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Monetary Policy Design with Recurrent Climate Shocks

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Monetary Policy Design with Recurrent Climate Shocks*

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ABSTRACT: As climate change intensifies, the frequency and severity of climate-induced disasters are expected to escalate. We develop a New Keynesian Dynamic Stochastic General Equilibrium model to analyze the impact of these events on monetary policy. Our model conceptualizes these disasters as left-tail productivity shocks with a quantified likelihood, leading to a skewed distribution of outcomes. This creates a significant trade-off for central banks, balancing increased inflation risks against reduced output. Our results suggest modifying the Taylor rule to give equal weight to responses to both inflation and output growth, indicating a gradual approach to climate-exacerbated economic fluctuations.

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WORKING PAPERS

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Contents

List of Figures

List of Tables

1. Introduction

Central banks face an evolving challenge: determining the optimal response to climate-induced shocks. Traditional views on monetary policy have largely focused on reactive stances towards supply-side events. This paper presents a different and more forward-thinking perspective, examining the possibility of incorporating climate-induced disaster-risk considerations into policy rule formulation. This perspective moves beyond the conventional debate over whether to respond proactively to supply-side shocks or look through them. Instead, it proposes that central banks should integrate the likelihood of high-impact disasters into their standard policy-setting mechanisms. This approach is predicated on the idea that climate change shocks are not only immediate and reactive challenges but also predictable in a probabilistic sense over a longer time horizon. Integrating potential disaster scenarios into the central banks' policy rule formulation would allow for a more robust monetary policy.

Bridging this perspective to a concrete analysis, this paper expands the existing literature on monetary policy by factoring in climate-induced shocks. Drawing from Barro (2006)[1], we characterize these events as left-tail shocks that have a considerable adverse effect on productivity.[2] We propose a monetary policy framework that not only accommodates regular productivity fluctuations but also considers the possibility of significant disruptions. With a probability of p, a significant fall in productivity is anticipated. Our model

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[1] Climate events like major hurricanes and catastrophic floods fit within the 'rare disasters' framework suggested by Rietz (1988) and Barro (2006). Barro quantifies these disasters' likelihood and impact, noting an annual 1.7 percent chance of occurrence with associated output declines between 15 percent and 64 percent, averaging 29 percent. This framework has been adapted for examining the impacts of such disasters on risk premiums (Andreasen (2012)), business cycles (Nakamura et al. (2013)), and foreign exchange markets (Farhi and Gabaix (2016)).

[2] Bolton et al. (2020) note the tail characteristic of climate-induced shocks and, inspired by the concept of The Black Swan, they refer to them as The Green Swan.

is sufficiently general to account for a range of scenarios with different shock sizes and frequencies. Within this framework, we examine how these disruptions might recalibrate existing monetary policy paradigms.

With this objective in mind, we employ a model that is shown to reasonably match the key aggregate data and can handle such occasional large shocks. Specifically, we use a non-linear formulation of the standard New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model, as outlined in works like Christiano et al. (2005) and Smets and Wouters (2007). The model incorporates both nominal and real rigidities, with price and wage stickiness. Additionally, we assume that wages are indexed to past inflation. Real rigidities arise from the assumptions of monopolistic competition in both labor and product markets, as well as investment adjustment costs. A key feature of our analysis is the assumption that both monetary and fiscal policies are set according to Taylor-style policy rules. We consider Taylor rules in which the nominal interest rate reacts to changes in inflation and the growth rate of output, instead of the output gap, because measuring potential output, which is necessary for calculating the output gap, is a daunting task. Due to their effects on productivity, and consequently on capital and labor, climate-induced shocks may further complicate the measurement of potential output. This is critical for policy implementation, as Orphanides (2003) argues that mismeasurement of the output gap contributed to the excessive inflation of the 1970s in the US. When the probability of a disaster shock is zero, the model simplifies to that of Smets and Wouters (2007).

Due to the left-tail nature of the shock, the shock introduces non-linearities to the model that need to be accounted for and there may be large deviations from the steady state. Therefore, we move beyond the usual first-order approximations and instead employ higher-order approximations to accurately capture the effects of such shocks in the economy.

We proceed with the analysis in three steps: First, we consider the implications of rare disasters within the current policy setting using the standard

Taylor rule. Second, we search for a Taylor rule that minimizes the effects of climate-induced disasters on the welfare of households. Third, we assess the viability and potential impact of increasing the inflation target from 2 percent to 4 percent. Finally, we examine the effects of these considerations on fiscal policy, specifically focusing on the debt-to-GDP ratio.

Our analysis yields several key findings. First, climate-induced shocks present a policy trade-off for the central bank between its two primary objectives: maintaining price stability and output stability, with a newfound emphasis on the role of skewness. While shocks increase skewness in inflation, the skewness of output becomes more negative. Skewness, in this context, refers to the asymmetric distribution of potential economic outcomes following climate-induced events. Specifically, it represents a higher probability of observing extreme negative deviations from targets. This finding builds upon the insight introduced by John Taylor (1993) regarding the trade-off between inflation and output in terms of volatility. Taylor also introduced what became known as Taylor curves, which graphically represent the trade-off between inflation and output volatility. We apply this concept to skewness. Using Taylor-inspired skewness curves, we show the range of choices central banks face in achieving a balance between stable inflation and output. This illustrates that prioritizing one objective can come at the expense of the other.

Second, a policy prioritizing the stabilization of both inflation and output effectively mitigates the adverse impacts of shocks on household welfare. This stabilization of output subsequently helps in maintaining a stable debt-to-GDP ratio. Finally, while a higher inflation target can ease the policy trade-off facing the central bank, it is not the optimal choice as it results in diminished household welfare.

A key to understanding these results is that climate-induced shocks change the distribution of outcomes, making tail events more likely by fattening the tail. Such shocks increase the skewness in inflation and make output skewness more negative. This is due to the fact that climate-induced shocks can heavily impact productivity, potentially leading to major declines in capital and output. The skewed distribution also suggests that there could be significant rises in inflation due to the changes these disasters bring to cost structures. Therefore, when faced with such climate-induced disturbances, central banks face a complex trade-off between the goal of inflation stabilization and the need to support output. In the benchmark scenario without climate shocks, skewness is not a concern and the central bank can formulate its policy along traditional lines without special consideration for the asymmetry of economic outcomes.

To understand our second finding that the policy should aim to stabilize both inflation and output, note that the climate-induced shock triggers a significant drop in productivity and, consequently, potential output. With output being demand-driven, a positive output gap will emerge, leading to an increase in inflation. Monetary policy reacts to changes in the growth rate of output, which depends on lagged output, thereby introducing inertia into monetary policy. This gradual approach to closing the output gap results in a sustained period of above-target inflation. However, this inertia in monetary policy helps in mitigating the skewness of welfare distribution, as it avoids sudden policy changes, smoothing the impact of shocks on household welfare.

Considering these findings, next, we examine the proposal to increase the inflation target from 2 percent to 4 percent to evaluate its potential impact on the policy trade-off and household welfare in the presence of disasters.[3] We find that a higher inflation target indeed helps to ease the policy trade-off we identified. However, this policy comes at the cost of lower household welfare. This is because higher inflation introduces costs to the economy, primarily in

[3]Blanchard et al. (2010) and Ball (2014) argue that the inflation targets of central banks should be raised to around 4% to tackle the zero lower bound on interest rates. This argument is based on the idea higher inflation targets would provide more room for interest rate cuts in response to future recessions.

two ways. First, price mark-ups increase because firms - prices being sticky - would set higher mark-ups to compensate for higher inflation. Second, given prices on average are sticky, larger price adjustments of resetting firms mean price dispersion is greater. Both of these factors contribute to lower output.[4] A reduction in output increases the debt-to-GDP ratio. On the other hand, the Taylor rule that places greater weight on output stabilization helps to stablize the debt-to-GDP ratio.

While our analysis has focused on the short-run implications, it is important to acknowledge the potential long-run impacts of climate-induced shocks on output and monetary policy. As Woodford (2003) shows, equilibrium determinacy in New Keynesian models is tightly connected to the slope of the long-run Phillips curve. Considering the long-run consequences of rare disasters reported by Nakamura et al. (2013), such events may lead to lower output. Their study, using consumption data from 24 countries over more than a hundred years, indicates that rare disasters can reduce consumption by 15 percent. Assuming all else remains equal, this could imply a flatter, or even negative, Phillips curve slope. In New Keynesian models, achieving equilibrium determinacy requires that the nominal interest rate increase more than inflation in the long run. Therefore, the diminished output would necessitate a stronger response to inflation to preserve equilibrium determinacy.

Our paper is closely related to the findings reported in Gali (2008) and Schmitt-Grohe and Uribe (2007b), both of which conclude that a strict inflation-targeting policy is optimal. A key distinction between these studies and ours is that we incorporate climate-induced shocks into our analysis. In

[4] Ascari and Sbordone (2014) explore these dynamics within the standard new Keynesian framework, while Kara and Yates (2021), extending Kara (2015), find these effects more pronounced in multi-sector models, leading to a significant output decline and a reduction on the region monetary policy is determinate when the inflation target increases, providing arguments against higher inflation targets. Taylor (2016) reviews multi-sector new Keynesian models.

fact, when we set the probability of disaster (p) to zero, our model simplifies to the one presented in Schmitt-Grohe and Uribe (2007b). The difference in results shows that accounting for climate-induced shocks significantly alters their conclusions. With only technology shocks, our proposed policy closely mirrors the outcome under the strict inflation-targeting policy because it mimics the optimal commitment policy. However, when climate-induced shocks are included, our proposed policy outperforms the strict inflation-targeting approach in reducing the skewness introduced by such shocks.

One might raise concerns about our reliance on a single reference model in our analysis. It is worth noting that while Levin and Williams (2003) did not specifically account for rare shocks, they explored the robustness of simple rules across various models, including an empirical VAR model, using Bayesian and minimax strategies. Their findings, even in a different context, are consistent with ours: a robust monetary policy is mainly achievable when the objective function prioritises the stabilization of both output and inflation. The consistency between their results and ours, even when considering different kinds of shocks, further strengthens our conclusion.

In our quest to study the interactions between climate-induced shocks and monetary policy, a notable study is the paper by Cantelmo et al. (2022). Our approach differs from theirs by considering such shocks as left-tail events affecting productivity, which the central bank then integrates into its framework when formulating its monetary policy strategy. Indeed, setting the probability of disaster (p) to zero in our model reduces to the model in Cantelmo et al. (2022). These authors view disasters as substantial, negative shocks that have immediate and profound effects on the capital stock. They make a case for a flexible inflation-targeting regime in times of disasters, whereas our findings suggest the importance of output stabilization through a Taylor rule approach in an economy facing the prospect of repeated climate-induced shocks.[5]

The rest of the paper is organized as follows: Section 2 outlines the model. Section 3 presents and discusses the results, with a particular emphasis on identifying a policy trade-off arising from rare disasters and illustrating it through Taylor-inspired skewness curves. This section also explores various approaches to address this trade-off and how rare disasters affect the long-run Phillips curve and the stability of the economy. Section 4 discusses the implications of monetary policy on fiscal policy, with a specific focus on the debt-to-GDP ratio. Section 5 reports and discusses the results of several robustness exercises. Section 6 concludes the paper.

2. The Model

The model is the standard new Keynesian model, as in Christiano et al. (2005) and Smets and Wouters (2007). A key difference between these studies and ours is that productivity (A_t) is subjected to rare disaster shocks that can occur with a probability p. Specifically, the probability follows the following stochastic process.

$$a_t = \rho_a a_{t-1} + \epsilon_{at} \tag{1}$$

where $a_t = \ln A_t$ and ϵ_a is given by

$$\epsilon_{at} = \begin{cases} N(0,1) & \text{with probability } 1-p \\ \phi & \text{with probability } p \end{cases} \tag{2}$$

Negative values of ϕ indicate innovations in the left tail of a distribution, indicating occurrences of rare disasters. We also added ϵ_{at} directly to the capital stock equation. However, doing so does not affect the results and

[5]We choose the Taylor rule approach to provide a consistent and predictable framework. This choice aims to reduce policy unpredictability and maintain stability, counterbalancing the additional uncertainty climate-induced shocks introduce to the economy.

therefore we omitted it. Given the left-tail nature of the shock, we solve the model by taking a third-order approximation of the model using Dynare.[6]

The rest of our assumption is standard new Keynesian. There are four agents in the economy: households, firms, the government and the central bank. Output is divided between consumption, investment and government spending. In the remainder of this section, we will outline the essential components of the model. We will first discuss the behaviour of households, then firms and finally, the government.

2.1. Households

We assume the economy consists of identical households indexed $h \in [0, 1]$. Household preferences are defined over consumption and labor. The expected lifetime utility function takes the following form:

$$E_t \sum_{t=1}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\eta}}{1+\eta} \right) \tag{3}$$

where β denotes the discount factor, C_t denotes consumption, N_t denotes hours worked, σ is the intertemporal elasticity of substitution in consumption and η is the inverse of Frisch elasticity of labor supply.

The intertemporal budget constraint is given by

$$P_t C_t + I_t + \sum_{s_{t+1}} Q\left(s_{t+1}|s_t\right) B\left(s^{t+1}\right) \leq B_t + R^k K_t + W_t N_t + \Pi_t + T_t \tag{4}$$

Where $B_{s^{t+1}}$ is a one-period nominal bond that costs $Q\left(s_{t+1}|s_t\right)$ at state s^t and pays off one dollar in the next period if s^{t+1} is realised. B_t is the value of household's existing claims given the realised state of nature. P_t is the general price level, I_t is investment in capital, K_t is the capital stock, R_k the

[6]For a comprehensive comparison of various solution methods in computing the equilibrium of DSGE models with rare disasters, see Fernández-Villaverde and Levintal (2018).

rental rate of capital, W_t is the wage rate, T_t is the lump-sum tax paid by household, and Π_t denotes the profit that households obtain from the firms.

The household is assumed to own physical capital, K_t. The capital stock grows according to the following equation

$$K_{t+1} = (1-\delta)K_t + \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) i_t \tag{5}$$

where I_t denotes investment and δ is the depreciation rate. S represents investment adjustment costs and exhibits the standard properties: $S = S^{'} = S^{''} = 0$ and $S^{''} > 0$. Following Christiano et al. (2005), it is assumed to have the following functional form:

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \tag{6}$$

S follows a quadratic form and varies with the square of the growth rate of investment.

The first-order conditions of the household optimization problem are

$$\lambda_t = C_t^{-\sigma} \tag{7}$$

$$Q\left(s_{t+1}|s_t\right) = \frac{1}{R_t} \tag{8}$$

$$\lambda_t = \beta E_t[\lambda_{t+1}\frac{R_t^k}{\pi_{t+1}}] \tag{9}$$

$$\begin{aligned} 1 = q_t &\left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right) \\ &+ \beta q_{t+1}\frac{\lambda_{t+1}}{\lambda_t}\kappa\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{i_t}\right)^2 \end{aligned} \tag{10}$$

$$q_t = \beta\frac{\lambda_{t+1}}{\lambda_t}\left((1-\delta)q_{t+1} + R_{t+1}^k\right) \tag{11}$$

Where λ_t is the Lagrangian multiplier.

2.2. Wage Setting

Households supply differentiated labor input N_h. Different labor inputs are combined into a composite labor input by a union. The aggregation labor input is done according to the following equation:

$$N_t = \left(\int_0^1 N_{ht}^{\frac{\theta_w - 1}{\theta_w}} \, dh \right)^{\frac{\theta_w}{\theta_w - 1}} \tag{12}$$

where θ_w is the elasticity of substitution between different labor inputs. The demand for type h labor input is given by

$$N_t(h) = \left(\frac{W_{ht}}{W_t} \right)^{-\theta_w} N_t \tag{13}$$

The demand for type j labor input depends on her own wage (W_{ht}), aggregate wage (W_t) and aggregate labor demand. Consequently, the aggregate wage rate is

$$W_t = \left(\int_0^1 W_{ht}^{1-\theta_w} \, dh \right)^{\frac{1}{1-\theta_w}} \tag{14}$$

Households set their wages according to the Calvo process. In each period, only a fraction of $1 - \gamma_w$ of households can adjust their nominal wages. Households will update to an identical reset wage (W_t^*). We express wages in terms of their real value: $w_t^* = \frac{W_t^*}{P_t}$ is the real reset wage and $w_t = \frac{W_t}{P_t}$ is the real wage. Therefore, the real reset wage can be expressed as:

$$\left(w_t^*\right)^{1+\theta_w \eta} = \frac{\theta_w}{\theta_w - 1} \frac{f_t^1}{f_t^2} \tag{15}$$

where f_t^1 and f_t^2 are auxiliary variables and are expressed as follows:

$$f_t^1 = (w_t)^{\theta_w (1+\eta)} N_t^{1+\theta_w} + \beta \gamma_w E_t \left(\frac{\pi_{t+1}}{\pi_t} \right)^{\theta_w - 1} (w_{t+1})^{\theta_w - 1} f_{t+1}^1 \tag{16}$$

$$f_t^2 = (w_t)^{\theta_w} \lambda_t N_t + \beta\theta_w E_t \left(\frac{\pi_{t+1}}{\pi_t}\right)^{\theta_w(1+\eta)} (w_{t+1})^{\theta_w(1+\eta)} f_{t+1}^2 \tag{17}$$

The average (real) wage is given by

$$w_t^{1-\theta_w} = \gamma_w w_{t-1}^{1-\theta_w} \left(\frac{\pi_{t-1}}{\pi_t}\right)^{1-\theta_w} + (1-\gamma_w)(w_t^*)^{1-\theta_w} \tag{18}$$

The presence of π_{t-1} in this equation captures the influence of wage indexation on the aggregate wage level.

2.2.1. Firms

There is a continuum of firms, indexed by i. Firms have monopoly power over a specific good and produce differentiated goods. Firms operate a technology that transforms labor into output subject to productivity shocks:

$$Y_{it} = A_t N_{it}^{1-\alpha} K_{it}^{\alpha} \tag{19}$$

The differentiated goods are then combined to produce the final consumption good according to the standard Dixit-Stiglitz production function.

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}} \tag{20}$$

where ϵ is the elasticity of substitution between different intermediate goods. The corresponding price index is

$$P_t = \left(\int_0^1 P_{it}^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}} \tag{21}$$

Where P_t is the general price level. With these assumptions, the demand for firm i's output is given by

$$Y_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\epsilon} Y_t \tag{22}$$

The marginal cost is given by

$$mc_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} \frac{w_t^{1-\alpha}\left(R_t^k\right)^{\alpha}}{A_t} \tag{23}$$

We assume that prices are sticky and are set according to the Calvo process. The equations for price setting are given by The reset price P_t^* is given by

$$x_{1t} = \lambda_t mc_t y_t + \beta\gamma_p \pi_{t+1}^{\theta_p} x_{1t+1} \tag{24}$$

$$x_{2t} = \lambda \bar{p}^* y_t + \beta\gamma_p \pi_{t+1}^{\theta_p - 1} \left(\frac{\bar{p}_t^*}{\bar{p}_{t+1}^*}\right) x_{2t+1} \tag{25}$$

$$(\theta_p - 1)x_{2t} = \theta_p x_{1t} \tag{26}$$

where x_{1t} and x_{2t} are auxiliary variables. $1-\gamma_p$ is the hazard rate. The price index evolves according to the following equation.

$$1 = (1-\gamma_p)\bar{p}_t^{*1-\theta_p} + \gamma_p \pi_t^{\theta_p - 1} \tag{27}$$

Price dispersion is given by

$$s_t = (1-\gamma_p)\left(\frac{1}{\bar{p}_t^*}\right)^{-\theta_p} + \gamma_p \pi_t^{\theta_p} s_{t-1} \tag{28}$$

where s_t denotes price dispersion.

Using Equations (19) and (22) and aggregating, aggregate output can be expressed as

$$Y_t = \frac{A_t N_t^{1-\alpha} K_t^{\alpha}}{s_t} \tag{29}$$

Aggregate output depends on price dispersion and is reduced by the presence of it. In this sense, as suggested by Damjanovic and Nolan (2010), price dispersion can be thought of as a negative productivity shock.

2.3. The Government

The government spends g_t in each period. This expenditure is financed by taxes and borrowing. The government's budget evolves according to the following equation

$$b_t = b_{t-1}\frac{R_{t-1}}{\pi_{t-1}} + g_t - T_t \tag{30}$$

where b_t denotes the real value of the government debt. To set taxes, the government follows the following rule:

$$\frac{T_t}{y_t} = \tau^* + \gamma_1\left(\frac{b_{t-1}}{y_{t-1}} - b^*\right) + \gamma_1\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b_{t-2}}{y_{t-2}}\right) \tag{31}$$

where τ^* denotes the steady state value the tax ratio, b^* is the fiscal target and γ - coefficients are the parameters on the targeting variables. Fiscal policy aims to stablize a certain target (b^*) of the debt ratio $(\frac{b_t}{y_t})$ by changing the tax rate τ_t.

2.4. The Central Bank

The interest rate is set according to the Taylor style rule and is given by (in logs)

$$r_t - r = \phi_\pi(\pi_t - \pi) + \phi_y(y_t - y_{t-1}) \tag{32}$$

where for a generic variable X_t, $x_t = \ln(X_t)$. The nominal interest rate responds to inflation and the growth of output. ϕ_π and ϕ_y are the coefficients in front of the targeting variables. Variables with a time subscript denote the steady-state values.

2.5. The steady-state of the model

We now outline the steady-state relationships in our model.

$$\bar{p}^* = \left(1 - \gamma_p \pi^{\theta_p - 1}\right)^{\frac{1}{1-\theta_p}} \tag{33}$$

$$s = (1 - \gamma_p)\left(\frac{1}{\pi^*}\right)^{\theta_p} \tag{34}$$

$$mc = \frac{\theta_p - 1}{\theta_p}\bar{p}^*\left(1 - \beta\gamma_p\pi^{\theta_p}\right) / \left(\theta_p\left(1 - \beta\gamma_p\pi^{\theta_p - 1}\right)\right) \tag{35}$$

$$w = (1 - \alpha)\left(mc\left(\frac{\alpha}{R}\right)^{\alpha}\right)^{\frac{1}{1-\alpha}} \tag{36}$$

$$n = \left(\frac{\theta_n}{\theta_n - 1}\right)^{\frac{-1}{\eta+\sigma}}\left\{(1 - \frac{g}{y})\left(\frac{1}{s}\right)\left(\frac{\alpha R(1-\alpha)}{R(1-\alpha)}\right)^{\alpha} w^{\alpha - \frac{1}{\sigma}}\right. \tag{37}$$

$$\left. - \delta\left(\frac{\alpha R(1-\alpha)}{R(1-\alpha)}\right) w^{\frac{1}{\sigma} - 1}\right\}^{-\frac{\sigma}{\eta+\sigma}} w^{\alpha - 1/\sigma} - \delta\left(\frac{\alpha R(1-\alpha)}{\alpha}\right) w^{1 - 1/\sigma} \tag{38}$$

$$k = \frac{\alpha}{1-\alpha}\left(\frac{w}{R}\right) n \tag{39}$$

$$i = \delta k \tag{40}$$

$$y = k^{\alpha} n^{1-\alpha} / s \tag{41}$$

$$y = c + g + i \tag{42}$$

$$T = G + \left(\frac{R}{\pi} - 1\right) b \tag{43}$$

$$\tag{44}$$

where variables without a time subscript represents the steady-state values of the respective variables.

2.6. Choice of Parameters

We calibrate the model at quarterly frequency using values common in the business cycle literature. The values are listed in Table 3.

Table 1: Calibration

Structural parameters		
β	0.994	Discount factor
σ	1	Risk aversion
$\frac{1}{\eta}$	0.5	Frisch elasticity
ϵ_p	0.6	Calvo probability (Price)
ϵ_w	0.75	Calvo probability (Wage)
θ_p	10	Elasticity of subs. (goods)
θ_w	10	Elasticity of subs. (labor)
δ	0.0025	Depreciation rate
$\frac{b}{y}$	0.7	the steady-state debt-to-GDP ratio
g_y	0.0025	the share of government in the economy
Policy parameters		
ϕ_π	1.5	Inflation response coefficient
ϕ_y	0.5	Output response coefficient
γ_1	0.04	Fiscal rule coefficient on debt
γ_2	0.3	Tax smoothing parameter
g_y	0.2	Steady-state share of government spending
b_y	0.4	Steady-state share of bonds
Shock parameters		
ρ_a	0.9	Persistence of the productivity shock
$std(\epsilon_{at})$	0.0075	Standard deviation of the shock
p	0.0045	the probability of a disaster occurring (quarterly)
ϕ	-38.67	Given a disaster, parameterised by ϕ, productivity drop by 29%

We set the discount factor β to 0.994. The relative risk aversion parameter σ is assumed to be 1. Both elasticities of substitution ϵ_p and ϵ_w are set to 10. The Frisch elasticity of labor supply $\frac{1}{\eta}$ is set to 0.5. The share of capital (α) is assumed to be 21 percent. The depreciation rate, δ, is specified at 0.0025. The Calvo price stickiness θ is 0.6, implying a hazard rate of 0.4. The Calvo wage stickiness θ is 0.75. For the monetary policy rule, the values chosen for the Taylor rule parameters are as follows: $\phi_\pi = 1.5$, $\phi_y = 0.5$, Finally, for the fiscal feedback rule, following Mitchell et al. (2000), we assume $\gamma_1 = 0.04$ and $\gamma_2 = 0.3$.

The persistence of the productivity shock is assumed to be 0.9, and the standard deviation is 0.0075. These are common assumptions in the RBC literature. For disasters, we calibrate ϕ to be -38.67, so that disasters induce a 29 percent decline in productivity, as in Barro(2006). In Barro's model, this represents a yearly fall. However, in our model, with a persistence parameter of 0.9, the shock is less persistent than in Barro's case. Our assumption is consistent with the findings of Nakamura et al. (2013), who found that the economic aftermath of disasters lingers for about six years, on average. We will later discuss the potential implications of varying assumptions regarding shock persistence for our conclusions. Finally, we set the disaster frequency at $p = 0.45$ percent for each quarter.

3. Results

In this section, we examine the impact of rare disasters on key model variables. We begin by presenting the means and standard deviations of these variables in the presence of rare disasters. The results are presented in Table 2.

Our simulation results reveal an interesting pattern where the mean values of most variables remain stable despite varying degrees of negative skewness. Table 2 shows that there is an increase in the skewness of inflation to 4.6, while the skewness of output decreases to -4.14. An increase in inflation

Table 2: Summary of Moments

Variable	**Mean**	**Std. Dev.**	**Skewness**
		a. Standard	
Inflation	1.00	0.01	-0.08
Output	2.15	0.04	0.04
labor	0.94	0.00	0.51
Wages	1.62	0.01	0.09
Marginal cost	0.90	0.01	0.41
Capital	47.57	0.21	-0.17
Rental Rate	0.01	0.00	0.38
Productivity	1.00	0.01	-0.03
Welfare	35.90	0.17	-0.17
		b. Disaster	
Inflation	1.00	0.00	4.63
Output	2.14	0.03	-4.14
labor	0.94	0.00	9.22
Wages	1.62	0.01	-3.34
Marginal cost	0.90	0.01	7.54
Capital	47.47	0.23	-0.90
Rental Rate	0.01	0.00	-0.29
Productivity	1.00	0.01	-5.13
Welfare	35.81	0.19	-1.81

Note:This table presents a summary of moments for different scenarios, including the standard case (a) and a case with a rare disaster (b). “Mean” represents the mean value, “Std. Dev.” represents the standard deviation, and “Skewness“ represents the skewness of the respective variables.

skewness to 4.6 and a decrease in output skewness to -4.14 indicate significant shifts in the distribution of these variables. A closer inspection of the table reveals that the increase in inflation skewness is attributed to a substantial rise in the skewness of marginal costs. Specifically, the skewness of marginal costs escalates from approximately zero to 7.54. This upturn originates from a significant decrease in the skewness of productivity. Rare disasters directly impact productivity, resulting in a decline to -5.13. Furthermore, it becomes evident that the shock leads to a significant reduction in factor inputs. Specifically, the skewness of wages diminishes to -3.34. In comparison, the decrease in the skewness of the real rate of capital is relatively smaller at -0.90. Another important result from the table is the considerable increase in the skewness of labor supply, rising to 7.54. This surge seems to be driven by the shock's negative wealth effect, prompting households to position themselves to work more as a countermeasure against the shock's impact on welfare. Indeed, when comparing the magnitude of changes in the skewness of output, inflation, and labor supply, the reduction in welfare remains relatively modest. The welfare skewness decreases to -1.81, showing that increasing labor supply helps reduce the economic impact of rare disasters on welfare.[7]

The finding that the mean values of most variables remain stable, while skewness varies significantly is puzzling. One would expect that increased

[7] To illustrate the distinction between average outcomes and the shape of their distribution in a simple way, we appeal to the following simple exam. Consider two distinct monthly weather scenarios in the same city, both with a mean temperature of $21°C$ and a standard deviation of approximately $5°C$. In the first scenario, temperatures are distributed in a manner resembling a normal distribution. Here, temperatures fluctuate symmetrically around the mean. The second scenario offers a different experience. While most days are similar to the first scenario and are pleasantly warm, but there are a few rare and sudden cold days in the mix. While the average and variability across both scenarios remain consistent, living through each would be a different experience. Relying solely on the mean and standard deviation might mislead one into believing that a jacket is not needed all month. Yet, the pronounced skewness in the second scenario indicates the potential for unexpected cold surprises.

negative skewness, indicative of a higher propensity for adverse outcomes, would translate to a noticeable decline in the mean. However, this does not happen. This result is important and emphasizes the need to consider the distributional characteristics beyond the mean when evaluating economic implications of climate-induced shocks.

This result can be attributed to the nature of the economic shocks within our model. We assume a shock to the left side of the distribution. This event is more extreme than the typical fluctuations and tends to have a disproportionately large impact on productivity and has the potential to induce substantial disruptions of a negative nature within the broader economy. However, the shocks, while inducing a negative skew, does not have long-lasting effects of output.

Indeed, we find that the persistence of shocks plays an important role in affecting the mean output. As we extend the duration over which shocks exert influence within the model—transitioning from transient to nearly permanent—the mean output exhibits a more pronounced decline. This pattern is visually represented in Figure 1, which plots the persistence of shocks against the annualized fall in output. The figure highlights a clear positive correlation, elucidating how longer-lasting shocks have the potential to significantly depress the mean output level. In our benchmark calibration, we assume that the persistence parameter in the shock process to be 0.9. The annualized output less, relative to the no disaster scenario, is almost 2 percent. if we increase the persistence to 0.98, the loss increases to 7 percent.

3.1. The Policy Trade-Off Imposed by Rare Disasters

These numbers suggest a significant change in the skewness of the distribution. Importantly, rare disasters move the two objectives of the central bank in opposite directions: price stability and output stability, creating a trade-off between the two objectives. In this section, we will discuss this trade-off in more detail. We will start by showing how the increased frequency of disasters affects this trade-off.

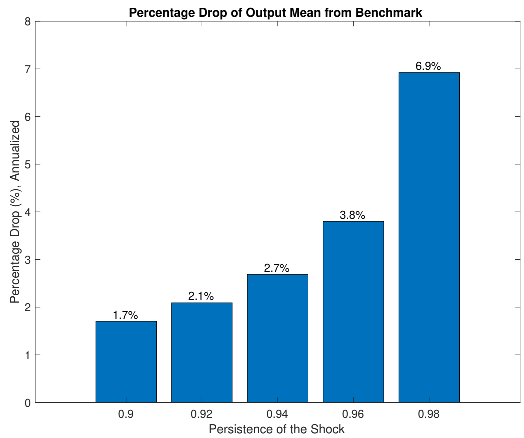

Figure 1: Percentage Drop of Output (Mean) from the No Disaster Case

Note: This figure illustrates the effects of climate shocks on mean output, with the numbers presented on an annualized basis.

We start from the absence of disasters and incrementally raise the probability of a disaster until it reaches the benchmark value of 1.7 percent and in each case, we compute the skewness of output and inflation. In each case, we maintain the shock size the same as in the benchmark case. In Figure 2 report the results from this experiment.

In Figure 2 plots the skewness of output and inflation against the frequency of disasters. As the figure highlights, an increase in the frequency of disasters leads to a more negative skewness in output, while also causing a significant increase in the skewness of inflation. This figure further substantiates the previously identified policy trade-off facing the central bank. If the central bank attempts to counteract the shock's impact on output by adjusting the nominal interest rate, such a policy would increase inflation. The greater the likelihood of a disaster, the more challenging the policy trade-off becomes.

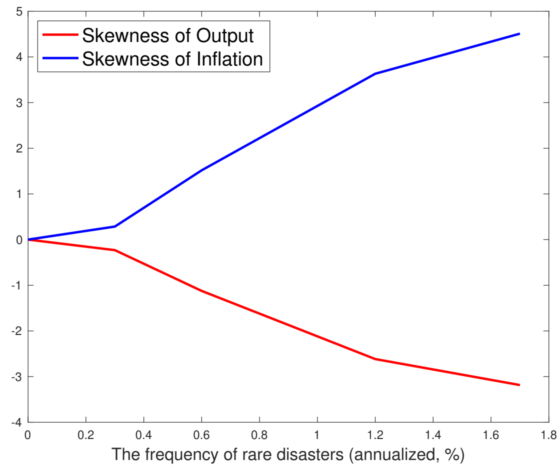

Figure 2: Skewness of Output and Inflation as the Frequency of Rare Disasters Increases
Note: This figure presents the skewness of output and inflation plotted against the frequency of rare disasters. When the frequency is zero, we have the standard case with no disasters. The case with 1.7 percent is the frequency suggested by Barro (2006). As shown, an increase in disaster frequency results in a more negative skewness in output and a significant increase in inflation skewness. This figure shows the policy trade-off faced by the central bank.

In Figure 3, we show the trade-off using Taylor-inspired skewness curves. To construct this figure, we vary the output coefficient within the Taylor rule. For each value of the coefficient, we calculate and plot the resulting skewness values for both inflation and output.

What is the intuition behind this finding? To understand this result, we consider the marginal cost equation, which is repeated here for convenience:

$$mc_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} \frac{w_t^{1-\alpha} \left(R_t^k\right)^{\alpha}}{A_t} \tag{45}$$

Due to the impact of disaster shocks on productivity, there is a significant drop in output at the time of these shocks. These shocks also affect marginal costs, thereby increasing costs and leading to higher inflation. Consequently, these shocks cause inflation and output to move in opposite directions, creating a trade-off.

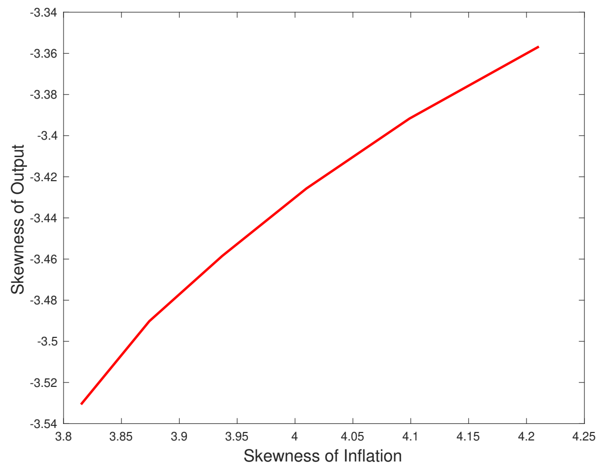

Figure 3: The Taylor-inspired Skewness Curve

Note: This figure illustrates how changes in the central bank's response to output fluctuations impact the skewness of both inflation and output. The curve is generated by varying the output coefficient within the Taylor rule. To compute the curve, we vary the coefficient on output in the Taylor rule from 0.5 to 1.1.

Figure 3 effectively illustrates the trade-off between aiming for stable inflation and stable output in terms of skewness. Opting to reduce skewness in output by prioritizing output stabilization comes at the cost of introducing higher skewness in inflation. Conversely, striving for lower inflation skewness entails the trade-off of yielding more pronounced negative output skewness. This highlights the balance central banks must strike while navigating the complexities of monetary policy, a challenge further reinforced by the increased importance of climate-induced disasters.

As the central bank adjusts the interest rate to keep output as close as possible to its mean, this policy causes an increase in the skewness of marginal costs, leading to higher skewness in inflation. Therefore, the central bank's adjustment of the interest rate to bring output closer to its mean causes more pronounced spikes in inflation.

3.2. Navigating the Policy Trade-Off Imposed by Climate-Induced Disasters

These findings raise a question: How should the central bank navigate the identified trade-off? To provide insights, we turn our focus to the impact of monetary policy on household welfare. Our objective is to identify a policy that minimizes welfare skewness in the presence of rare disasters. To explore this, we vary the coefficient on output within the Taylor rule.[8] The results of this experiment are presented in Figure 4, with the x-axis representing the output coefficient and the y-axis showing welfare skewness. We define welfare as follows:

$$Welfare_t = E_t \sum_{t=1}^{\infty} \beta^t U_t \tag{46}$$

$$= U_t + \beta E_t Welfare_{t+1} \tag{47}$$

$$\tag{48}$$

Welfare depends on current and expected utility during the life-time at time t. Utility (U_t) at time t is defined at Equation (3). As with the other variables, the welfare measure we reported in the paper is the one implied by the third-order approximation of the model.

As Figure 4 illustrates, increasing the emphasis on output stabilization is effective in reducing the impact of rare disasters on household welfare, up to a certain threshold. This threshold is reached at a coefficient of output equal to 1.1. Beyond this point, welfare skewness begins to exhibit a more negative trend, indicating an optimal output coefficient from the perspective of households. An important finding is that strict-inflation policy is not effective in dealing with the consequences of climate-induced shocks.

As noted earlier, the reason for this result is that this policy introduces

[8] In additional tests, we investigate variations in the inflation coefficient and find that our main conclusions do not change much. We will discuss these tests in detail in Section 5.

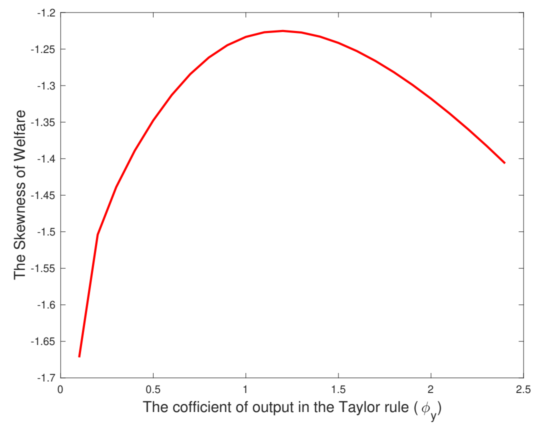

Figure 4: Welfare Skewness as Output stabilization Priority Varies

Note: This figure displays the relationship between the coefficient on output in the Taylor rule (ϕ_y) (x-axis) and the skewness of household welfare (y-axis). The Taylor we assume is $r_t - r = \phi_\pi(\pi_t - \pi) + \phi_y(y_t - y_{t-1})$, where we assume $\phi_\pi = 1.5$. Variations in the inflation coefficient do not significantly change our main conclusions (see Section 5.2).

inertia in policy-making. Climate-induced shocks reduce productivity and potential output, creating a positive output gap and rising inflation. Monetary policy, by responding to the growth rate of output influenced by lagged output, introduces inertia. This gradual approach, while leading to a period of above-target inflation, mitigates welfare distribution skewness by avoiding abrupt policy shifts and smoothing the shocks' impact on household welfare.

3.3. Increasing the inflation target

So far in our analysis, we have explored potential solutions through adjustments in the Taylor rule. Now, let's consider a more significant change in the monetary policy landscape. One such change involves increasing the inflation target from 2 percent to 4 percent.[9] The idea here is simple: if

[9] Studies like that of Etienne Gagnon (2009) in the context of Mexico highlight that in relatively low inflation environments (below 10%-15%), the correlation between the frequency of price adjustment and inflation is weak. Gagnon suggests that increases in the frequency of price adjustment offset the decreases in the frequency. Even if we as-

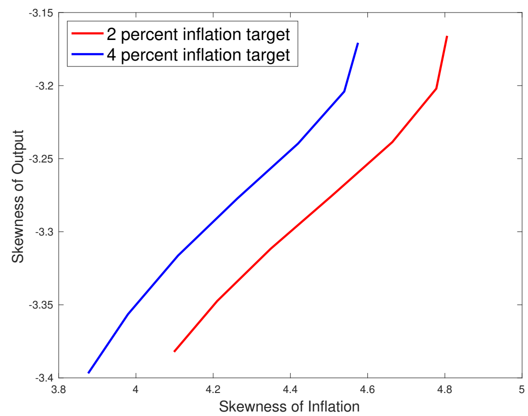

Figure 5: Taylor inspired Skewness Curves: 2 percent inflation target vs. 4 percent inflation target

Note: This figure examines the impact of raising the inflation target from 2 percent to 4 percent on the central bank's policy trade-off during rare disasters. The higher inflation target reduces the cost of stabilizing output, but the improvement is limited compared to the 2 percent target.

inflation often deviates from the target due to rare disasters, it might be beneficial to set a higher target. With a higher inflation target, the inflation gap becomes smaller, meaning that smaller adjustments in output are needed to stablize it. Consequently, this reduces the central bank's necessity to change interest rates frequently.

In Figure 5, we show the policy trade-off due to rare disasters with the 4 percent inflation target. For comparison, we also include the policy frontier for the case with the 2 percent inflation target, as shown in Figure 3.

Indeed, as shown in Figure 5, raising the inflation target proves helpful in addressing the policy trade-off facing the central bank. In scenarios with a higher inflation target, achieving indeterminacy becomes more challenging.

sume that the increases in the frequency dominate, it is hard to imagine that all prices adjust immediately. What matters in models is the average price stickiness. Furthermore, our experiments, where prices became more flexible as we increased the inflation target, demonstrated that our key findings remained unchanged.

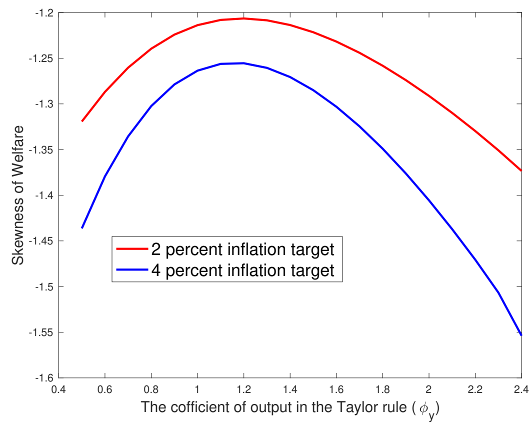

Figure 6: Welfare Skewness as Output stabilization Priority Varies: 2 percent inflation target vs. 4 percent inflation target

Note: This figure compares the welfare implications of a 4 percent inflation target versus a 2 percent inflation target. While the 4 percent target reduces the cost of output stabilization, it results in a more negatively skewed welfare measure. This is due to firms setting higher price mark-ups and increased price dispersion, reducing long-run output. This highlights the trade-off between the benefits and costs of choosing a higher inflation target.

Consequently, the results are reported for a more limited range of values for ϕ_y. With a higher inflation target, the policy frontier shifts towards the left. This means that the cost of stabilizing output is reduced compared to the case with the 2 percent inflation target. However, it's worth noting that the figure also demonstrates that the extent of improvement is somewhat limited.

It's essential to examine the welfare implications of choosing a higher inflation target. Opting for a higher inflation target has the potential to introduce distortions into the economy, possibly resulting in adverse effects on overall welfare and economic stability. Taking this concern into account, in Figure 6, we compare the skewness of welfare with a 4 percent inflation target and a 2 percent inflation target. Once again, the x-axis corresponds to the coefficient on output, while the y-axis portrays the skewness of welfare.

The key finding we have consistently observed remains valid: the Taylor rule with the 1.2 coefficient on output minimizes the skewness of welfare.

However, the figure clarifies a drawback of pursuing a higher inflation target. It's evident from the figure that opting for a higher inflation target leads to a more negatively skewed welfare measure. This implies that adopting a higher inflation target might result in a lasting reduction of overall welfare.

This result is driven by two reasons. First, firms tend to make more substantial price adjustments than usual. This arises from the fact that, given that the price set will be valid for some time, firms choose higher prices to protect their prices throughout that span. Larger price adjustments mean higher price mark-ups. Second, since resetting firms makes larger price adjustments, a higher inflation target leads to larger price dispersion. The combined effect of higher price markups and price dispersion causes a fall in potential output.

Taken together, although opting for a higher inflation target does come with benefits, the presence of associated costs makes it a less straightforward choice.

3.4. Implementation of Monetary Policy during the Era of Rare Disasters

From the perspective of a central bank, we've discussed the necessary adjustments in interest rates to address the impact of rare disasters. Our findings emphasise the need for interest rates to prioritise output more. This does not downplay the importance of inflation stabilization. Indeed, Woodford(2003) suggests that achieving a unique equilibrium in new Keynesian models requires that the nominal interest rate increase more than the inflation rate in the long-run. This emphasis on the long run naturally makes the long-term consequences of rare disasters more relevant. In this section, we'll explore how rare disasters affect the Woodford principle and the conditions for equilibrium determinacy in the models.

To understand how rare disasters interact with these dynamics, it's instructive to examine the Taylor rule in the long-run. The rule in the long-run can be expressed as:

$$r = \phi_\pi \pi + \phi_y y \tag{49}$$

The proposition that the nominal interest rate should increase more than the increase in inflation in the long-run can be formally expressed as

$$\frac{\partial r}{\partial \pi} = \phi_\pi + \phi_y \frac{\partial y}{\partial \pi} > 1 \tag{50}$$

The modified Taylor principle dictates that $\frac{\partial r}{\partial \pi} > 1$. From this, the equilibrium determinacy condition emerges as[10]

$$\phi_\pi > 1 - \phi_y \frac{\partial y}{\partial \pi} \tag{51}$$

A key implication of this equation is that the inflation response is tied to the slope of the long-run Phillips curve. The term $\phi_y \frac{\partial y}{\partial \pi}$ emphasizes the importance of the slope of the long-run Phillips curve when setting interest rates. Any change in this slope, potentially due to rare disasters, carries significant implications for monetary policy and how the central bank should adjust its policy rate.

What happens when rare disasters come into play? Research by Nakamura et al. (2013) shows that disasters can reduce the long-run output. This finding is consistent with our results showing that negatively skewed output leads to a decline in output, and the extent of this decline is greater with increasing shock persistence. The cumulative effects of the shock would therefore be larger. Assuming that inflation is on target in the long run, for

[10] Technically, if one expresses the equilibrium dynamics implied by the standard New Keynesian model by means of a system of difference equations and solves for its roots, one can demonstrate that the unique equilibrium necessitates satisfying the following condition: $\kappa(\phi_\pi - 1) + (1-\beta)\phi_y > 0$, where κ is the coefficient of output in the Phillips curve. It follows from this expression that for maintaining determinacy, the inflation coefficient, ϕ_π, must exceed the threshold of $1 - \phi_y(1-\beta)/\kappa$, with $(1-\beta)/\kappa$ defining the slope of the long-run Phillips curve. The intuitive generalization of this mathematical condition leads to what is referred to as the generalized Taylor principle, which we apply when deriving the same condition. The generalized Taylor principle dictates that the equilibrium determinacy depends on the nominal interest rate's cumulative response to inflation. Woodford (2003, Chapter 4) provides an in-depth discussion on this topic.

a given value of ϕ_y, rare disasters lead to a fall in the term $\phi_y \frac{\partial y}{\partial \pi}$, thereby necessitating an amplified inflationary response — reflected in a larger ϕ_π.

After a disaster, central banks first see a big drop in output. They will want to help by focusing on stabilizing output, so they might increase ϕ_y. However, when setting the interest rate, they also need to consider the long-run implications of disasters. With the long-run output lower, the bank faces a new challenge. They might need to focus on output right after the disaster. However, at the same time, they need to ensure that ϕ_π increases sufficiently to maintain equilibrium determinacy.

4. Optimal Monetary Policy and Debt to GDP Ratio in the Presence of Climate-Induced Disasters

Up until this point, our main focus has been on analysing the monetary policy implications of rare disasters, with a particular emphasis on identifying the most effective monetary policy strategy. However, an equally important aspect involves assessing the consequences of implementing this policy, particularly in terms of its impact on public finances, specifically on the debt-to-GDP ratio. Given the adverse impact of rare disasters on output, there is potential for such disasters to distort public finances, increasing the debt-to-GDP. We find that a Taylor rule that puts greater emphasis on stabilizing output is optimal from the perspective of society. Intuitively, a policy that helps to stablize output would naturally contribute to stabilizing the debt-GDP ratio. To examine this proposition, Figure 7 presents the debt-to-GDP ratio under varying coefficients on output in the Taylor rule in the presence of rare disasters.

We begin by examining the debt-to-GDP ratio using the standard Taylor rule, where ϕ_y is set to 0.5. As Figure 7 illustrates, when the central bank places greater emphasis on stabilizing economic output, the asymmetry in the debt-to-GDP ratio significantly diminishes. Within a 2 percent inflation target, with a coefficient on output of $\phi_y = 1.2$, the ratio's skewness reduces

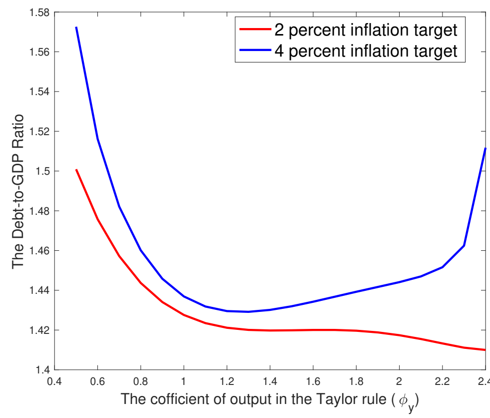

Figure 7: Skewness of the Debt-to-GDP ratio as Output stabilization Priority Varies: 2 percent inflation target vs. 4 percent inflation target

Note: This figure presents the skewness of the debt-to-GDP ratio across different output coefficients (ϕ_y) and inflation targets. The minimum skewness occurs at a ϕ_y value of 1.2, indicating improved debt-to-GDP stability through output stabilization. However, adopting a higher inflation target can negatively impact skewness.

to 1.42. This finding shows the direct link between output stability and the stabilization of the debt-to-GDP ratio.

However, a closer analysis of the figures reveals a more nuanced pattern. Beyond the threshold of $\phi_y = 1.2$, the diminishing returns in skewness reduction become increasingly evident, highlighting the limitations of fine-tuning monetary policy to address the consequences of rare disasters.

Similar conclusions hold for the case with a 4 percent inflation target: prioritizing output stabilization remains beneficial. Nonetheless, when the coefficient on output exceeds $\phi_y = 1.2$, the skewness of the ratio worsens. These findings echo earlier results indicating that a higher inflation target can negatively impact output. While a higher inflation target can serve as a policy lever, it simultaneously introduces adverse effects on output, causing an increase in the debt-to-GDP ratio

5. Robustness

We now consider how variations in key parameters affect our results. We begin by examining the role of shock persistence.

5.1. The role of shocks

In our benchmark case, we set the persistence parameter of the shock process to 0.9. We consider two alternative values: 0.8 and 0.95. Results are reported in Table 4.

Persistence of the shock	0.8	0.9 (benchmark)	0.95
Optimal coefficient on output in Taylor rule	1.5	1.2	1.1
Reduction in skewness	16%	9%	4%

Table 3: Optimal Coefficient on Output (ϕ_y) Across Shock Persistence.

Note: The table illustrates the optimal coefficient on output (ϕ_y) to minimize shock effects on household welfare and the corresponding reduction in skewness when the coefficient on inflation is set to $\phi_\pi = 1.5$. The table indicates that regardless of shock persistence variations, the main conclusion remains unchanged: a balanced focus on both output and inflation is crucial. Note also that a more persistent shock results in a slightly lower Taylor rule coefficient, with benefits from output stabilization being more pronounced for less persistent shocks.

The table shows the value of the coefficient on output (ϕ_y) that minimizes the effects of the shocks on household welfare. In the benchmark case with 0.9, the optimal value of ϕ_y is 1.2. This value reduces the skewness of welfare by 9 percent. Results reported in the table suggest that alternative assumptions regarding shock persistence do not change our main conclusion: that monetary policy should aim to stablize both output and inflation. It appears from the table that a higher persistence generally corresponds to a lower coefficient in the Taylor rule. The value implied by the more persistent case is not too different from the benchmark case (1.2 vs. 1.1). There is a slightly larger difference in the less persistent case (1.2 vs. 1.5), suggesting that there will be greater gains from output stabilization when the shock is less persistent, as the unavoidable losses are smaller. Indeed, in the case with less persistence, the reduction in skewness is larger, at 16 percent. In the benchmark case, the reduction is 9 percent. In the more persistent case, since the disaster is more disruptive, unavoidable losses are larger, and, therefore, the reduction in skewness is 4 percent. However small the gain might be, there are still gains from a policy that places equal emphasis on output and inflation stabilization.

Persistence of the shock	0.8	0.9 (benchmark)	0.95
Optimal coefficient on output in Taylor rule	1.4	1.2	1.1
Reduction in skewness	19%	11%	5%

Table 4: Optimal Coefficient on Output (ϕ_y) with Milder Disasters

Note: The table performs the same experiment as in the previous case but assumes less severe disasters. The disaster shock size is assumed to be 15 percent, rather than 29 percent in the benchmark case.

Table 4 replicates the earlier experiment but with a milder disaster. Instead of the benchmark's 29 percent fall in productivity after a fall, we assume a 15 percent fall. Our main conclusion remains robust: a policy targeting both output and inflation is optimal. The notable difference in this experiment, compared to the previous one, is that with a reduced shock size, there are greater gains from implementing an optimal policy and the reduction in skewness is greater. For example, in the benchmark case, the reduction in skewness is 9 percent, while in the less severe disaster case, the reduction is larger at 11 percent. Consistent with our earlier discussion, in the less persistent shock case, the gain is even larger.

In our analysis, we examine various shock configurations to ensure the robustness of our results. For instance, we consider an alternative scenario where disaster shocks are recurrent and rare. However, occasionally (e.g., every 2 years), these shocks are even more pronounced than the typical disaster shocks. Despite this variation, our main conclusion remains unchanged.

5.2. Variations in the inflation coefficient

In our analysis, we have set the coefficient on inflation to 1.5. This assumption is based on our robustness checks showing that variations in this inflation coefficient do not change our main conclusion. We report these results here for completeness. Figure 8 visualizes the relationship between the coefficients of output, inflation, and the resulting skewness of welfare levels. Variations in the inflation coefficient can also be interpreted as capturing the central banker's "trembling hand". While the central banker intends to set the optimal inflation coefficient and knows its ideal value, involuntary deviations may occur. These deviations, similar to a trembling hand, might result in a coefficient that's slightly different than intended. As the figure shows, varying the inflation coefficient does not change the main conclusion: the skewness of welfare is minimized when the Taylor rule puts equal weight to output and inflation stabilization.

It is noteworthy that as the coefficient on inflation increases, the gains from emphasizing output stabilization diminish. However, in all scenarios, we've examined, a clear benefit arises from prioritizing output stabilization.[11]

6. Summary and conclusions

In this paper, we have examined the monetary policy implications arising from climate-induced shocks, building on the works of Rietz (1988) and Barro (2006). Through an analysis using new Keynesian models and Taylor rules, we have sought to understand the monetary policy implications of climate shocks and find a monetary policy rule that minimizes the effects of rare disasters on the central bank's objectives of price stability and output stability. Additionally, we have explored the potential impact of increasing the inflation target from 2 percent to 4 percent and the debt-to-GDP ratio.

[11] We also considered variations in parameters such as Fischer elasticity (η), depreciation rate (δ), and risk aversion (σ). While we do not report these results in this paper, they remain consistent and are available upon request.

Figure 8: Robustness of Results Across Different Inflation Coefficients

Note: This figure illustrates the interplay between output and inflation coefficients and their impact on the skewness of welfare levels. It shows that variations in the inflation coefficient do not alter our primary findings: a Taylor rule that stabilizes both inflation and output is the most effective in reducing the skewness of welfare.

Our main finding is the identification of a policy trade-off arising from climate shocks. Such shocks introduce a complex trade-off for policymakers between output stability and price stability. Due to the left-tail nature of the shock, this policy trade-off arises within the context of skewness. In other words, these shocks fundamentally alter the risk profile associated with central bank objectives. As the frequency of climate-related disasters increases, the risk profile becomes more asymmetrical: specifically, inflation exhibits an upward skewness while output displays a downward skewness. Inflation showing an upward skewness means the economy faces greater risks of unexpectedly high inflationary events. On the other hand, the downward skewness in output indicates heightened risks of significant economic downturns or recessions. This trade-off arises because the factors triggered by disasters might lead to a decline in output. But, these same factors can also drive up marginal costs, resulting in an increase in inflation.

The model suggests that a Taylor rule that places greater emphasis on output stabilization than the standard Taylor rule helps to mitigate the effects of the shock on household welfare. An advantage of this policy is that a Taylor rule emphasising output stabilization offers a stabilizing effect on the debt-to-GDP ratio. Moreover, we also consider the long-run implications of such shocks. When determining the nominal interest rate, Woodford (2003) suggests to consider the slope of the long-run Phillips curve to ensure equilibrium determinacy. Recent work by Nakamura et al. (2013) suggests that disasters can reduce the long-run output and the slope of the Phillips curve. These considerations imply a more aggressive response to maintain equilibrium determinacy. So, while addressing the disruptive effect of a disaster, they also have to ensure their response to inflation is strong enough to ensure determinacy.

Our findings further suggest that increasing the inflation target can indeed help to alleviate the policy trade-off associated with climate-induced disasters. This is simply because the central bank aims to stablize inflation at a higher level. However, this comes at the expense of lower household welfare due to the inherent costs of higher inflation. Specifically, price mark-ups increase and price dispersion rise, both leading to lower output. This reduction in output also contributes to a higher debt-to-GDP ratio.

Our analysis highlights the need to consider the asymmetric impacts of disasters in policy decisions. Traditional measures like means and standard deviations are no longer sufficient. With the growing importance of climate shocks, it is crucial for policymakers to recognize these unique dynamics and factor in the entire outcome distribution in policy formulation.

Finally, while our analysis has focused on the design of standard monetary policy taking into account potential climate shocks, our approach does not preclude the possibility of a central bank deploying unconventional measures at the time of the shock. Indeed, there may be a role for unconventional measures, such as QE. A detailed investigation into the role and design of unconventional measures would be helpful. We leave this matter for further research.

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Monetary Policy Design with Recurrent Climate Shocks
Working Paper No. WP/2023/243