The Expectations Channel of Climate Change: Implications for Monetary Policy

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Introduction

Emerging consensus: climate change is key challenge for monetary policy

- *"[...] it is vital for monetary policymakers to understand the nature of climate disturbances to the economy, as well as their likely persistence and breadth, in order to respond effectively."* — Lael Brainard - FED, *November 8, 2019*
- *"I want to explore every avenue available in order to combat climate change."* — Christine Lagarde - ECB, *July 8, 2020*

Much debate about **physical** phenomenon of climate change

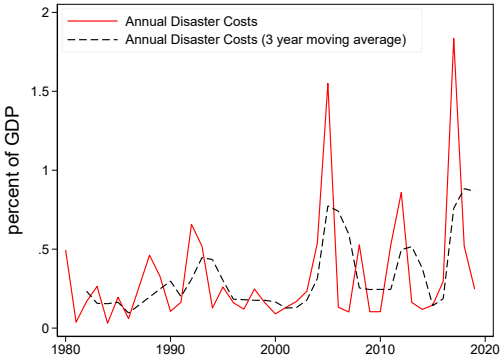
- Climate change hazards may threaten financial stability
- Use monetary policy instruments to combat climate change

This paper: **expectations** of climate change influence economic activity today

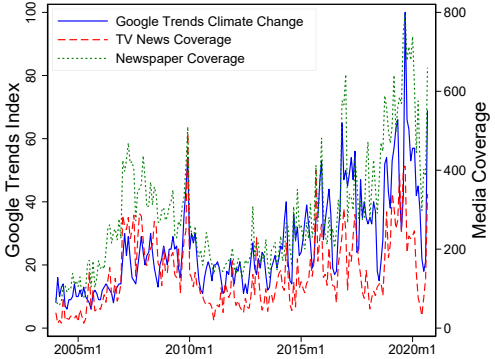
- Matters for monetary policy

Climate Change Trends

Actual costs of natural disasters

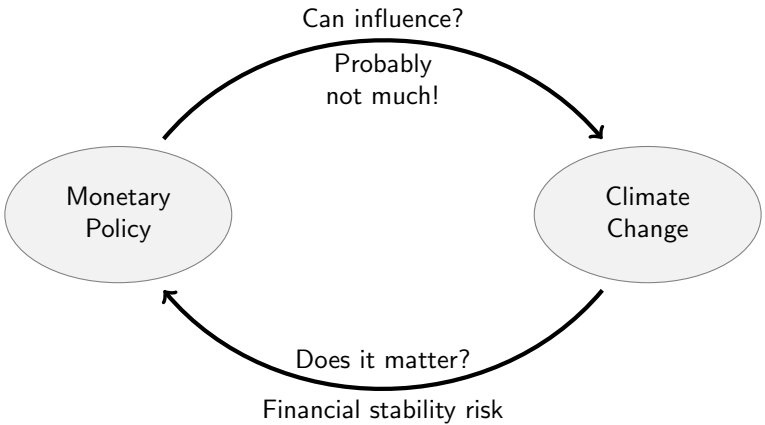


Media focus

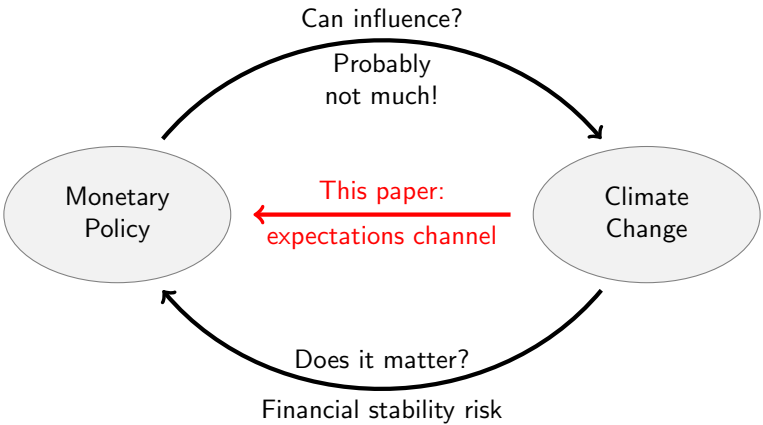


Note: actual costs is sum of natural disaster damages USA (in excess of 1 bn)
Source: National Centres for Environmental Information

Climate Change and Monetary Policy



Climate Change and Monetary Policy



This Paper: Main Results

Survey of U.S. consumers and their climate change expectations

- Small, negligible impact of climate change on GDP growth: 0.16 ppts
- Large prob of large natural disasters within next 12 months (damages of 5% of GDP): 12%
- Evidence for salience effects (media consumption/personal experience)

New Keynesian model with rare disasters (Fernandez-Villaverde Levintal 2018)

- Climate-change related disaster expectation cuts natural rate in half
- Particularly adverse impact on economy unless accommodated by monetary policy
- But: difficult to achieve at effective lower bound

Our Survey

Extension of Federal Reserve Bank of Cleveland's daily tracking survey

- Representative of U.S. consumers, $N = 14,162$.
- Survey weights to adjust for sampling inaccuracy.

Includes regular Cleveland Fed questions (demographics, expectations, media use) plus additional block of questions on effects of climate change

- expected distribution of GDP growth, and economic damages due to natural disasters
- tail risk probability of natural disaster risk
- information treatments

Probability literacy: repeated draws of black/white balls from urn

- 14/70 draws yield black balls, what is probability that next draw is black too?
- 44 percent of respondents: probabilities in range of 10-30 percent; high ability group: probability in range 18 – 22 percent (17%)

Survey Question: Probability of Large Natural Disaster

"As a result of climate change, the risk of natural disasters (such as hurricanes, tropical cyclones, droughts, wildfires, or flooding) is likely to increase. The economic damage of such disasters may be sizeable. Considering the next 12 months, what do you think is the probability of a large disaster causing damage of about 5 percent of GDP?

The probability of a large disaster will be ___ percent."

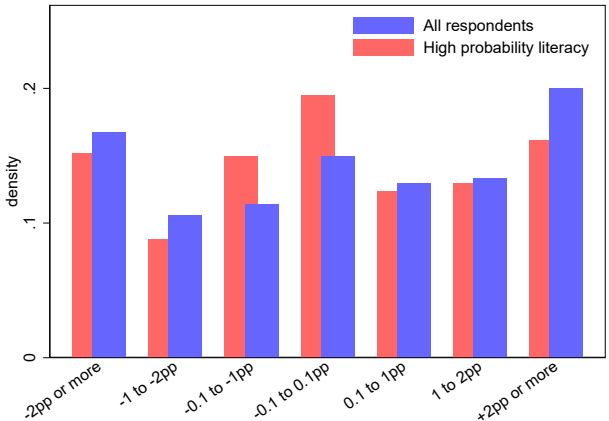
- We also ask about expected GDP growth impact and economic damages over the next 12 months.

Four Information Treatments

Newspaper treatment (T1)	Extract from an USA Today article summarizing the 2020 hurricane season on the east cost and in the gulf region and the wildfires on the west cost. The article links both developments to global warming.
Historic disaster size (T2)	"Over the past 20 years there have been 197 natural disasters in the United States, but even the largest caused damages of less than 1% of GDP (Source: National Centers for Environmental Information)."
Lagarde treatment (T3)	"I think when it comes to climate change, it's everybody's responsibility. Where I stand, where I sit here as head of the European Central Bank, I want to explore every avenue available in order to combat climate change."
Historic disaster frequency (T4)	"Over the past 20 years there have been 197 natural disasters in the United States. Two of them caused damage of more than 0.5 percent of GDP (Source: National Center for Environmental Information)."

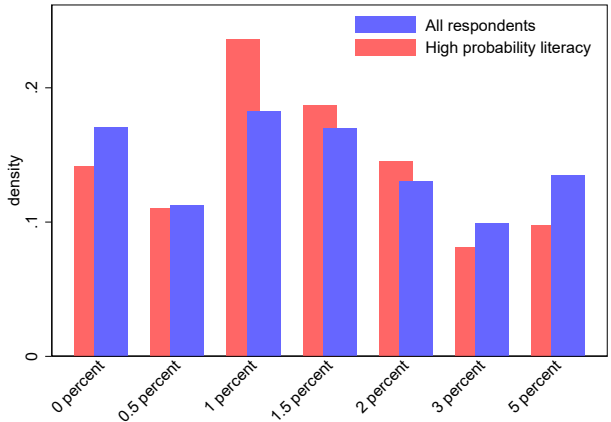
Full Questions

Q1: Expected GDP Growth Impact Over Next 12 Months



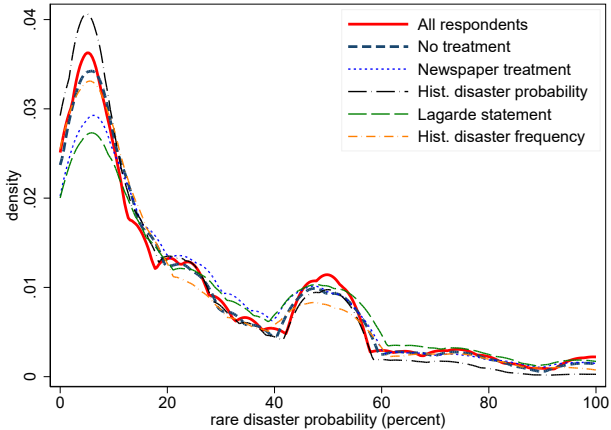
- Average effect of 0.16pp moderate, but sizeable disagreement (std: 1.24)

Q2: Economic Damages Over Next 12 Months



- Large expected damages of 1.51pp.
- Heavy tail: more than 10% expect losses of more than 5%

Q3: Expected Probability of Rare Natural Disasters: dist. of responses



What Is Behind These Responses?

- Likely not measurement error:
  - Similar responses for high probability literacy respondents
  - Meaningful variance with socio-economic variables and economic behavior
- Salience plays an important role:
  - Personal experience
  - Media usage
  - Policy communication

No Difference For High Probability Literacy

All Respondents	Mean	Median	Std. Dev.	N
Growth Impact (Question 1)	0.16 pp	0.00 pp	1.24 pp	4344
Disaster Costs (Question 2)	1.51 %	1.50 %	0.81 %	3228
Disaster Probability (Question 3)	23.08 %	12.00 %	23.76 %	3223

High Probability Literacy Respondents	Mean	Median	Std. Dev.	N
Growth Impact (Question 1)	0.11 pp	0.00 pp	1.18 pp	157
Disaster Costs (Question 2)	1.51 %	1.50 %	0.69 %	151
Disaster Probability (Question 3)	20.38 %	15.00 %	19.13 %	363

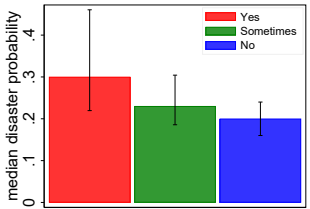
Notes: statistics are weighted using survey weights as well as Huber-robust weights. High probability literacy ability respondents answer a question on probabilities with an error margin of at most 2 percentage points (Q6 in survey appendix).

Responses Vary With Socio-Economic Variables In Meaningful Way

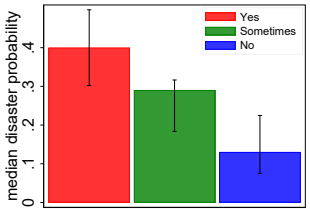
	(1) Growth	(2) Growth	(3) Damage	(4) Damage	(5) Disaster Prob.	(6) Disaster Prob.
Female	0.00293	-0.0100	0.121**	0.119**	3.835***	4.005***
	(0.07)	(-0.22)	(3.29)	(3.27)	(4.46)	(4.60)
35 to 44 years	0.0291	0.0473	0.0697	0.0609	2.078	2.581*
	(0.54)	(0.88)	(1.43)	(1.25)	(1.87)	(2.27)
45 to 54 years	0.0116	-0.0211	0.000592	-0.0162	-1.288	-0.993
	(0.18)	(-0.32)	(0.01)	(-0.29)	(-0.97)	(-0.75)
above 55 years	0.219***	0.217***	-0.142***	-0.134**	0.234	0.602
	(4.17)	(4.10)	(-3.39)	(-3.20)	(0.22)	(0.57)
High Educated	-0.0860	-0.0868	0.0196	0.0296	-0.658	-0.631
	(-1.68)	(-1.68)	(0.47)	(0.70)	(-0.70)	(-0.67)
Middle Income	-0.0826	-0.0965	-0.116*	-0.108*	-0.518	-0.838
	(-1.49)	(-1.74)	(-2.53)	(-2.37)	(-0.50)	(-0.80)
High Income	-0.0946	-0.102	-0.0611	-0.0738	0.263	0.0417
	(-1.31)	(-1.43)	(-1.05)	(-1.26)	(0.21)	(0.03)
Republican	-0.0363	-0.0244	-0.131**	-0.128**	-3.779***	-3.591***
	(-0.67)	(-0.45)	(-2.96)	(-2.92)	(-3.83)	(-3.61)
Democrat	0.0368	0.0574	0.209***	0.210***	3.468***	3.756***
	(0.74)	(1.16)	(5.08)	(5.08)	(3.40)	(3.65)
State FE	no	yes	no	yes	no	yes
N	4344	4344	3222	3210	3223	3223
r2	0.00915	0.0388	0.0549	0.0856	0.0322	0.0629

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

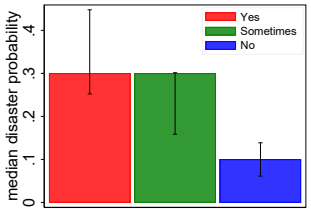
Disaster Expectations and Behavior



eat no or less meat
due to climate change
(Yes: 15.7%)
(No: 58.8%)



refrain from flight
travel
(Yes: 22.6%)
(No: 58.4%)



avoid plastic products
due to climate change
(Yes: 27.3%)
(No: 35.1%)

Salience of Disasters Affects Risk Perception

	(1) Disaster Prob.	(2) Disaster Prob.	(3) Disaster Prob.	(4) Disaster Prob.	(5) Disaster Prob.
County Wildfire Experience	6.505**		3.582*		5.121*
	(2.93)		(2.01)		(2.13)
County Flood Experience	3.429*		4.151***		3.913**
	(2.56)		(3.46)		(2.92)
County Hurricane Experience	0.186		1.175		1.027
	(0.11)		(0.81)		(0.56)
# Hurricane Events in State		0.00368	0.0123		
		(0.51)	(1.24)		
# Flood Events in State		0.00589	0.00842		
		(0.46)	(0.57)		
# Fire Events in State		0.0100	-0.00326		
		(1.23)	(-0.32)		
High Wildfire Risk				8.089***	6.708**
				(3.84)	(3.13)
High Hurricane Risk				-3.520	-3.409
				(-1.61)	(-1.43)
High Flood Risk				-0.625	-0.743
				(-0.38)	(-0.47)
State FE	yes	no	no	yes	yes
Demographic Controls	yes	yes	yes	yes	yes
N	2167	2148	2148	2167	2167
r2	0.138	0.0463	0.0536	0.140	0.148

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Same With Media Usage . . .

	(1) Disaster Prob.	(2) Disaster Prob.	(3) Disaster Prob.
no major TV station	-5.185***		
	(-4.43)		
no major Newspaper		-3.348***	
		(-3.69)	
consume major TV station × no major newspaper			-1.476
			(-1.42)
no major TV station × consume major newspaper			0.673
			(0.23)
no major TV station × no major newspaper			-6.880***
			(-5.31)
State FE	yes	yes	yes
Demographic Controls	yes	yes	yes
N	3223	3223	3223
r2	0.0695	0.0684	0.0718

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Info Treatments Shift Disaster Probability

	(1)	(2)	(3)	(4)
Newspaper (T1)	1.612*	0.943	1.837***	1.497**
	(2.36)	(1.20)	(3.75)	(2.75)
Historic Disaster Size (T2)	-1.624*	-1.808*	-0.728	-0.984
	(-2.43)	(-2.32)	(-1.57)	(-1.89)
Lagarde treatment (T3)	2.855***	2.557**	1.620**	1.383*
	(3.92)	(3.09)	(3.13)	(2.44)
Historic Disaster Freq (T4)	0.240		-1.123	
	(0.27)		(-1.95)	
Climate Change Scale		2.046***		1.026***
		(22.61)		(16.83)
State Fixed Effect	yes	yes	yes	yes
Demographic Controls	yes	yes	yes	yes
Drop largest 25% probabilities	no	no	yes	yes
N	10603	8436	8678	6935
r2	0.0387	0.0992	0.0424	0.0862

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Climate Change Expectations—Taking Stock

Perceived probability of climate-change related natural disaster very large (median 12%)

- Much larger than what historical record suggests (0.34%)
- Varies systematically with socioeconomic characteristics, behavioral adjustment, media exposure, info treatment

Possible deeper explanations:

- Peso problems
- Tipping points
- "Greta" effect

New Keynesian Model With Rare Disasters

Setup largely follows Fernandez-Villaverde and Levintal (2018)

- Solve simplified version of model analytically
- Calibrate to survey expectations on climate disasters
- Solve full model numerically

Rare disaster $d_t \in \{0, 1\}$:

- Probability of climate-change related natural disaster $Prob_t(d_t = 1) = p_t$
- If $d_t = 1$: Fraction of capital is lost, productivity growth drops

Households

Consume, work, and save via bond or capital stock in order to

$$\begin{aligned} \max V_t^{1-\psi} &= U(C_t, N_t)^{1-\psi} + \beta E_t \left(V_{t+1}^{1-\gamma} \right)^{\frac{1-\psi}{1-\gamma}} \\ \text{s.t.} \int_0^1 P_t(i) Y_t(i) di + Q_t B_t &\leq B_{t-1} + W_t N_t + R_t^K K_t + D_t \\ K_t &= \left\{ (1-\delta) K_{t-1} + \left[1 - S\left(\frac{X_t}{X_{t-1}} \right) X_t \right] \right\} e^{d_t \log(1-\mu_t)} \end{aligned}$$

- Consumption and investment goods are standard Dixit-Stigliz aggregates
- Rare disaster destroys fraction μ_t of capital with

$$\mu_t = \bar{\mu}^{(1-\rho_\mu)} \mu_{t-1}^{\rho_\mu} e^{\sigma_\mu \epsilon_{\mu,t}},$$

Firms

Firms produce using labor N_t and capital K_t:

$$Y_t(i) = A_t K_t(i)^{\alpha} N_t(i)^{1-\alpha}$$

Productivity growth

$$\frac{A_t}{A_{t-1}} = e^{d_t(1-\alpha)\log(1-\mu_t)+\Lambda}$$

Calvo constraint: set P_t^* to solve

$$\max \sum_{k=0}^{\infty} \theta^k E_t \left\{ Q_{t,t+k} \left[P_t^* \left(\frac{P_{t-1+k}}{P_{t-1}} \right)^{\chi} Y_{t+k|t} - \mathcal{C}(Y_{t+k|t}) \right] \right\},$$

Market Clearing And Monetary Policy

Firms adjust production to meet demand given at posted prices

- Labor market clearing implies

$$N_t = \int_0^1 N_t(i)di = \left(\frac{Y_t}{A_t K_t^{\alpha}}\right)^{\frac{1}{1-\alpha}} \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\frac{\epsilon}{1-\alpha}} di.$$

Central bank adjusts the short-term nominal interest rate, given by $i_t = -\log Q_t$

- Consider a set of rules below

A Special Case And Some Closed-Form Results

Simplifying assumptions

1. Restrict preferences ($\gamma = \psi$): households maximize expected utility
2. Investment costs prohibitively high and no depreciation: abstract from capital dynamics
3. Focus exclusively on productivity shock
4. No trend growth in productivity: $\Lambda = 0$
5. Extent of disaster not time-varying: $\mu_t = \bar{\mu}$

Canonical (textbook) representation of the model (Galí, 2015)

$$\begin{aligned} \pi_t &= \beta E_t \pi_{t+1} + \kappa \tilde{y}_t \\ \tilde{y}_t &= E_t \tilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - r_t^n) \end{aligned}$$

Natural Rate Drops In Response To Bad News: Intensive and Extensive Margin of Expected Disaster

Given the simplified model, the solution for the natural rate and for potential output is given by:

$$r_t^n = \rho - \Omega(1-\alpha)p\bar{\mu}$$

and

$$y_t^n = \begin{cases} 0, & \text{if } d_t = 0, \\ \Xi_\mu \bar{\mu}, & \text{if } d_t = 1, \end{cases}$$

where $\rho = -\log(\beta)$, $\Omega = \frac{\sigma(1+\varphi)}{\sigma(1-\alpha)+\alpha+\varphi} > 0$ *and* $\Xi_\mu = -\frac{\sigma(1-\varphi)(1-\alpha)}{\sigma(1-\alpha)+(\alpha+\varphi)} < 0$.

Monetary Policy Matters for How Disaster Expectation Plays Out

Assume that monetary policy follows the interest-rate feedback rule, i.e.

$$i_t = \phi_r r_t^n + \phi_{\pi,t}\pi_t$$

with $\phi_{\pi,t} > 1$ *if monetary policy is unconstrained or* $\phi_{\pi,t} = 0$ *and* $P(\phi_{\pi,t+1} > 1) = \zeta$ *if the ELB binds.*
In this case, the unique and stable solution for the output gap and inflation depends on monetary policy and is given by:

$$\tilde{y}_t = \begin{cases} 0 \\ \Pi_y r_t^n \\ \Gamma_y r_t^n \end{cases} \qquad \pi_t = \begin{cases} 0, & \text{if } \phi_r = 1 \\ \Pi_\pi r_t^n, & \text{if } \phi_r = 0 \text{ and } \phi_\pi \in (1,\infty) \\ \Gamma_\pi r_t^n, & \text{if } \phi_r = 0 \text{ and } \phi_{\pi,t} = 0; \end{cases}$$

where the natural rate r_t^n *declines with disaster expectations (both along the intensive and the extensive margin), as established in Proposition 1. Also,* $\Pi_y, \Pi_\pi \geq 0$ *and* $\Gamma_y, \Gamma_\pi \geq 0$*. It holds that* $\Gamma_y > \Pi_y$ *and* $\Gamma_\pi > \Pi_{\pi,t}$*. If* $\phi_{\pi,t} \to \infty$*,* $\Pi_y \to 0$ *as well as* $\Pi_\pi \to 0$*.*

Simulation of Full Model

Calibration to annual frequency, follows Fernandez-Villaverde and Levintal (2018) details

- Monetary policy: conventional Taylor rule
- Set average disaster size to $\bar{\mu} = 0.05$, $p = 0.12$ and $\sigma_p = 0.069$ in line with survey

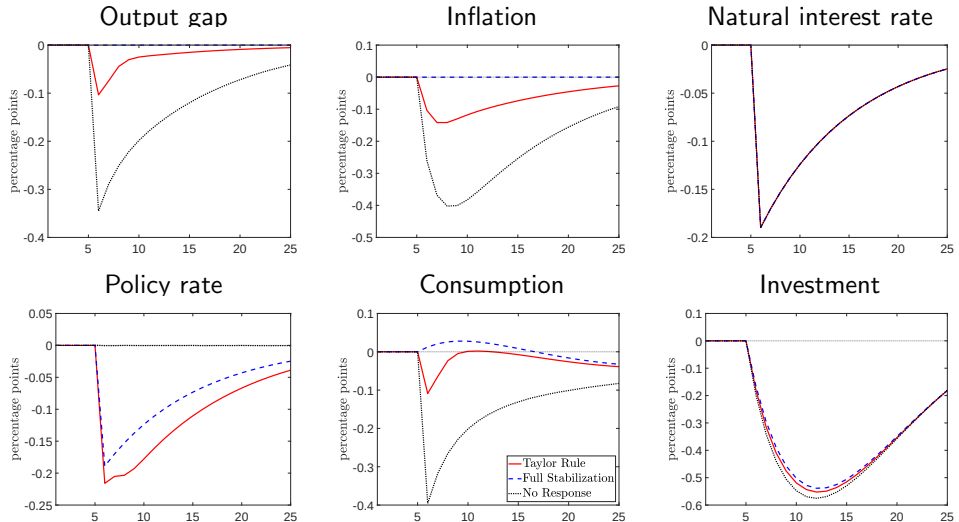
Risky steady state

	No Disaster	Historical Prob.	Survey Prob.
Mean disaster size $\bar{\mu}$	0	0.05	0.05
Std. of disaster size σ_μ	0	0.014	0
Mean disaster prob. $\bar{p}$	0	0.034	0.12
Std. of disaster prob. σ_p	0	0	0.069
Natural rate of interest r^n	1.67%	1.65%	0.85%
Output gap $\tilde{y}$	-0.01p	-0.01pp	-0.17pp
Inflation π	1.94%	1.93%	1.41%

Notes: This table gives simulated risky steady states for different disaster calibrations.

Impulse Response Functions to a Disaster Probability Shock

- Transitory increase in disaster probability from 12% to 14.2%



Conclusion

Expectations regarding short-run economic impact of climate change

- Positive but small for GDP growth
- Prob(large natural disaster)=12%

New Keynesian model with rare disasters

- Bad news lower natural rate
- Directly relevant for monetary policy

"Paradox of Communication"

- Monetary policy by engaging in the climate change debate may deliver bad news
- Adverse impact on natural rate makes life harder for conventional monetary policy, given low interest-rate environment

Question 1: Expected Growth Impact of Climate Change

"The average growth rate of real GDP in the US between 2009 and 2019 has been about 2 percent. Climate change might influence future growth rates positively, say, because it triggers technological innovation or negatively because of regulation and taxes.

What do you think is the overall impact of climate change on economic growth over the next 12 months? Please assign probabilities to each scenario listed below:

Due to climate change, economic growth, compared to what it would be otherwise, will be . . .

- *2 percentage points higher or more (say, more than 4 percent rather than 2)*
- *1 - 2 percentage points higher (say, between 3 and 4 percent rather than 2)*
- *0.1 - 1 percentage points higher (say, between 2.1 and 3 percent rather than 2)*
- *different by -0.1 to 0.1 percentage points.*
- *0.1 - 1 percentage points lower (say, between 1 and 1.9 percent rather than 2)*
- *1 - 2 percentage points lower (say, between 0 and 1 percent rather than 2)*
- *2 percentage points lower or more (say, less than 0 percent rather than 2)"*

Question 2: Expected Economic Damages

"Recently, the economic damage due to natural disasters amounted to about 1% of GDP per year (Source: National Center for Environmental Information). In your view, will these damages be larger or smaller because of climate change? Please assign probabilities to each scenario listed below:

Specifically, what would you say is the percent chance that, over the next 12 month there will be . . .

- *no damage.*
- *less damage then in the past. (say, around 0.5% of GDP)*
- *the same as in the past. (say, 1% of GDP)*
- *more damage than in the past. (say, 1.5% of GDP)*
- *considerably more than in the past (say, 2% of GDP)*
- *much more than in the past (say, 3% of GDP)*
- *extremely rare disasters, with damage in an order of 5% of GDP."*

Calibration Parameters

Variable		Value
$\bar{\mu}$	Mean disaster size	0.05
σ_μ	Standard deviation of disaster size	0
$\bar{p}$	Disaster probability	0.12
σ_p	Standard deviation of disaster probability	0.069
ρ_μ	Persistence of disaster risk shock	0.9
β	Discount factor	0.995
σ	Intertemporal elasticity of substitution	2
ν	Leisure preference	2.33
γ	Risk aversion	3.8
α	Capital share in production	0.21
δ	Depreciation	0.025
ϵ	Elasticity of substitution	10
Λ_A	Trend growth of technology	1.12%
σ_A	Standard deviation of technology shock	0.01
κ_k	Capital adjustment costs parameter	9.5
θ	Calvo price setting parameter	1/2
χ	Price indexation parameter	0.98
ϕ_π	Taylor Rule parameter inflation	1.5
ϕ_y	Taylor Rule parameter output growth	0.5
$\bar{\Pi}$	Inflation target	1.02
$\sigma_{m,t}$	Standard deviation of monetary shock	0.0025

Information Treatment 1

Information treatment 1: Salience of hurricanes and wildfires

We have just a few more questions. But next, before you give us your responses, we would like you to know the following. On September 17, 2020, USA Today summarized information about wildfires and hurricanes as follows:

"This extraordinarily busy Atlantic hurricane season – like the catastrophic wildfire season on the West Coast – has focused attention on the role of climate change. [...] Federal government forecasters from the National Oceanic and Atmospheric Administration announced La Nina' formation last week. It's expected to exacerbate both the hurricane and wildfire seasons.

In the West, climate scientists say rising heat and worsening droughts in California consistent with climate change have expanded what had been California's autumn wildfire season to year-round, sparking bigger, deadlier and more frequent fires like the ones we've seen this year. [...]

And as for hurricanes, scientists also say global warming is making the strongest of them, those with wind speeds of 110 mph or more, even stronger. Also, warmer air holds more moisture, making storms rainier, and rising seas from global warming make storm surges higher and more damaging."

Back

Information Treatment 2

Information treatment 2: Damages, upper bound

"Over the past 20 years there have been 197 natural disasters in the United States, but even the largest caused damages of less than 1% of GDP. (Source: National Center for Environmental Information)."

Back

Information Treatment 3

Information treatment 3: Central bank attention to climate change

You are doing well with the survey. We have just a few more questions. But before you give us your responses, we would like you to read the following extract from an interview with Christine Lagarde, president of the European Central Bank (ECB) from July 08, 2020:

"I think when it comes to climate change, it's everybody's responsibility. Where I stand, where I sit here as head of the European Central Bank, I want to explore every avenue available in order to combat climate change."

Back

Information Treatment 4

Information treatment 4: Size of damages

"Over the past 20 years there have been 197 natural disasters in the United States. Two of them caused damage of more than 0.5 percent of GDP. (Source: National Center for Environmental Information)."

Back

Information Treatments

	(1) Disaster Costs	(2) Disaster Costs	(3) Growth	(4) Growth
Newspaper (T1)	0.0468	-0.0422	-0.0700	-0.0350
	(1.27)	(-0.86)	(-1.45)	(-0.51)
Historic Disaster Size (T2)	-0.0641	-0.146**	-0.0324	0.00855
	(-1.66)	(-2.90)	(-0.60)	(0.12)
Lagarde treatment (T3)	-0.00171	-0.102*	-0.130*	-0.0844
	(-0.05)	(-2.06)	(-2.49)	(-1.20)
Climate Change Scale		0.0638***		0.0495***
		(11.06)		(5.67)
State Fixed Effect	yes	yes	yes	yes
Demographic Controls	yes	yes	yes	yes
N	5816	3444	6938	3462
r2	0.0642	0.115	0.0228	0.0523

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Back