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Monetary Policymaking under Climate Uncertainty

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Abstract: *The most effective policy to prevent climate change is the decarbonization of the production process. Decarbonization, which should be planned and not delayed, will cause some assets to become idle or stranded, either entirely or partially. Therefore, the transition to a low-carbon economy results in sudden and unexpected fluctuations in asset prices. These shocks will affect the relevant sector and all production sectors with a domino effect and deteriorate financial stability. To the extent that these shocks are predictable, policymakers can prepare for the repercussions of green financial transformation. However, the tools needed to pre-measure them are new and dependent on many economic variables. Therefore, policymakers need a road map to act under this uncertainty. This paper theoretically provides insights into central banks' role/engagement under climate change ambiguity. The paper shows that the less the central bank trusts its policy model, the higher the sensitivities of inflation, output-gap, and asset price-gap to climate-related shocks. Hence, an aggressive response of monetary policy is required in the face of uncertainty.*

Keywords: Climate Change, Monetary Policy, Financial Stability, New Keynesian Model, Knightian Uncertainty, DSGE Model

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1. Introduction

The ecological risks caused by climate change are indisputably more significant than the financial risks that will arise with its prevention. By evaluating all the risks that climate change will cause, countries agreed that decarbonization is the most critical step to preventing climate change. During the emission reduction process, the greening of energy resources was inevitable to meet the Paris agreement's targets. Even if the transformation is flawless, it is likely to have major implications for macroeconomic and financial markets, relative prices and inflation, output and technology, and hence monetary policy reaction.

To comply with the Paris Agreement's limit of global warming to well below 2◦C, preferably to 1.5◦C, compared to pre-industrial level target requires that the global economy's climate impacts be neutral by the middle of the century (IPCC, 2018). Reaching targets of the Paris Agreement requires a reduction in anthropogenic emissions assertively. However, the reduction comes with certain costs. Some of the costs originate from changing how we produce in the current period. The rest of the costs, which are relatively large, comes from the ineffectiveness of the physical capital assets, i.e., *stranded* assets. It is possible to see this as the fact that a machine in a factory is physically functional but not economically efficient anymore. Therefore, the transition to a low-carbon economy results in sudden and unexpected fluctuations in asset

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prices, which may lead to financial shocks (Caldecott et al., 2013; Carbon Tracker Initiative, 2016; Caldecott, 2017).

Climate change affects prices in two ways. In the scenario of a smooth and planned transition to low-carbon energy, shifts in energy resources and thus relative prices may destabilize inflation expectations. It can even create an inflation bias. In another scenario where climate change is not brought under control, extreme weather events such as hurricanes, droughts, floods, and heatwaves will seriously disrupt the global economy (Basel Committee on Banking Supervision, Climate-related Risk Drivers and Their Transmission Channels, 2021; Financial Stability Board, The Implications of Climate Change for Financial Stability, 2020). These, and the social effects they cause, can have long-term effects on aggregate supply and demand and, therefore, on inflation. Also, the transition to a low-carbon economy will lead to higher commodity prices, resulting in *greenflation*. Increasing demand for materials used in the transition period will put upward pressure on prices. This will be a new challenge for inflation-targeting central banks.

The impact of climate change and the effects of policies to prevent it on the economy are new challenges for policymakers (Barnett et al., 2020). New information and experience have an impact on the comprehension of trade-offs that policymakers face. This paper analyzes the effects of uncertainties originating from climate-related policies on monetary policymaking. To do so, we utilize a New Keynesian model with a financial sector, which considers these uncertainties in the financial and real sectors. The design of optimal monetary policy under a climate change environment inherits model uncertainty. Using the Hansen and Sargent (2001, 2008) approach we propose a robust monetary policy design which incorporates policymakers concerns on climate related risks. Hansen and Sargent (2001, 2008) incorporate the notion of robustness to model uncertainty and concern about model misspecification. The findings of the paper suggest that a higher preference for robustness, i.e., the less the central bank trusts its policy model, the higher the sensitivities of inflation, output gap, and asset price gap to all climate-related shocks. When there is no persistence in shocks, discretionary monetary policy responds more aggressively to all shocks to lessen the effects of ambiguity on the economy. When we allow shocks to be long-lasting, to prevent detrimental effects of the wealth effect channel from asset stranding, interest rate response becomes weaker. The choice of the policy rate implies a stronger real interest rate due to higher inflationary expectations. Hence, the real rate becomes more aggressive under climate-related uncertainty. To the extent of our knowledge, this is the first study that focuses on the optimal monetary policymaking under climate change originated uncertainties.

The remainder of the paper is organized as follows: Section 2 summarizes the relevant literature. Section 3 develops the model incorporating model uncertainty. Section 4 analyzes the responses of monetary policy under model uncertainty. Finally, Section 5 concludes.

2. Related Literature

Our paper is part of the growing climate macroeconomics literature that studies the impact of climate-related risks on the implementation of monetary policy. There is bulk of literature on the impact of climate change and climate policies on macroeconomy and monetary policy. Several recent studies provide a coherent environment to analyze the climate-related risks and transition process on macroeconomic indicators and policymaking. Pioneering papers, Annicchiarico and Di Dio (2015) and Annicchiarico and Di Dio (2017), employ a New Keynesian model with environment-related features such as greenhouse emissions due to production and its negative externality and the policy tools for controlling climate change. Economides and Xepapadeas (2018) employs a closed economy new Keynesian dynamic stochastic general equilibrium (DSGE) model with a climate module. The paper compares the conduct of monetary policy both with and without climate change and finds that climate change will influence the response of monetary policy to economic shocks. Diluiso et al. (2021), in a DSGE model, analyzes the impact of monetary policy under climate policies on financial stability. According to their findings, the impact of green quantitative easing (QE) is similar to neutral QE. Decarbonizing the balance sheet of the banks reduces the stringency of the financial turmoil; however, it prolongs its impact of it. McKibbin et al. (2020) emphasizes the relation between climate change and monetary policy under urgent ambitious climate actions. These two separate policy blocks should be embedded to form more sophisticated macroeconomic modelling frameworks developed. Chen and Pan

(2020) and Chen et al. (2021) suggest an optimal policy mix of monetary and climate policies by providing a climate augmented E-DSGE model. All these papers in the literature have a common finding. Central banks' involvement in climate policy must be carefully designed to align with their mandates and avoid undesirable trade-offs. Otherwise, the impact of the uncertainty it will create on macro and financial stability will be devastating.

On the other hand, a little attention has been paid to the policymaking under climate uncertainty. As emphasized by Farmer et al. (2015) existing models are not capable to address the issues raised by the climate change. Hence, new wave of models is required to be developed to tackle these challenges. Similarly, Punzi (2019) shows that energy price and uncertainty in climate policies lead to high macroeconomic volatility in the business cycle. Therefore, the increasing uncertainty is another challenge for the central banks besides climate shocks. This paper discusses how the central bank should behave and implement its policy under uncertainty.

The robust control approach has been widely employed for the optimal monetary policy design under model ambiguity. There are several applications of the technique on climate models such as Roseta-Palma and Xepapadeas (2004) and Gonzalez (2008). Roseta-Palma and Xepapadeas (2004). These papers mainly focus on the precautionary decisions under uncertain resource management and a policymaker prefers to be robust against uncertainty. In terms of macroeconomic policymaking, Gonzalez (2008) suggests optimal carbon taxes under model misspecification. Funke and Paetz (2011) have focused on robust carbon abatement policies in an uncertain framework and suggests an aggressive response to reduce carbon emissions. To the extent of our knowledge, this is the first study that focuses on optimal monetary policy making under climate change originated uncertainty. Our paper focuses on the above-mentioned inflation and financial sector uncertainties originated from the climate related risks. The findings of the paper shows that a policymaker, who fears about model ambiguity, should react more aggressively to changes in the climate change induced price and financial shocks.

3. The Framework

We characterize the economy by a DSGE model introduced by Nistico (2012). The model features the standard intermediate-final good firms framework with Calvo-type price stickiness. On the other hand, the household side is a stochastic variant of Blanchard (1985) and Yaari (1965)'s perpetual-youth model. Only a fixed proportion of the households are assumed to survive through each period which are replaced by newborns. Hence, the model creates a heterogeneity in the level of capital accumulation between survivor households and newborns with no financial wealth. This structure enables us to study the stance of the monetary policy in the existence of the asset market. The following system of equations represents the economy:

$$\pi_t = \tilde{\beta} E_t \pi_{t+1} + \kappa x_t + \epsilon_t^{\pi} \tag{1}$$

$$x_t = \frac{1}{1+\psi} E_t x_{t+1} + \frac{\psi}{1+\psi} q_t - \frac{1}{1+\psi}(i_t - E_t\, \pi_{t+1}) \tag{2}$$

$$q_t = \tilde{\beta} E_t q_{t+1} - \lambda\, E_t\, x_{t+1} - (i_t - E_t\, \pi_{t+1}) + \epsilon_t^{q} \tag{3}$$

where π, x, q, and i denote inflation, output gap, asset price, and nominal interest rate represented by log deviations from their steady-state values. As the purpose of this study is to analyze the effects of climate change, we introduce shocks capturing the climate-related risks discussed in the introduction section. ϵ_t^q is a shock that accounts for asset price fluctuations due to the transition risks of climate change. ϵ_t^{π} represents a cost-push shock to firms originating from the physical risks of climate change.

In this model, $\tilde{\beta} = \beta/(1+\psi)$ refers to the stochastic discount factor. It is different from the intertemporal discount factor since the length of being active in the financial market is less than an agent's life span. $\tilde{\beta}$ converges to β as the time increases, and the model converges to the representative agent setup.

Equation (1) is the forward-looking New Keynesian Phillips Curve equation. Inflation is determined by the marginal cost of firms, i.e., the output gap, and expected future inflation. Equation (2) represents the dynamic IS equation which shows the relation between the expected output gap, real interest rate, and asset prices. Ex-ante real interest rate lowers whereas the expected output rises current output. q_t in this equation stands for the financial wealth channel on the demand side of the economy. As the value of the financial wealth increases, so does the aggregate demand and hence output. Asset price dynamics are represented by equation (3). Asset prices depend positively on their expected value, negatively on the expected output gap and the real interest rate.

Shocks follow first-order autoregressive processes with persistence ρ_i as below:

$$\epsilon_t^i = \rho_i \epsilon_{t-1}^i + \nu_t^i, \quad \nu_t^i \sim i.i.d. \quad N(0,1), \quad i \in \{q, \pi\} \tag{4}$$

The central bank minimizes the following quadratic loss function, which depends on deviations of inflation, the output gap, and asset prices from their steady-state levels by setting the short-term interest rate i_t:

$$L_t = \pi_t^2 + \lambda_x x_t^2 + \lambda_q q_t^2 \tag{5}$$

where λ_x and λ_q show the relative weights of output gap stability, and financial stability, respectively. Since the primary mandate of many monetary authorities is the price stability, we assume the relative weights for the stability of output and financial markets satisfies $0 < \lambda_x, \lambda_q < 1$.

In the perpetual-youth model, heterogeneous agents' interactions in financial markets distort the distribution of consumption across households. Financial stability plays a crucial role in this distributional distortion. As a result, an optimal monetary policy design must include financial stability as an explicit aim in addition to inflation and output gap. Nistico (2016) shows the derivation of a welfare-based loss function for a similar model.

3.1. Accounting for Model Uncertainty

We characterize the model uncertainty as a second type of shock, w_t^j, in the disturbance process as in Hansen and Sargent (2008):

$$\epsilon_t^j = \rho^j \epsilon_{t-1}^j + \left[\nu_t^j + w_t^j\right] \quad j = q, \pi \tag{6}$$

The two elements, ν^j and w^j, defined in the shock process, are different from each other. ν^j indicates random errors with known stochastic properties. On the other hand, w^j is an add-on of the robust control methodology and expresses model specification error. In addition, the policymaker cannot assign a probability distribution for w^j in advance.

The misspecified model is bounded by a positive parameter η^j since the misspecified model is not distant from the reference model.

$$E_t \sum_{t=0}^{\infty} \left[w_t^q + w_t^\pi \right]^2 \leq \eta^j, \quad \eta^j > 0 \tag{7}$$

Equation (7) is required to limit the amount of model misspecification. Otherwise, the model misspecification error would be too large, and the policymaker becomes implausible rather than being cautious to model uncertainty.

The central bank seeks to implement policies that are immune to model misspecification. The central bank's concerns regarding model ambiguity are formalized by supposing that an evil agent selects the worst-case specification in order to maximize the central bank's loss function. The worst-case situation is that the central bank uses interest rates to reduce the value of its loss function, while the evil agent uses specification mistakes to enhance loss. This is the central bank's primary concern, and it desires monetary policy to be as robust as possible to avoid it.

The methodology enables us to investigate the effect of incorporating specification errors by having one of the $w^j s$ be positive while the others are set to zero, in addition to evaluating the overall impact of misspecification by letting all w^j be positive. We will show how different sources of misspecification have a wide range of implications for robust monetary policy.

3.2. Robust Optimal Policy Problem

The policymaker operates under discretion, taking expectations as given. Following Hansen and Sargent (2008), we assume that the central bank and the evil agent play a Nash game, so each player's choice is optimal given the other player's choice. In the setup with central bank's concerns about uncertainty, the policy problem can be written as the following Lagrangian equation:

$$\begin{aligned}\min_{\{x_t,q_t,\pi_t,r_t\}}\max_{\{w_t^q,w_t^\pi\}} \mathcal{L} = \frac{1}{2}\left[\pi_t^2 + \lambda_x x_t^2 + \lambda_q q_t^2 - \theta_q {w_t^q}^2 - \theta_\pi {w_t^\pi}^2\right] \\ +\mu^x\left[x_t - \frac{1}{1+\psi}x^e - \frac{\psi}{1+\psi}q_t + \frac{1}{1+\psi}(i_t - \pi^e)\right] \\ +\mu^q\left[q_t - \tilde{\beta}q^e + \lambda x^e + (i_t - \pi^e) - \rho^q \epsilon_{t-1}^q - \left(\nu_t^q + w_t^q\right)\right] \\ +\mu^\pi\left[\pi_t - \tilde{\beta}\pi^e - \kappa x_t - \rho^\pi \epsilon_{t-1}^\pi - \left(\nu_t^\pi + w_t^\pi\right)\right]\end{aligned} \tag{8}$$

where θ_j is the Lagrange multiplier associated with the budget constraint of the evil agent. The optimal stabilization rule and the worst-case misspecification is found as follows:

$$\lambda_x x_t + \kappa\pi_t + \lambda_q q_t = 0 \tag{9}$$

$$w_t^q = \frac{\lambda_q}{\theta_q(1+\psi)}q_t \tag{10}$$

$$w_t^\pi = \frac{1}{\theta_\pi}\pi_t \tag{11}$$

Equation (9) represents the optimal targeting rule of the central bank. This implies that there is a trade-off between inflation, output, and asset price, consistent with Equation (5). Moreover, the optimal trade-off is not affected by model misspecification since model specification errors does not appear in (9). Using the above solution of the worst-case choices of disturbances, i.e., (10)-(11), we analyze how an increase in policymaker's uncertainty aversion —a decrease in θ_q and θ_π —affects the worst-case equilibrium solutions for inflation, output gap, asset price, and the policy rate.

4. Results

When there is no persistence in shocks, i.e., the shocks last for only one period, we can obtain the closed-form analytical solutions (Leitemo & Söderström, 2008). Accordingly, assuming that all expectations regarding the future values of the target variables are zero, we can solve the system to obtain the endogenous variables as functions of the exogenous shocks. The following system of equations gives the allocations for the endogenous variables:

$$x_t = \frac{1}{\phi_1\phi_4 - \phi_2\phi_3}\left(-\phi_4\kappa\nu_t^\pi + \frac{\phi_2}{1+\psi}\nu_t^q\right) \tag{12}$$

$$q_t = \frac{1}{\phi_1\phi_4 - \phi_2\phi_3}\left(\phi_3\kappa v_t^{\pi} - \frac{\phi_1}{1+\psi}v_t^{q}\right) \tag{13}$$

$$\pi_t = -\frac{1}{\kappa}\left(\lambda_x x_t + \lambda_q q_t\right) \tag{14}$$

$$i_t = \psi q_t - (1+\psi)x_t \tag{15}$$

4.1. Specification Errors in Inflation

When $v_t^q = 0$ and θ_q, we have $\phi_4 = -1$. In this case, the solutions can be found from the following system:

$$x_t^{worst} = -\frac{\kappa\theta_\pi v_t^{\pi}}{\theta_\pi\left(\lambda_x + \lambda_q + \kappa^2\right) - \left(\lambda_x + \lambda_q\right)} \tag{16}$$

$$q_t^{worst} = x_t^{worst} \tag{17}$$

$$\pi_t^{worst} = -\left(\frac{\lambda_x + \lambda_q}{\kappa}\right)x_t^{worst} \tag{18}$$

$$i_t^{worst} = -x_t^{worst} \tag{19}$$

We analyze the effects of an increase in the policymaker's concern for model ambiguity on the optimal monetary policy and the resulting dynamics of the economy. We establish the following proposition:

Proposition 1. *In the worst-case equilibrium, a higher uncertainty aversion of the policymaker —that is a fall in θ_π—increases the sensitivities of inflation ($\boldsymbol{\pi_t^{worst}}$), output gap ($\boldsymbol{x_t^{worst}}$), and asset price ($\boldsymbol{q_t^{worst}}$) to the inflation shock ($\boldsymbol{v_t^{\pi}}$).*

Proof.

$$-\left|\frac{\frac{\partial x_t^{worst}}{\partial v_t^{\pi}}}{\partial\theta_\pi}\right| = -\left|\frac{\frac{\partial q_t^{worst}}{\partial v_t^{\pi}}}{\partial\theta_\pi}\right| = \frac{\kappa\left(\lambda_x + \lambda_q\right)}{\left[\theta_\pi\left(\lambda_x + \lambda_q + \kappa^2\right) - \left(\lambda_x + \lambda_q\right)\right]^2} > 0 \tag{20}$$

$$-\left|\frac{\frac{\partial \pi_t^{worst}}{\partial v_t^{\pi}}}{\partial\theta_\pi}\right| = \frac{\left(\lambda_x + \lambda_q\right)^2}{\left[\theta_\pi\left(\lambda_x + \lambda_q + \kappa^2\right) - \left(\lambda_x + \lambda_q\right)\right]^2} > 0. \tag{21}$$

Note that a positive sign above partial derivatives indicates that a variable becomes more sensitive to the shock as the uncertainty aversion of the policymaker increases. A stronger preference for robustness is represented by a lower value of the parameter θ_π. In this context, Equations (20)-(21) show that the less the central bank trusts its policy model, the higher the sensitivities of inflation, output gap and asset price gap to the supply-side shocks are. In other words, the robust central bank fears that inflation, output gap and asset price gap are more sensitive to the mark-up shock and therefore more volatile than in the reference model, as uncertainty increases the volatilities of the worst-case solutions.

Proposition 2. A stronger uncertainty aversion against a cost-push shock makes monetary policy respond more aggressively to shocks to inflation.

Proof.

$$-\left|\frac{\frac{\partial i_t^{worst}}{\partial v_t^{\pi}}}{\partial \theta_\pi}\right| = \frac{\kappa(\lambda_x+\lambda_q)}{\left[\theta_\pi(\lambda_x+\lambda_q+\kappa^2)-(\lambda_x+\lambda_q)\right]^2} > 0 \tag{22}$$

As the cost-push rises inflation, and the policymaker fears that this shock will raise them even more under misspecification, uncertainty aversion makes policy respond more aggressively to the inflation shock to suppress the effects of ambiguity on the economy.

4.2. Specification Errors in the Asset Price

When $v_t^{\pi}=0$ and θ_π, we have $\phi_1=\kappa^2+\lambda_x$, $\phi_2=\lambda_q$, and the solution becomes as follows:

$$x_t^{worst} = -\frac{\theta_q\lambda_q(1+\psi)}{\theta_q(1+\psi)^2(\lambda_x+\lambda_q+\kappa^2)-\lambda_q(\kappa^2+\lambda_x)}v_t^q \tag{23}$$

$$q_t^{worst} = \frac{\theta_q(1+\psi)(\kappa^2+\lambda_x)}{\theta_q(1+\psi)^2(\lambda_x+\lambda_q+\kappa^2)-\lambda_q(\kappa^2+\lambda_x)}v_t^q \tag{24}$$

$$\pi_t^{worst} = -\frac{\theta_q\kappa\lambda_q(1+\psi)}{\theta_q(1+\psi)^2(\lambda_x+\lambda_q+\kappa^2)-\lambda_q(\kappa^2+\lambda_x)}v_t^q \tag{25}$$

$$i_t^{worst} = \frac{\theta_q\lambda_q(1+\psi)^2+\theta_q\psi(1+\psi)(\kappa^2+\lambda_x)}{\theta_q(1+\psi)^2(\lambda_x+\lambda_q+\kappa^2)-\lambda_q(\kappa^2+\lambda_x)}v_t^q \tag{26}$$

We analyze the effects of an increase in the concern for model ambiguity on the optimal monetary policy and the resulting dynamics of the economy. We establish the following proposition:

Proposition 3. *In the worst-case equilibrium, a higher uncertainty aversion of the policymaker —that is a fall in $\boldsymbol{\theta_q}$ —increases the sensitivities of output gap ($\boldsymbol{x_t^{worst}}$), inflation ($\boldsymbol{\pi_t^{worst}}$) and asset price ($\boldsymbol{q_t^{worst}}$) to the shock to the asset price ($\boldsymbol{v_t^q}$).*

Proof. We use equation (23)-(25) to obtain:

$$-\left|\frac{\frac{\partial x_t^{worst}}{\partial v_t^{q}}}{\partial \theta_q}\right| = \frac{\lambda_q^2(1+\psi)(\kappa^2+\lambda_x)}{\left[\theta_q(1+\psi)^2(\lambda_x+\lambda_q+\kappa^2)-\lambda_q(\kappa^2+\lambda_x)\right]^2} > 0, \tag{27}$$

$$-\left|\frac{\frac{\partial \pi_t^{worst}}{\partial v_t^{q}}}{\partial \theta_q}\right| = \frac{\kappa\lambda_q^2(1+\psi)(\kappa^2+\lambda_x)}{\left[\theta_q(1+\psi)^2(\lambda_x+\lambda_q+\kappa^2)-\lambda_q(\kappa^2+\lambda_x)\right]^2} > 0, \tag{28}$$

$$-\left|\frac{\frac{\partial q_t^{worst}}{\partial v_t^{q}}}{\partial \theta_q}\right| = \frac{\lambda_q(1+\psi)(\kappa^2+\lambda_x)^2}{\left[\theta_q(1+\psi)^2(\lambda_x+\lambda_q+\kappa^2)-\lambda_q(\kappa^2+\lambda_x)\right]^2} > 0. \tag{29}$$

When θ_q falls, that is, uncertainty aversion increases, sensitivity of output and inflation and stock price to the shock rises.

Proposition 4. *A stronger uncertainty aversion against asset price shock leads monetary policy to reacts more aggressively to shocks to the asset price.*

Proof.

$$-\left|\frac{\frac{\partial i_t^{worst}}{\partial v_t^q}}{\partial \theta_q}\right| = \frac{\lambda_q^2(1+\psi)^2(\kappa^2+\lambda_x)+\lambda_q\psi(1+\psi)(\kappa^2+\lambda_x)^2}{\left[\theta_q(1+\psi)^2\left(\lambda_x+\lambda_q+\kappa^2\right)-\lambda_q(\kappa^2+\lambda_x)\right]^2} > 0. \quad (30)$$

As the shock to the asset price decreases inflation and output below their steady-state values and increases the output gap above its steady-state, the policymaker fears that this shock will deviate them even more under misspecification, and uncertainty aversion makes policy react more aggressively to the asset price shock in order to attenuate the effects of uncertainty in the economy.

4.3. Persistence in Shocks

In this section, we analyze whether and to what extent persistence in the shock processes affects the model dynamics under uncertainty. When we allow for persistent shocks, we rely on numerical simulations to discuss the impact of uncertainty since the system does not have an analytical solution. To simulate the model, we calibrate the parameters as in Nistico (2012). Table 1 presents the calibration of the parameters.

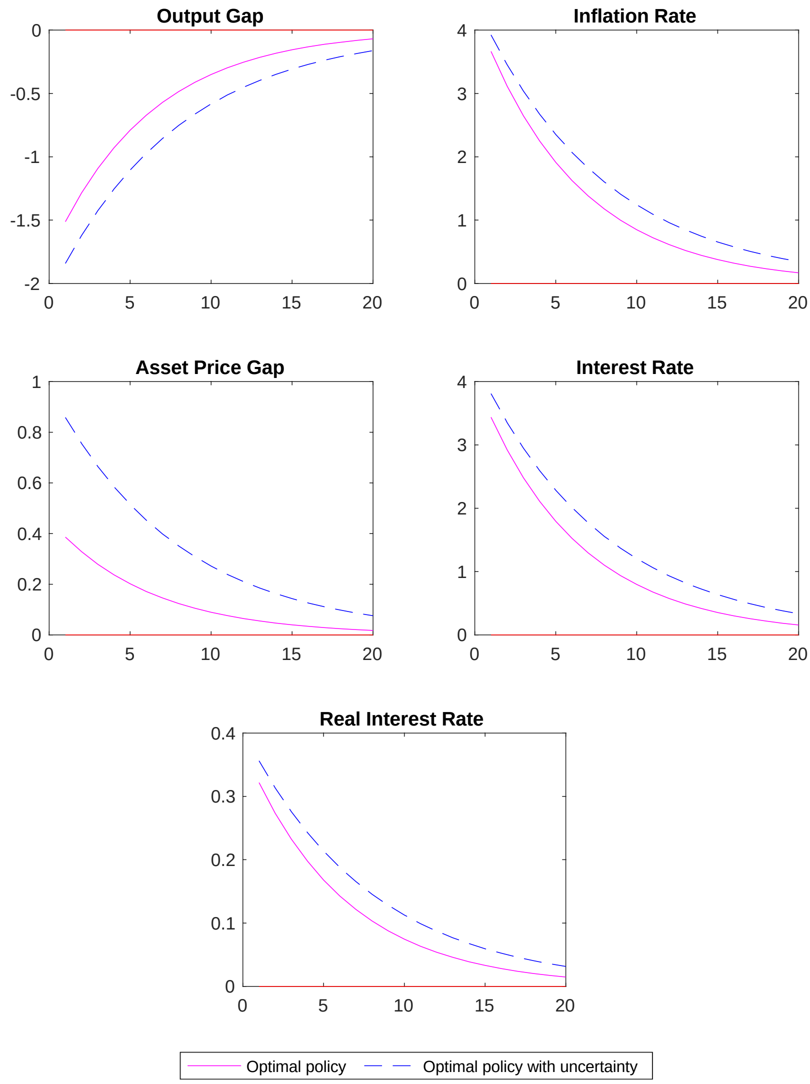
Table 1. Calibration

Parameter	Description	Values
β	Discount factor	0.99
ψ	Composite parameter	0.05
λ	Weight of the expected output gap in stock price equation	0.31
κ	Slope of the Phillips curve	0.18
λ_x	Weight of the output gap in loss function	0.5
λ_q	Weight of the asset price gap in loss function	0.25
ρ_q	Persistence in asset price shock	0.7
ρ_π	Persistence in asset cost-push shock	0.85
θ_q	Robustness parameter for the asset price shock	56
θ_π	Robustness parameter for the cost-push shock	440

Notes: We use an error detection probability (EDP) to quantify the uncertainty aversion of the central bank as proposed by Hansen and Sargent (2008). We set θ_q and θ_π to capture a EDP between 15% and 20 % in a sample of 200 observations. The model becomes representative agent model as ψ converges to 0. In this case, the financial wealth effect disappears.

Figure 1 demonstrates the responses of the output gap, inflation rate, asset price gap, and nominal and real interest rates to one standard deviation of cost-push shock with and without uncertainty. A positive cost-push shock causes an increase in inflation and, hence, the policy rate, leading to a decline in the output gap. As the marginal cost of firms has a positive impact on expected real dividends -i.e., there is a stabilizing wealth effect-, the contemporaneous asset price rises. Due to policymaker's uncertainty aversion, we observe larger volatility in the worst-case level of inflation; thus, the response of the policy rate becomes more aggressive, leading to greater deviations in the output gap and asset prices. Uncertainty aversion of the policymaker escalates the wealth effect channel.

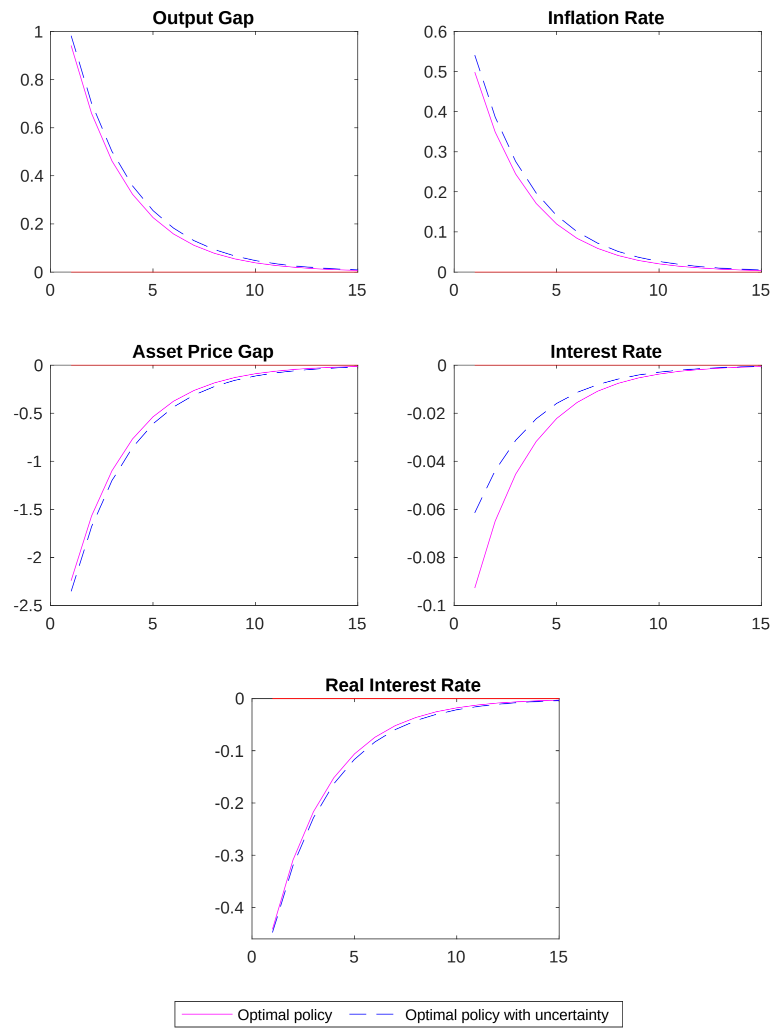
Figure 1. Responses to Cost-Push Shock



Notes: The calibrated impulse-response functions to cost-push shock. The (ex-ante) real interest rate is defined as $i_t - E_t\pi_{t+1}$. All magnitudes are in percentage points.

Through the transition to a low-carbon economy, climate-related policies could lead to sudden adjustments in asset prices and changes in defaults for the entire financial market, resulting in negative financial shocks. In Figure 2, we illustrate how model dynamics respond to a negative shock to the price of financial assets by one standard deviation. A negative shock to the asset price is associated with a fall in the policy rate due to the central bank's financial stability mandate. Despite the negative wealth effect of asset prices on the output gap, there is an expansion because of the rise in the short rate, implying that the financial stabilization goal is strong enough to dominate the wealth effect. Subsequently, inflation goes above its steady state. The price effect is small due to competing effects of the policy rate and the effective financial wealth on aggregate demand.

Figure 2. Responses to Asset Shock



Notes: The calibrated impulse-response functions to shock to the asset price gap. The (ex-ante) real interest rate is defined as $i_t - E_t\pi_{t+1}$. All magnitudes are in percentage points.

With model uncertainty concerns, the policymaker overestimates the effect of the climate shock on the asset price. However, this induces a weaker response in the policy rate in order to prevent even larger volatilities in the output gap and inflation. To discuss this in more detail, it is necessary to analyze how real interest rates are shaped. Because the central bank operates under discretion —that is, there is no commitment technology —it is not successful in managing expectations. In other words, although the central bank keeps the policy rate weaker than in the absence of uncertainty, the ex-ante real interest rate, $i_t - E_t\pi_{t+1}$, is more aggressive due to larger inflationary expectations.

5. Conclusion

The initial step to prevent climate change is to decarbonize the production process. However, the measures taken will not only cause inflation by creating costs in the production process but also reduce the firm's value by making some physical capital used in production idle and result in negative pressure on asset prices. These climate risks will threaten financial stability and deteriorate other macroeconomic variables, as tested in the 2008 Global Financial Crisis. This paper contributes to the literature to shed light on the design of macroeconomic policies that aim at containing the economic risks of climate change.

Fiscal authority is one of the responsible parties in the fight against the adverse effects of climate change and enables adaptation to it by implementing targeted taxation and subsidies that encourage investment in greener technologies on a path aligned with the goals of the Paris Agreement. These policies should be planned gradually in a way that will cause the least damage to the production process. However, the complementary role of an independent monetary policy in addition to the practices of the fiscal policy authority in the transition to a green economy cannot be denied. In particular, controlling the uncertainties mentioned in this study is the most important task of central banks during this transition.

Although the monetary policy does not have specific climate-related objectives, it is practical to provide a roadmap for the policy design anticipating the repercussions of climate mitigation policies on price stability and financial stability. Yet, the economic models to be used to understand the impact of climate policies on the economy are still premature. For this reason, the impacts of the policies cannot be fully quantified, and their effects cannot be accurately predicted. This paper provides a framework that embraces policymakers' fears about model misspecification. The analysis analytically characterizes the impact of cost-push and financial shocks in such an environment. We pay particular attention to the design of monetary policy to provide insights into central banks' engagement in the climate change debate. According to the findings of the paper, the less the monetary policy authority relies on the economic model, the more aggressive the policy rate responds. In other words, the sensitivities of the target variables, such as inflation, output gap, and asset price gap, increase as climate-related shocks are observed.

Our findings have several implications for central banks’ role in the climate change debate. It is crutial for the central banks to acknowledge the effects of climate-related uncertainties on price and financial stability. This sometimes implies taking pre-emptive policy actions before the risks materialize, at the cost of tighter economic conditions. Policymakers should do whatever it takes to support a smooth transition to a climate-resilient economy.

The implications of our findings should be interpreted with caution as our analysis has only considered a broad sense of model uncertainty. Climate policies have the potential to deteriorate macroeconomic indicators and complicate the monetary policy decision-making process. The European Central Bank has recently discussed to embrace climate risks into its operational framework and decision-making processes, which includes gradually decarbonizing the corporate bond holdings in monetary policy portfolios and adjusting the inflation target to provide a buffer against unexpected food price increases due to climate shocks (ECB, 2021a, 2021b). Future work could explore the role of model uncertainty in an E-DSGE model which explicitly models a climate module, i.e., damages originating from carbon emissions and climate-targeted monetary policy strategies. Policy implications will likely vary depending on different types of monetary and fiscal policy instruments and whether they are used in a coordinated manner.

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References

Annicchiarico, B., & Di-Dio, F. (2015). Environmental policy and macroeconomic dynamics in a new Keynesian model. *Journal of Environmental Economics and Management,* 69, 1-21.

Annicchiarico, B., & Di-Dio, F. (2017). Ghg emissions control and monetary policy. *Environmental and Resource Economics,* 67(4), 823-851.

Barnett, M., Brock, W., & Hansen, L. P. (2020). Pricing uncertainty induced by climate change. *The Review of Financial Studies*, 33(3), 1024-1066.

Basel Committee on Banking Supervision, (April, 2021). *Climate-related risk drivers and their transmission channels.* https://www.bis.org/bcbs/publ/d517.htm (Access Date: 19 May 2022).

Blanchard, O. J. (1985). Debt, deficits, and finite horizons. *Journal of Political Economy*, 93(2), 223-247.

Caldecott, B. (2017). Introduction to special issue: Stranded assets and the environment. *Journal of Sustainable Finance & Investment*, 7(1), 1-13.

Caldecott, B., Howarth, N., & McSharry, P. 2013. Stranded assets in agriculture: Protecting value from environment-related risks. Smith School of Enterprise and the Environment, University of Oxford.

Carbon Tracker Initiative. n.d. Carbon tracker initiative's definition of stranded assets. http://www.carbontracker.org/resources/ (Access Date: 23 August 2016).

Chen, C., & Pan, D. (2020). The Optimal mix of monetary and climate policy. MPRA Paper 97718, University Library of Munich, Germany.

Chen, C., & Pan, D., Huang, Z., & Bleischwitz, R. (2021). Engaging central banks in climate change? The mix of monetary and climate policy. *Energy Economics*, 103(C), 105531.

Diluiso, F., Annicchiarico, B., Kalkuhl, M., & Minx, J. C. (2021). Climate actions and macrofinancial stability: The role of central banks. *Journal of Environmental Economics and Management,* 110, 102548.

ECB, (2021a). An overview of the ECB's monetary policy strategy. Frankfurt: European Central Bank.

ECB, (2021b). Detailed roadmap of climate change-related actions. Frankfurt: European Central Bank.

Economides, G., & Xepapadeas, A. (2018). Monetary policy under climate change. Unpublished manuscript.

Farmer, J. D., Hepburn, C., Mealy, P., & Teytelboym, A. (2015). A third wave in the economics of climate change. *Environmental and Resource Economics*, 62, 329-357.

Financial Stability Board, (November 23, 2020). The implications of climate change for financial stability. https://www.fsb.org/2020/11/the-implications-of-climate-change-for-financial-stability/ (Access Date: 15 May 2022).

Funke, M., & Paetz, M. (2011). Environmental policy under model uncertainty: A robust optimal control approach. *Climatic Change*, 107(3), 225-239.

Gonzalez, F. (2008). Precautionary Principle and Robustness for A Stock Pollutant with Multiplicative Risk. *Environmental & Resource Economics*, 41(1), 25-46.

Hansen, L. P., & Sargent, T. J. (2001). Acknowledging misspecification in macroeconomic theory. *Review of Economic Dynamics*, 4(3), 519-535.

Hansen, L. P., & Sargent, T. J. (2008). *Robustness*. Princeton University Press.

IPCC, (2018). Summary for policymakers. Special Report: Global Warming of 1.5 °C. https://www.ipcc.ch/sr15/chapter/spm/ (Access Date: 12 May 2022).

Leitemo, K., & Söderström, U. (2008). Robust monetary policy in a small open economy. *Journal of Economic Dynamics and Control*, 32(10), 3218-3252.

McKibbin, W. J., Morris, A. C., Wilcoxen, P. J., & Panton, A. J. (2020). Climate change and monetary policy: Issues for policy design and modelling. *Oxford Review of Economic Policy*, 36(3), 579-603.

Nistico, S. (2012). Monetary policy and stock-price dynamics in a DSGE framework. *Journal of Macroeconomics*, 34(1), 126-146.

Nistico, S. (2016). Optimal monetary policy and financial stability in a non-Ricardian economy. *Journal of the European Economic Association*, 14(5), 1225-1252.

Punzi, M. T. (2019). The impact of energy price uncertainty on macroeconomic variables. *Energy Policy*, 129, 1306-1319.

Roseta-Palma, C., & Xepapadeas, A. (2004). Robust control in water management. *Journal of Risk and Uncertainty*, 29(1), 21-34.

Yaari, M. E. (1965). Uncertain lifetime, life insurance, and the theory of the consumer. *Review of Economic Studies*, 32(2), 137-150.

Appendix

Closed-form Solution for the Optimal Policy

The first-order conditions for the optimal discretionary policy problem (8) is as follows:

π_t: $\pi_t + \mu^\pi = 0$

x_t: $\lambda_x x_t + \mu^x - \kappa\mu^\pi = 0$

q_t: $\lambda_q q_t - \frac{\psi}{1+\psi}\mu^x + \mu^q = 0$

i_t: $\frac{1}{1+\psi}\mu^x + \mu^q = 0$

ϵ^q: $-\mu^q + \rho^q\mu^{\epsilon^q} = 0$

w_t^q: $-\theta_q w_t^q - \mu^q = 0$

ϵ^π: $-\mu^\pi + \rho^\pi\mu^{\epsilon^\pi} = 0$

w_t^π: $-\theta_\pi w_t^\pi - \mu^\pi = 0$

Isolating and substituting the Lagrange multipliers gives the optimal stabilization rule and the worst-case misspecification as follows:

$\lambda_x x_t + \kappa\pi_t + \lambda_q q_t = 0$

$w_t^q = \frac{\lambda_q}{\theta_q(1+\psi)} q_t$

$w_t^\pi = \frac{1}{\theta_\pi}\pi_t$

Using (2), (3) and (11) yields

$$\phi_1 x_t + \phi_2 q_t = -\kappa v_t^\pi \quad (31)$$

where $\phi_1 = \kappa^2 + \left(1 - \frac{1}{\theta_\pi}\right)\lambda_x, \phi_2 = \left(1 - \frac{1}{\theta_\pi}\right)\lambda_q$.

Inserting (9) and (10) in (1) gives

$$\phi_3 x_t + \phi_4 q_t = -\frac{v_t^q}{1+\psi} \quad (32)$$

where $\phi_3 = 1, \phi_4 = -\left(1 - \frac{\lambda_q}{\theta_q(1+\psi)^2}\right)$.

We combine (31) and (32) to obtain

$$\begin{bmatrix}\phi_1 & \phi_2 \\ \phi_3 & \phi_4\end{bmatrix}\begin{bmatrix}x_t \\ q_t\end{bmatrix} = \begin{bmatrix}-\kappa v_t^\pi \\ -v_t^q/(1+\psi)\end{bmatrix}$$

Given that $\phi_1\phi_4 - \phi_2\phi_3 \neq 0$ we have

$$\begin{bmatrix}x_t \\ q_t\end{bmatrix} = \frac{1}{\phi_1\phi_4 - \phi_2\phi_3}\begin{bmatrix}\phi_4 & -\phi_2 \\ -\phi_3 & \phi_1\end{bmatrix}\begin{bmatrix}-\kappa v_t^\pi \\ -v_t^q/(1+\psi)\end{bmatrix}$$

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