inflation rate	0.005

Source: model established in this paper via MATLAB R2019b.

coefficient, this study is consistent with Gourio (2012), and the values are 2.33 and 3.8, respectively, which is additionally consistent with the values of most classic studies.

The second is the calibration of the coefficient of rare disaster shocks. Barro and Ursua (2008) expanded Barro's (2006) model by implementing consumption related to asset pricing models and found that since 1870, the probability of a quarterly disaster in the United States has been 0.9%, and the average disaster scale has been 22%. Although the data come from the United States, the occurrence of disaster events will have different levels of impact on the global economy. Therefore, in the parameter calibration, this model sets the average disaster probability $\bar{\theta}$ to 0.009 and the disaster scale Δ to 0.22; according to Gourio (2012), the disaster's persistent impact coefficient ρ_θ is set to 0.9; finally, according to the time series data of disaster probability estimated by Siriwardane (2015), the standard deviation σ_θ of disaster risk to is chosen to be 0.6 to make the model output fluctuation match with the actual data.

The parameters of the bank mainly involve the survival probability of bankers. The value in this paper is 0.95, which indicates that the banker's tenure is 20 years; while the wealth transfer ratio of the bank refers to the research of Gertler and Kiyotaki (2015), with a value of 0.19.

For the firm, the value of capital-output elasticity in relevant studies conducted outside China is predominantly between 0.3 and 0.4. Chinese scholars have revised the value of capital-output elasticity. For example, Zhang (2002) estimated the value to be 0.499. The value estimated by Tong (2017) is 0.43, which is typically higher than the value commonly used in literature from outside China. This study utilizes the value of 0.45 estimated by Gao et al. (2018) as the parameter value and refers to both Fernández-Villaverde et al. (2015) and Wang and Ji (2019) for setting the substitution elasticity of intermediate products to 21. The price stickiness parameter of domestic intermediate product manufacturers is frequently used as 0.75 (Wang et al., 2019). The capital depreciation coefficient refers to Kang and Gong (2014), with the value of the calculation as 2.5%. This means that the annualized depreciation rate is 10%. The growth trend of total factor productivity and the capital adjustment cost coefficient is based on the research of Isoré and Szczerbowicz (2017), corresponding to 0.5% and 2, respectively.

For the setting of the parameters of the Taylor rule, this study adopts the actual calculation of Yang et al. (2017) on Chinese data. This sets the reaction coefficient of

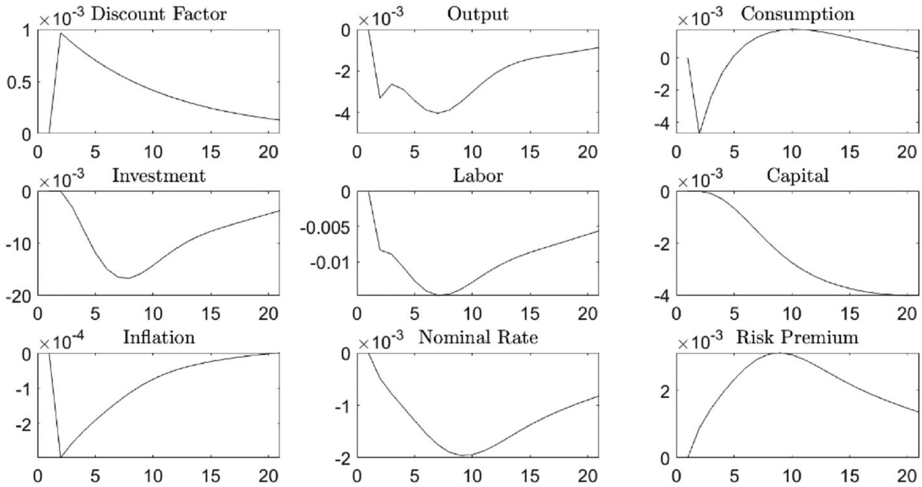

Figure 1. Response of the main variables in the benchmark model to disaster shocks.
Source: model established in this paper via MATLAB R2019b.

nominal interest rate to inflation as 1.6, the reaction coefficient of nominal interest rate to output as 0.5, and nominal interest rate of inertia is set to 0.8. This article refers to the research of Isoré and Szczerbowicz (2017) to fix the inflation rate, and the value is 0.5%.

3.2. Numerical simulation results

After solving the model in the steady-state and calibrating the parameters, the pulse response graph is obtained. Figure 1 reflects the impact of introducing a 1% disaster shock probability on the main economic variables.

The impulse results in Figure 1 show that as the risk of disasters rises, consumers will become more patient. Their propensity to save rose, consumption fell, and deflation followed. However, higher savings will not immediately turn into higher investment, thus the output will fall. There are a few possible explanations for this. On the one hand, because of price stickiness, companies cannot reduce production prices to the optimal level, so they will reduce output, thereby reducing the demand for production factors to maximize profits (or minimize their losses). On the other hand, as the enterprise's demand for production factors (labor and capital) decreases, the profits earned by households from capital accumulation will also decrease. Savings will not immediately be converted into an investment, leading to a further decline in output. For the same reason, labor demand and wages have also fallen. The research results of this study are consistent with Isoré and Szczerbowicz (2017), and different from Gourio (2012), that is, during the economic recession, the consumption level of residents is declined, consistent with the actual data.

Additionally, to analyze the impact of disaster shocks on financial intermediaries, this study introduces the financial intermediary section of Gertler and Kiyotaki (2015). Figure 2 reflects the response from the bank to disaster shocks. When the economy is impacted by rising disaster risks, consumers become more patient, the

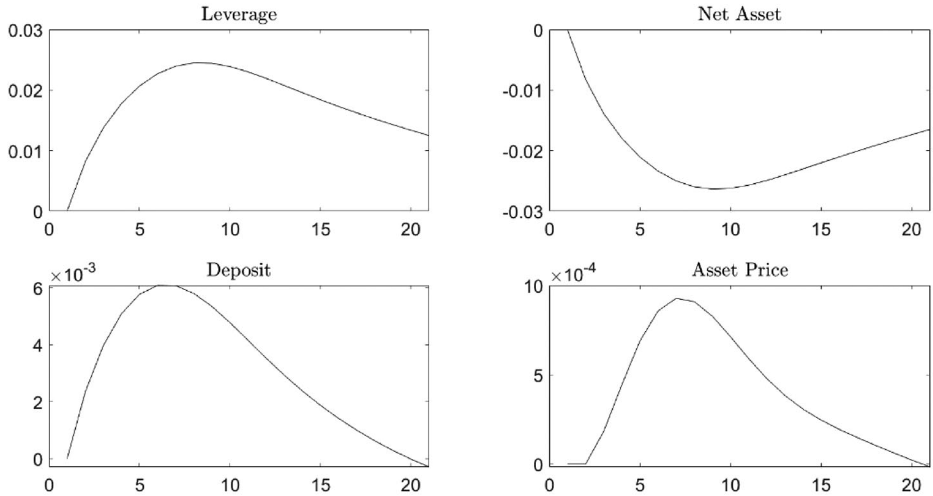

Figure 2. Response of the main variables of the banking sector to disaster shocks in the benchmark model.
Source: model established in this paper via MATLAB R2019b.

propensity to save increases, and the household deposits absorbed by bank increase. On the other hand, the occurrence of disaster events will destroy 22% of the existing capital stock. This will lead to a decline in the bank's total assets, and a consequent decline in the bank's net assets, which further causes an increase in asset prices. For bank, the decline in total capital is accompanied by the rise in deposits, producing a further increase in the leverage ratio of the bank. Excessive leverage means that the accumulated risks of bank increase.

4. Further analysis: recovery policies simulation

4.1. Supply-side policy stimulus: refinancing

The following section will analyze the economic impact of the central bank's refinancing policy (RFP) on commercial banks from the view of the supply side. Since disaster shocks will cause partial losses of existing capital stock, starting from the supply side, injecting liquidity into the market can mitigate the adverse effects of disaster shocks to a certain extent. Additionally, it is important to note that commercial banks obtain the central bank's refinancing funds injection. As commercial banks do not need to return this part of the funds in the short term, this can be regarded as the central bank injecting capital into commercial banks. After the commercial bank receives the re-loan from the central bank, its balance sheet can be expressed using Equation (25):

$$Q_t S_t = N_t + D_t + \xi Q_t S_{t-1} \tag{25}$$

where, $\xi Q_t S_{t-1}$ represents the re-loan obtained by commercial banks from the central bank. ξ is the central bank's refinancing rate, which is an exogenous parameter.

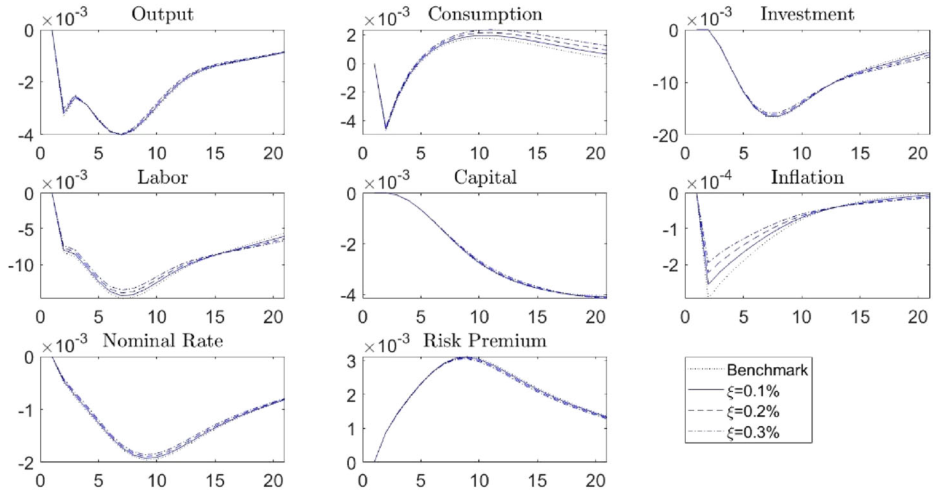

Figure 3. Response of main variables to disaster shocks under RFP.
Source: model established in this paper via MATLAB R2019b.

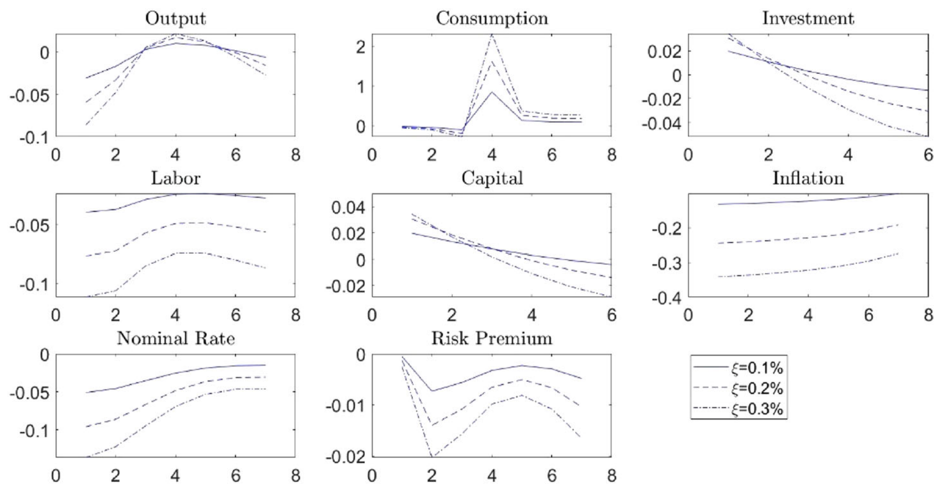

Figure 4. The rescue effect of the refinancing policy on the main macro variables.
Source: model established in this paper via MATLAB R2019b.

The larger it is determined to be, the greater the central bank's assistance to the market in the face of a disaster.

After introducing RFP, the response to the main variables of the economy under the impact of the disaster is shown in Figure 3. It can be seen that after the implementation of RFP, the fluctuation direction of macroeconomic variables has not substantially changed. However, compared with the benchmark model without the implementation of RFP, the implementation of the policy will ease the macro variables to a certain extent.

To more intuitively reflect the effect of policy implementation, this study compares the responses of various macro variables under different refinance rate on the benchmark model, and reduces the ratio by one to obtain the relative impact of RFP on major macro variables, as shown in Figure 4.

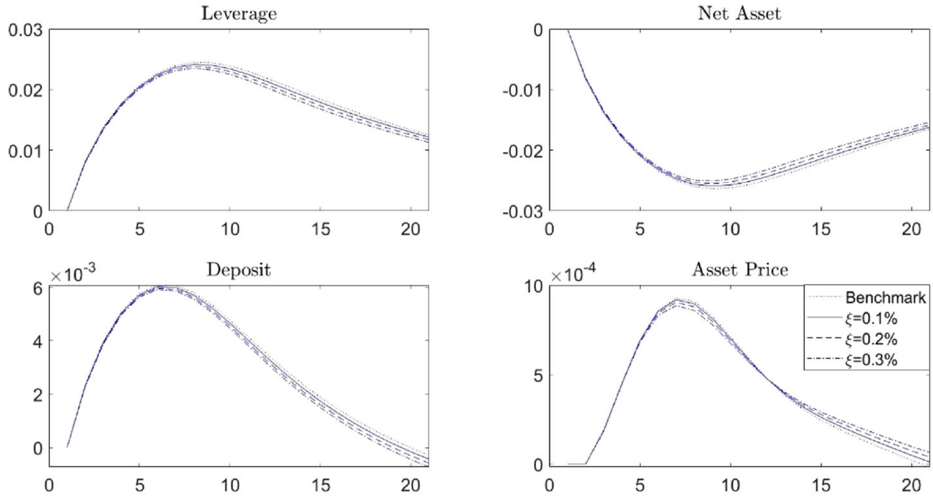

Figure 5. Response of main variables of the banking sector to disaster shocks under the refinancing policy.
Source: model established in this paper via MATLAB R2019b.

When the result is less than 0, it means that compared with the benchmark model, the implementation of the policy will reduce the fluctuation of associated variables, that is, it will have a certain mitigation effect on the disaster impact; when the result is greater than 0, it means that compared with the benchmark model, the policy's implementation will amplify the impact of disaster shocks on macroeconomic variables. Based on this, output volatility has been significantly alleviated relative to the benchmark model, and as the intensity of refinancing increases, the alleviation has been further strengthened. There will be no drastic changes in consumption in the short term, while investment and capital stock will continually decline in the short term due to the lag effect, but soon as the intensity of refinancing increases, the investment level will rise further. Under the RFP, labor supply increased, deflation eased, nominal interest rates rose and risk premiums fell, and the economy began to recover, and this degree of improvement increased as the central bank's assistance to the market during disasters increased.

Figure 5 shows the response of the bank to disaster shocks after introduces RFP. It is seen that in the short term, there is no significant difference in the implementation effects of different levels of RFP.

According to the previous treatment method, the primary variables of the bank were compared with the benchmark model, and the effect of RFP on the primary variables of the bank was obtained, as shown in Figure 6.

Under the RFP, the bank's net assets have risen significantly. This is because the central bank's refinancing has injected additional capital into commercial banks, leading to a rise in the bank's net assets in a short period. As shown in Figure 4, the RFP will help the economy develop, while the consumption level of residents will increase to a certain extent. Therefore, savings will fall, and asset prices will rise in a short time. This will further lead to a decline in the level of leverage in the bank.

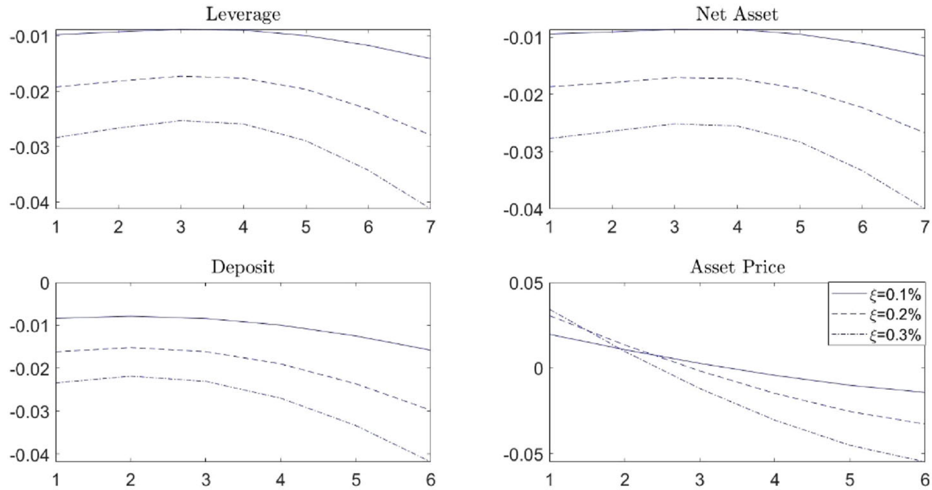

Figure 6. The rescue effect of RFP on the main variables of the banking sector.
Source: model established in this paper via MATLAB R2019b.

4.2. Demand-side policy stimulus: consumption coupons

Consumption remain a crucial force for economic growth and promoting consumption has become an important measure to stabilize the economy when disasters occur. Unlike the measures taken by developed countries to issue cash, local governments in China have begun to issue consumer vouchers one after another from March 2020. According to statistics from the Ministry of Commerce, as of May 8, 2020, China has 170 prefecture-level cities that have issued more than 19 billion yuan in consumer vouchers. This is the first large-scale issue of consumer vouchers in Chinese history to respond to economic shocks. A large number of studies have found that consumer vouchers can result in additional consumption (Senauer & Young, 1986; Wilde et al., 2009). Among them, Hanson (2010) estimate that the GDP growth driven by food stamps is 1.7 to 1.8 times the amount distributed, making this the most effective policy among all of the government's economic stimulus plans.

At present, academics seldom portray consumer coupon policies (CCP) in models. This study attempts to simulate the impacts of government and corporate consumer coupons on the economy in the form of consumer price discounts. For example, when the discount is 10%, it means that the coupons are 'full 100 minus 10', and when the discount is 20%, it means the coupons are 'full 100 minus 20', and so on. After the introduction of the CCP, the budget constraints of the household were expressed as:

$$(1-\lambda)C_t + \frac{D_t}{p_t} = \frac{W_t}{p_t}L_t + \frac{D_{t-1}R_{t-1}}{p_t} + \Pi_t \tag{26}$$

where λ represents the discount strength of consumer coupons. After the introduction of the CCP, the response of the economy's main variables under the disaster impact is shown in Figure 7. Similarly, after the government or merchants implemented the CCP, the fluctuation direction of macroeconomic variables did not

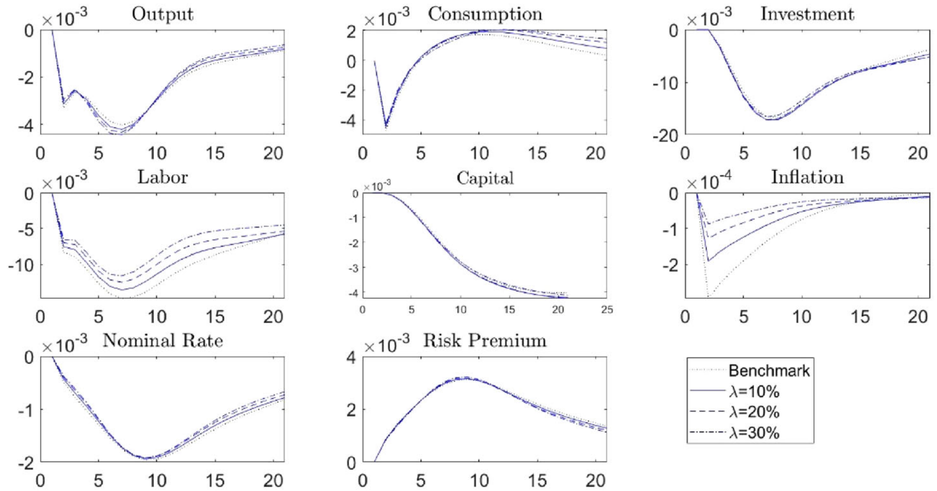

Figure 7. Response of main variables to disaster shocks under CCP.
Source: model established in this paper via MATLAB R2019b.

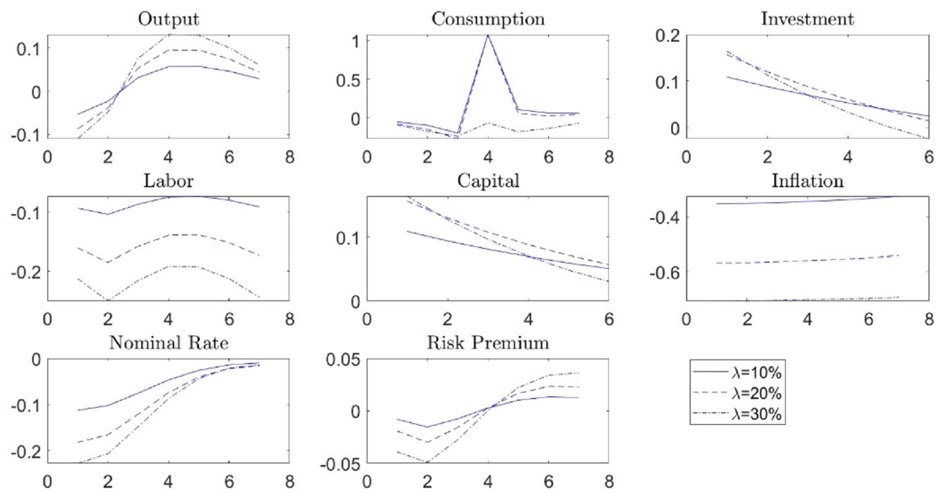

Figure 8. The rescue effect of CCP on major macro variables.
Source: model established in this paper via MATLAB R2019b.

substantially change. However, compared with the benchmark model that did not implement the consumer voucher policy, the implementation of the policy did ease the macro variables to a certain extent.

Comparing the variable responses under different consumer coupon strengths with the benchmark model, It is found that the CCP can reduce economic fluctuations to a certain extent. From the rescue effect of the CCP on the primary macro variables in Figure 8, CCP can improve the consumption level of consumers to a certain extent. This is because the CCP, as a demand-side stimulus, often limits the scope of use and requires a certain amount of consumption to be used. This means that the residents who have received consumer coupon will specifically place them into a specific mental account (Thaler, 1980), and actively consume to a certain amount to take

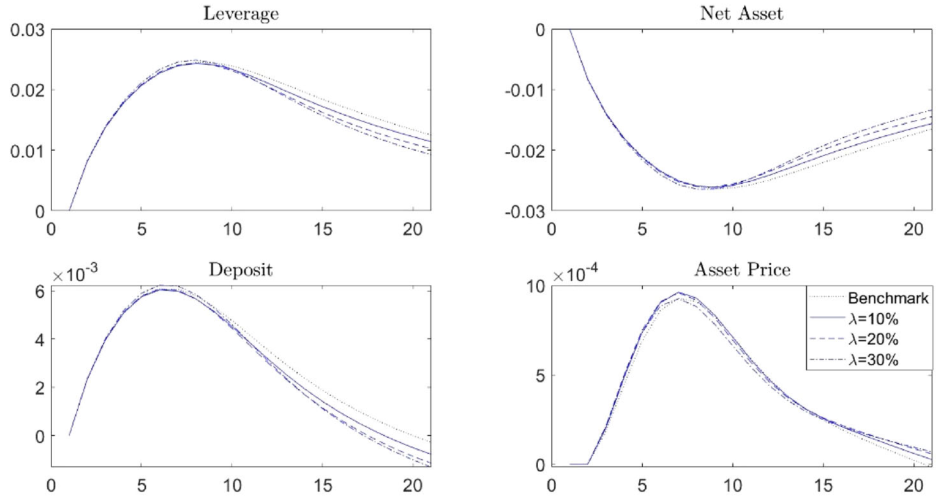

Figure 9. Response of the main variables of the banking sector to disaster shocks under CCP.
Source: model established in this paper via MATLAB R2019b.

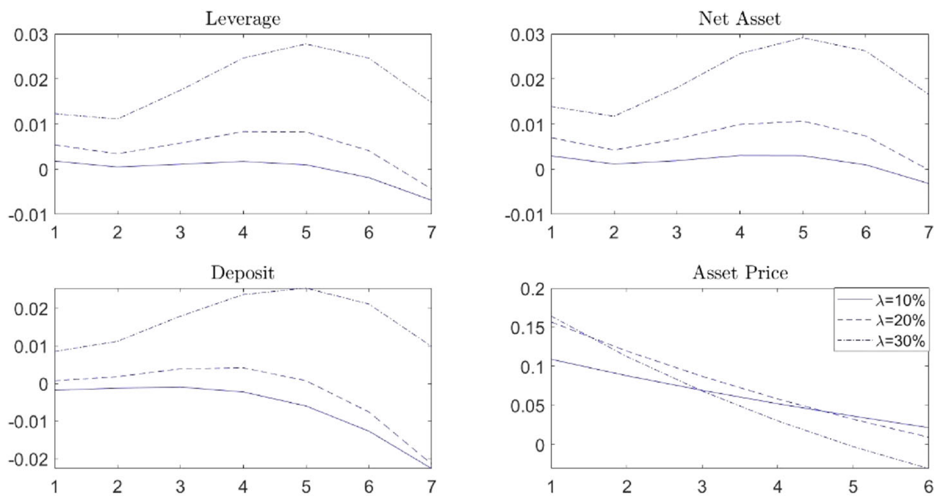

Figure 10. The rescue effect of CCP on the main variables of the banking sector.
Source: model established in this paper via MATLAB R2019b.

advantage of the financial gain consumer vouchers offer. By stimulating consumption, consumers' propensity to save can be reduced, and funds can be converted into reinvestment through consumption, thereby alleviating the declining trend in output. Consumers' increased demand for final products and relatively insufficient supply has produced an increase in the price of final products, which has further alleviated the deflation situation. At the same time, the nominal interest rate level has risen, the risk premium level has further eased, and thus the economy will move toward recovery.

Figure 9 depicts the response of the main variables of the bank to disaster shocks under CCP. The main variables of the bank are compared with the benchmark model, and the influence of CCP on the main variables of the banking sector is obtained, as shown in Figure 10.

Figure 10 explains that under CCP, the leverage ratio of the bank has increased. This is because the disaster impact has led to a decline in the capital stock and the bank's net assets. On the other hand, the CCP is a kind of demand-side stimulation that can stimulate consumers' desire for consumption through price discounts.

Consumers increase the level of utility by converting savings into consumption when the discount is small, so the bank's deposits are reduced. However, when the discount is large, to satisfy consumer desires, the household will increase income (such as increasing labor hours, bond investment, etc.) to consume the final product, so consumption and savings will increase simultaneously. For bank, if savings rise and net assets fall, the leverage ratio of the banking sector will rise, and asset prices will rise further due to the increase in demand for capital.

4.3. Policies comparison: welfare loss analysis

To evaluate the effect of policy implementation, this study measures the social welfare under different policy stimuli. The measurement methods of social welfare primarily include two categories: one is the welfare loss function, which is mainly derived from the variance of output and inflation, such as in Woodford (2003) and Gali (2008); the other is the compensation variation. Consumption is typically selected as the metric, that is, Consumption Equivalent Variation, such as in Schmitt-Grohé and Uribe (2007). This study mainly considers the average welfare loss per period (AWLPP) based on Mei and Gong (2011), Ma (2011), Zhang (2009), Gali and Monacelli (2005), namely:

$$\Gamma = \frac{1}{2}\left(\lambda_1 var(\pi_t) + \lambda_2 var(y_t)\right) \tag{27}$$

where, Γ represents AWLPP of society under different policy levels, $var(\pi_t)$ and $var(y_t)$ are the variances of the inflation gap and output gap, respectively, and λ_1 and λ_2 represent the inflation gap and output, respective to the weight of the gap. λ_1 and λ_2 can be expressed as functions of model structure parameters (Gali, 2008):

$$\lambda_1 = \frac{\nu\zeta(1-\alpha+\alpha\nu)}{(1-\zeta)\left(1-\beta(\theta)\zeta\right)(1-\alpha)} \tag{28}$$

$$\lambda_2 = \gamma + \frac{1/\varpi + \alpha}{1-\alpha} \tag{29}$$

In Equations 28 and 29, ν represents the elasticity of substitution among commodities, ζ represents the price stickiness parameter, $1-\alpha$ is the labor output share, $\beta(\theta)$ is the adjusted discount factor of the household, γ is the risk aversion coefficient, and ϖ represents the household's leisure preference parameters. The values of all parameters are consistent with Table 1. Table 2 shows the average welfare loss of the economy under different policy stimuli.

Table 2. Average welfare loss per period under different policies (%).

Policy	Parameter Value		Average Welfare Loss	Relative Welfare Loss
Benchmark	$\lambda = 0$,	$\xi = 0$	0.0228	–
RFP	$\lambda = 0$,	$\xi = 0.1\%$	0.0232	1.7544
	$\lambda = 0$,	$\xi = 0.2\%$	0.0236	3.5088
	$\lambda = 0$,	$\xi = 0.3\%$	0.0240	5.2632
CCP	$\lambda = 10\%$,	$\xi = 0$	0.0225	−1.3158
	$\lambda = 20\%$,	$\xi = 0$	0.0222	−2.6316
	$\lambda = 30\%$,	$\xi = 0$	0.0220	−3.5088

Source: model established in this paper via MATLAB R2019b.

It can be noted from Table 2 that the RFP will reduce AWLPP, and as the central bank's refinancing rate increases, the average welfare loss will increase; and the implementation of the CCP will help improve the AWLPP. To further compare the effects of different intensity policies, the last column of Table 2 shows the relative magnitude of AWLPP (RAWLPP) between the implementation of various policies and the benchmark model. When the central bank's re-lending rate level is 0.1%, the RAWLPP will increase by 1.75% compared to before the implementation of the policy. When the central bank's refinancing rate level rises to 0.3%, the RAWLPP will reach 5.26%; On the other hand, when the stimulus ratio of CCP is 10%, the RAWLPP is 1.32% lower than that before the implementation of the policy, that is, the RAWLPP has increased by 1.32%, and when the stimulus ratio of consumer vouchers is 30%, the RAWLPP increases to 3.51%. Therefore, policies that stimulate the consumer's desire to stimulate the economy have an important effect on reducing social welfare losses.

5. Conclusion

The paper introduces financial intermediation into the New Keynesian model with rare disasters, analyzes the impacts of rare disaster shock on the macroeconomic and compares the effects of different economic recovery policies. The numerical analysis of benchmark model shows that, on the one hand, with the increase in disaster risk, consumers' propensity to save increases and consumption decreases, but higher savings will not instantly turn into higher investment. Therefore, total social output declines, which is similar to the conclusions of Isoré and Szczerbowicz (2017). On the other hand, under the impact of disaster risk, the decline in total capital is accompanied by the increase in deposits, causing a further increase in the leverage ratio of the bank and aggravating the accumulation of risks in the bank.

Subsequently, this study further analyzes the rescue effect of RFP and CCP. RFP and CCP can alleviate economic fluctuations caused by disaster risks from different channels. The RFP is an economic stimulus policy given by the supply side. This policy mainly injects liquidity into the bank and enters the real economy through the bank's loans and investment channels, thereby promoting economic development. Under the RFP, the primary channel for economic recovery is the increase in the net assets of the bank. This then leads to an increase in investment received by the real sector. In turn, this leads to an increase in output. The increase in output further leads to the alleviation of deflation, the rise in nominal interest rates, and the decline in the level of risk premiums. The stimulus of CCP from the demand side mainly stimulates the consumer's desire to stimulate the economy. From the perspective of transmission channels, the CCP increases the consumption level of consumers, reduces the consumer's propensity to save, and converts funds through consumption into reinvestment. Thus, it alleviates the downward trend in output. The increase in output will, in turn, ease the pressure of deflation, while the rise in nominal interest rates and the fall in the level of risk premiums reflect the reduction in market uncertainty and further promote economic recovery. Welfare loss analysis finds that the RFP will reduce AWLPP, while the implementation of the CCP will help improve the AWLPP.

With the deepening of economic, political, and cultural ties among countries around the world, community with a shared future for mankind is constantly taking shape. Disasters in a country will not only cause huge losses to the country but also have a more serious and far-reaching impact on all countries in the world. Therefore, building a sustainable long-term mechanism for stimulating economic growth, fundamentally mitigating the impact of catastrophic events on the macroeconomy, and achieving economic recovery in a short period are important issues that all countries need to resolve. However, in reality, the response to disaster shocks is often the simultaneous implementation of multiple policies. Whether the interaction between different policies plays a role in economic recovery is not analyzed in this study. There is scope for further analysis on the interaction between different policies to evaluate the effect of multiple policies on economic stimulus.

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