Greening Monetary Policy: 
Climate Change Expectations and the Natural Rate 

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January 28, 2021 

Abstract 

Using a representative consumer survey in the U.S., we elicit beliefs about the economic impact of climate change. Respondents perceive a high probability of costly, rare disasters due to climate change, but not much of an impact on GDP growth. Salience of rare disasters through media coverage increases the probability by up to 10 percentage points. Expectations about climate-change related disasters matter for monetary policy because they impact the natural rate of interest. We quantify this effect in a standard New Keynesian model and find that climate-change related disaster expectations cause a decline of the natural rate by about 70 basis points. If monetary policy fails to accommodate this effect, inflation and output decline by about 0.3 percent. 

Keywords: Climate change, Disasters, Households Expectations, Survey, Media focus, Monetary policy, Natural rate of interest, Paradox of Communication 

JEL-Codes: E43, E52, E58 

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1 Introduction

Climate change is a hotly debated topic and as such it presents a rising, complex challenge for policymakers. Even central bankers have recently begun to weigh in on this debate—as the quotes above illustrate. And while some consider an active role in climate policy to be part of central banks’ mandates, others argue that by assuming such a role, central banks run the risk of undermining their independence and their ability to maintain price stability (Weidmann, 2020). What seems less controversial is that central banks should make every effort to understand “the nature of climate disturbances to the economy.” This, however, is a daunting task because the extent of climate change and its immediate consequences are highly uncertain—let alone their implications for, say, price and financial stability.

Against this background we offer a fresh perspective: irrespective of how climate change actually plays out, the debate about climate change influences peoples’ expectations and these feed back into economically relevant decisions today. This, in turn, matters for monetary policy. In a nutshell our argument can be summarized as follows: for today’s policy it does not matter how climate change plays out; what matters is how people expect it to play out. Figure 1 may help to illustrate the point. The left panel shows how the costs of natural disasters have evolved since the early 1980s. Measured as a fraction of GDP these costs have been very volatile, but they appear to be on a rising trajectory. These data are only suggestive and the debate to what extent natural disasters are caused by climate change has certainly not been settled yet (e.g., Coronese et al., 2019). But ultimately this does not matter, because as the right panel of Figure 1 shows, climate change is on peoples’ minds and increasingly so over time: the panel displays an index for TV and newspaper coverage of the topic as well as the Google Trends indicator for “climate change” search queries—all three showing consistently a considerable increase over time.

In the first part of the paper, we make an attempt to measure the expectations regarding the economic consequences of climate change. To this purpose, we rely on a large, representative consumer survey in the U.S. In the survey we elicit beliefs about climate change and more specifically its likely economic impact. Among other things, we ask respondents whether, going...
forward, they expect climate change to impact output growth, either adversely, say, because of increased regulation or positively, say, because of technological innovation. We find that on average the expected impact on growth is negligible.\footnote{\footnote{For the actual impact of temperature on output and output growth, see the estimates of Dell et al. (2012), Burke et al. (2015), and Colacito et al. (2019).} We also ask them to assign a probability to natural disasters causing significant economic damage in the near future. Here we find a high probability—in fact, it is much higher than what would seem justified given the historical record.

There are various possibilities for why the perceived probability is so high. For instance, respondents may think we have been lucky in the past, just like in the case of “peso problems:” in the relatively short sample under consideration, adverse events have simply materialized less often than what the objective probability would imply. Alternatively, natural disasters due to climate change may be much more frequent in the future because we may have reached so-called “tipping points.” Yet another possibility is that we are picking up a salient “Greta effect:” people overestimate the risk of natural disasters because of a media focus on climate change, consistent with research that has documented that media focus can be an independent source of business cycle fluctuations (Chahrour et al., 2020).

In support of this last possibility we find in the survey that respondents that are not exposed to media at all report a significantly lower estimate for the probability of natural disasters. Moreover, we formally complement our survey analysis with several information treatments. We present several treatments: A “Newspaper treatment” that shows respondents sections of a USA Today newspaper article on the 2020 wildfire and hurricane season; a “Lagarde treatment” which is a recent statement by ECB President Lagarde on the importance of climate change for the...
ECB’s monetary policy; and two treatments which provide respondents with information about the frequency and extent of large disasters in the past. We find that in response to the newspaper treatment, respondents show a statistically significant, up to a 3.4 percentage point higher expected disaster probability. When we remove extreme outliers then the Lagarde treatment also becomes significant. Relaying the intention of the ECB to tackle climate change raises the perceived probability of a large natural disaster by nearly 5 percentage points. Accurate information about past disasters lowers the expected probability of future disasters, but not significantly so. But the reduction becomes significant for a subset of individuals with high numerical ability.

In the second part of the paper, we show why climate change expectations matter for monetary policy with a conventional New Keynesian model. Extended versions of this model are widely used in various contexts, notably by central banks to study the role of monetary policy in determining business cycle outcomes. In order to keep our analysis as transparent as possible we abstract from various complications and rely mostly on the textbook version of the model (Galí, 2015). We only depart from the basic version of the model in order to account for changing expectations about large natural disasters. Specifically, we use a Markov-switching framework that is simple enough for us to be able to derive our main results in closed form. We show, in particular, that as the probability of a natural disaster goes up, the natural rate of interest declines. At the heart of the mechanism which generates this result is a standard asset pricing equation as, for instance, in Barro (2006). Intuitively, as the perceived probability of a natural disaster increases, the desire to save increases as well. For asset markets to clear the natural rate of interest declines.

The natural rate of interest is the interest rate that would prevail if prices were flexible and it serves as an important benchmark for monetary policy (Woodford, 2003). As such it is a counterfactual outcome that cannot be observed directly, but several attempts have been made to estimate it following the seminal work of Laubach and Williams (2003). Recently, it has become clear that the natural rate is on a declining trajectory (e.g., Holston et al., 2017; Jorda and Taylor, 2019) and a number of important factors that may account for this decline have been identified. The list of suspects includes the slowdown of productivity growth, demographic trends and an increase in the convenience yield (e.g., Del Negro et al., 2019).

Once we analyze the results of our survey through the lens of our model, we find that expectations of natural disasters caused by climate also go some way in accounting for why the natural rate is low. Quantitatively, the effect is not trivial: for our baseline calibration we find that climate change related disaster expectations reduce the natural rate by about 70 basis points. This has important implications for monetary policy. In fact, there is a case for “greening monetary policy.” The argument goes as follows. As expectations of climate-change related losses increase, the natural rate declines. Monetary policy may insulate the economy from the impact of the decline of the natural rate by lowering the policy rate accordingly. But if policy makers fail to respond either because they are not willing or able to, say because they are constrained by the effective lower bound (ELB), the consequences may be severe.

To the extent that the ELB is a hard constraint, there is little central bankers can do using conventional monetary policy tools to contain the adverse effect of climate change expectations,
an effect which operates via the natural rate of interest. Yet, our analysis points towards a “paradox of communication” that may be of particular relevance for monetary policy: to the extent that central bankers engage in the debate about climate change they may themselves contribute to the media focus on climate change which, in turn, may foster adverse expectations about future climate-change related disasters. In this way, by trying to tackle a major global challenge upfront, they actually make their current tasks harder today—because interest rates are low and further reductions in the natural rate may be hard to accommodate.

Hence, our analysis thus provides a new angle on the debate of whether and how monetary policy should respond to climate change. A central distinction in this regard is between financial regulation and the implementation of monetary policy (Brunnermeier and Landau, 2020). That supervisors should take climate-change related risks into account in their risk assessment is uncontroversial. The same holds for the growth impact of climate change which is the focus of the present paper. Instead, whether monetary policy should use its instruments actively to impact climate change, say, by twisting asset purchases towards “green assets” raises interesting questions regarding the (secondary) objectives and legitimacy of today’s central banks (Honohan, 2019).

Our paper also relates to a growing literature that studies the interaction of climate change and macroeconomic performance following the influential work by Nordhaus (1994), Mendelsohn et al. (1994) and Nordhaus (2006). This includes the analysis of the optimal policy response to climate change via taxes on fossil fuels as well as the impact of the uncertainty about it (Fried et al., 2019; Golosov et al., 2014). Importantly, while climate change and macroeconomic performance are bound to influence each other, we focus on the impact of climate change (expectations) on macroeconomic performance, just like the work which investigates the extent of directed technological change in response to (actual) natural resource scarcity or to (actual) carbon taxes (Aghion et al., 2016; Hassler et al., 2020). Several studies also take an asset pricing perspective to analyze climate-change related issues (Bansal et al., 2019; Bauer and Rudebusch, 2020; Gollier, 2020). Batten et al. (2020), in turn, disentangle distinct channels through which climate-change related physical risks impact both aggregate demand—via increased uncertainty—and as well as aggregate supply through actual damages.

The remainder of this paper is organized as follows. We introduce our survey in the next section; we present key features of the survey as well as the most important results. Section 3 outlines our model framework and presents analytical results that we derive for a simplified version of the model presents analytical results. In Section 4 we map the main results form the survey into the full model to quantify the macroeconomic impact of climate-change related disaster expectations. A final section offers some conclusions.

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3See Hassler and Krusell (2018) for a recent review of the “macroeconomics and climate” literature.
2 The Survey

In what follows we first provide some basic information regarding the nature of the survey. We subsequently present the main survey results.

2.1 Survey Design

Our data come from a larger, nationally representative daily survey of consumers sponsored by the Federal Reserve Bank of Cleveland which has been running since March 11, 2020. The survey is described in detail in Dietrich et al. (2020) and Knotek et al. (2020). We add a number of questions on climate change to the survey, complementing the regular survey questions on consumers’ demographic characteristics, their expectations, and consumers’ perceptions surrounding COVID-19 and its impact on their behavior. The appendix contains a detailed list of questions.

The survey is administered by Qualtrics Research Services, which representatively draws respondents from several actively managed, double-opt-in market research panels, complemented using social media (Qualtrics, 2019). The survey includes filters to eliminate respondents who write in gibberish for at least one response, or who complete the survey in less (more) than five (30) minutes. Our analysis uses a raking scheme to compute respondent weights ensuring that our sample is representative of the U.S. population by gender, age, income, ethnicity, and Census region.

<table>
<thead>
<tr>
<th>Age</th>
<th>pct. (Target)</th>
<th>Race</th>
<th>pct. (Target)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-34</td>
<td>33.61% (33.3%)</td>
<td>non-Hispanic white</td>
<td>70.55% (66%)</td>
</tr>
<tr>
<td>35-55</td>
<td>33.61% (33.3%)</td>
<td>non-Hispanic black</td>
<td>12.03% (12%)</td>
</tr>
<tr>
<td>older than 55</td>
<td>32.78% (33.3%)</td>
<td>Hispanic</td>
<td>7.69% (12%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Asian or other</td>
<td>9.73% (12%)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>female</td>
<td>49.38% (50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>50.21% (50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>0.41% (-%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household Income</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>less than 50k$</td>
<td>46.23% (30%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50k$ - 100k$</td>
<td>29.08% (35%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>more than 100k$</td>
<td>24.69% (30%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region</td>
<td></td>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>Midwest</td>
<td>19.48% (20%)</td>
<td>some college or less</td>
<td>48.83% (50%)</td>
</tr>
<tr>
<td>Northeast</td>
<td>20.03% (20%)</td>
<td>bachelors degree or more</td>
<td>51.17% (50%)</td>
</tr>
<tr>
<td>South</td>
<td>40.74% (40%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>19.75% (20%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Survey Respondent Characteristics

N=5661

Notes: table reports characteristics of survey participants administered by Qualtrics.

Table 1 provides a detailed breakdown of our sample. It shows that our sample even before weighting is approximately representative of the U.S. population according to the sampling criteria such as age, gender and race. But it is also representative from a geographical point of view, as well as in terms of income and education. As we document below, these characteristic vary systematically with climate-change expectations.
We provide a list of all key questions in Appendix B. In what follows we focus on the three main question. Recall that our focus is on the short run impact of climate change expectations. In our first question we thus ask respondents how they expect climate change to impact economic growth over the next 12 months. Specifically, we ask:

“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)

The second question on climate change elicits respondents’ beliefs about the economic damage due to natural disasters also over the next 12 months, as follows:

“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 on an order of 5% of GDP.”

Our third question asks respondents about their perceptions of natural disaster risks. Specifically, we ask them about a large disaster causing damage of about 5 percent of GDP. Half of respondents receive an information treatment—given in bold below—before receiving the question, which is meant to gauge the extent to which official estimates of damages can affect responses. The info treatment comes in several variants, summarized in Table 2. The accompanying disaster risk question is always as follows:

“[Random Treatment (see Table 2 and Survey Appendix Q3.1 to Q3.5)]

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.”
### Table 2: Information Treatments

<table>
<thead>
<tr>
<th>Information Treatments</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historic disaster frequency (Q3.2)</td>
<td>“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).”</td>
</tr>
<tr>
<td>Newspaper treatment (Q3.3)</td>
<td>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.</td>
</tr>
<tr>
<td>Historic disaster size (Q3.4)</td>
<td>“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).”</td>
</tr>
<tr>
<td>Lagarde treatment (Q3.5)</td>
<td>Respondents are given the following quote by ECB President Lagarde: “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.”</td>
</tr>
</tbody>
</table>

Notes: Appendix B provides full set of questions and information treatments.

### 2.2 Survey Results

In what follows we present the results of the survey. We map the results of the survey into a model framework to quantify the effect of climate change expectations on macroeconomic activity in general and the natural rate of interest in particular. We believe, however, that the results of the survey are also of interest outside the scope of a specific structural model. In a nutshell, we find that respondents hold widely dispersed beliefs about the effects of climate change on economic growth and damages. Also, respondents believe that disasters causing large damages carry substantial probability.

Before discussing details, we briefly assess the numerical abilities of respondents. For this purpose the survey features a question which requires respondents to infer the probability of drawing a black rather than a white ball from an urn given a number of past observations. This is how we get a sense of respondents. We find that respondents’ statistical abilities are quite impressive. When given the information that 14 out of 70 draws from an urn yield black balls, 44 percent of respondents report expected probabilities of drawing a black ball next time within the range of 10-30 percent.

Turning to our main results, we note first, that on average respondents expect a slightly positive impact of climate change on economic growth with an average increase of GDP growth by 0.15 percentage points over the next 12 months. However, there is a lot of mass in the distribution on both positive and negative effects. For example, nearly 20% of respondents
expect a boost to growth by more than 2 percentage points over the next 12 months while nearly 15% expect a growth decline by more than 2 percentage points. The standard deviation is 1.54 percentage points. The first line of Table 3 and the top-left panel of Figure C.1 summarize and illustrate these results.

Table 3: Survey Summary Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Std. Dev.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth Impact (Question 1)</td>
<td>0.15pp</td>
<td>0.00pp</td>
<td>1.54pp</td>
<td>3382</td>
</tr>
<tr>
<td>Disaster Costs (Question 2)</td>
<td>1.67%</td>
<td>1.50%</td>
<td>1.15%</td>
<td>2266</td>
</tr>
<tr>
<td>Disaster Probability (Question 3.1)</td>
<td>27.59%</td>
<td>15.00%</td>
<td>29.96%</td>
<td>1979</td>
</tr>
</tbody>
</table>

Notes: statistics are weighted using survey weights.

Second, respondents expect substantial economic damages, amounting to 1.67% of GDP on average over the next 12 months. Again, expectations are widely dispersed over loss scenarios. For example, approximately 15% of respondents expect 0 losses, while 20% expect losses equal to 1% and more than 10% expect losses equal to more than 5% of GDP. The standard deviation of expected losses is at 1.15%. The second line of Table 3 and the top-right panel of Figure C.1 summarize and illustrate these results.

Third, when we ask respondents about the probability of a climate-change related disaster with damages of 5% of GDP within the next 12 months, we again obtain a wide distribution of responses. The mean probability for such a rare disaster is at 27.59% while the median is at 15%. In fact, as the high median probability suggests, there is a substantial mass of respondents that assign large probabilities to such an event. For example, almost 15% of respondents believe that such a rare disaster can occur with more than 60% probability. The lower-left panel of Figure C.1 shows a kernel estimate of the probability distribution, both for the case without information treatment (red solid line) and for various information treatments, to be discussed below. We also summarize the answers to the third question at the bottom of Table 3.

We also relate respondents’ climate-change expectations to their demographic and socioeconomic characteristics through a simple regression analysis, while we control for state fixed effects. Table C.1 in the appendix reports the results. In the case of the expected growth impact of climate change (columns 1 and 2), we note that those aged 55 and above expect climate change to boost growth, while middle and high income is associated with an expected adverse impact of climate change on growth. Regarding expected damages (columns 3 and 4), we obtain a large and negative effect of income. Highly educated respondents, instead, expect larger damages due to climate change in the future, as do women. The effect of age is non-linear: Relative to the youngest age group, those below age 35, those aged 35 to 44 expect a significantly higher damage. Those age 45 to 54 show no differential effect while those aged 55 and above expect significantly lower damages.

Lastly, we make three observations regarding reported probability disaster probabilities, three results emerge: First, by far the largest effect is given for those who identify as ethnically white. Respondents in this category believe that a very large rare disaster is 4% to 6% more likely. Women also report more pessimistic expectations. The expected larger damages, but they also report higher probabilities. For instance, they believe very large rare disasters are 4%
Figure 2: Expected Impact of Climate Change

Growth

<table>
<thead>
<tr>
<th>Growth Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2pp more</td>
</tr>
<tr>
<td>1 to 2pp</td>
</tr>
<tr>
<td>0.1 to 1pp</td>
</tr>
<tr>
<td>-0.1 to 0.1pp</td>
</tr>
<tr>
<td>-0.1 to -1pp</td>
</tr>
<tr>
<td>-1 to -2pp</td>
</tr>
<tr>
<td>-2pp more</td>
</tr>
</tbody>
</table>

Notes: top left panel shows mean probability assigned to each scenario for Question 1, the top right panel the mean probability assigned to each scenario for Question 2. Bottom panels show distribution of expected probabilities of a rare disaster with damage of 5% of GDP within the next 12 months, for baseline and for different information treatments (left) and according to political affiliation (right).

Dist. of disaster prob. (info treatments)

Dist. of disaster prob. (pol. affiliation)

Notes: top left panel shows mean probability assigned to each scenario for Question 1, the top right panel the mean probability assigned to each scenario for Question 2. Bottom panels show distribution of expected probabilities of a rare disaster with damage of 5% of GDP within the next 12 months, for baseline and for different information treatments (left) and according to political affiliation (right).

more likely than men. This finding echoes earlier findings according to which women tend to be more risk averse than men (e.g., Borghans et al., 2009; Charness and Gneezy, 2012; Gustafson, 1998; Jianakoplos and Bernasek, 1998). Republicans, all else equal, instead believe that a very large rare disaster is less likely, by 5%, compared to independent voters. Our treatment in question 3 does not change the probability in a significant way. This is also illustrated in the bottom-right panel of Figure C.1 which shows considerably more mass of the distribution of disaster probabilities on the left for respondents that identify as Republicans.

In the spirit of Malmendier and Nagel (2011) we also assess to what extent the personal experience of respondents shapes their expectations regarding climate-change related risks. For this purpose we rely on official data for natural disaster declarations on a county level provided by the Federal Emergency Management Agency (FEMA) for the last 10 years (Federal Emergency Management Agency, 2020). Within our sample 16.8% of respondents live in a county with a wildfire related disaster over the last 10 years, 42.99% wit a hurricane, tornado, or typhoon event and 40.64% with a flood in the past. From the same data source, we also construct data for the
total number of events (fire, flood and hurricane, etc.) within a state in the given time-span.

We relate the reported probability of a disaster to either respondents’ disaster experience as well as to a measure of “official” disaster risk. For the latter we use the US Natural Hazards Index, provided by the National Center for Disaster Preparedness of Columbia University (NCDP, 2020). For each county, the index categorizes the risk of a given type of natural disaster as either “None”, “Low”, “Medium” or “High”. Table C.4 in the appendix reports the results.

Three findings stand out: First, respondents within counties with a past record of natural disasters tend to expect higher disaster probabilities than respondents without a disaster experience. Second, concerning future risk, especially the increased possibility of wildfires drives up expectations for a future large disaster. Third, when including the total number of disasters of a type for a given state—which should be a good proxy for how common a disaster type is within the state, both in the past experience and for future risk—it is still local experiences which drive the results.

2.3 Media Usage, Information and Expected Disaster Probability

In what follows, we provide some suggestive evidence regarding the formation of climate-change related disaster expectations. Again, due to data limitations, we focus on the reported disaster probability (Question 3), rather than our other expectation measures. Here, we find an important role of information on expected disaster probabilities, consistent the notion that risk perception and expectation formation are governed by salience effects (Bordalo et al., 2016, 2012; Coibion et al., 2021). One the one hand, we find there is an important role of media—TV and newspapers—for the perception of disaster risks. On the other hand, we find that information treatments can affect perceived disaster probabilities, implying a more causal relationship.

To establish this point, we relate the reported probability of a disaster to either measures of respondents’ preferred TV stations and newspapers, or information treatments while continuing to control for the same demographic and socioeconomic variables as before.

Table 4 reports our main results, while Table C.3 in the appendix provides additional results for individual news stations. The main results can be summarized as follows: Respondents who consume news from neither a major TV Station nor a major newspaper exhibit approximately 8.3 percentage points lower rare disaster expectations. This effect corresponds to a reduction of the perceived disaster probability by 25%. Respondents who watch multiple news stations instead have more than 8 percentage point higher disaster expectations. There is some evidence for individual TV Station/Newspaper impacts on the disaster probability of respondents, even though impacts as well as systematic differences between different stations are not readily obvious. For example, readers of the Washington Post or the Wall Street Journal have a negative association with disaster risks, but readers of USA Today exhibit a positive association. TV channels all tend to raise probabilities. Overall, the evidence strongly suggests that salience of disasters communicated (or not) in the news has strong effects on perceptions.

Next, to give a more causal interpretation to these results, we study the effect of our information treatments related to media, public statements or factual information on natural

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4Due to data limitations, we focus on the reported disaster probability (Question 3), rather than our other expectation measures.
Table 4: Reported Probability of Disaster and Media Usage

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no major TV station</td>
<td>-6.054***</td>
<td>-6.054***</td>
<td>-6.054***</td>
</tr>
<tr>
<td>(6.54)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no major Newspaper</td>
<td>-4.131***</td>
<td>-4.131***</td>
<td>-4.131***</td>
</tr>
<tr>
<td>(5.89)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consume major TV station × no</td>
<td>-2.116**</td>
<td>-2.116**</td>
<td>-2.116**</td>
</tr>
<tr>
<td>major newspaper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2.65)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no major TV station × consume</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
</tr>
<tr>
<td>major newspaper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.17)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no major TV station × no major</td>
<td>-8.286***</td>
<td>-8.286***</td>
<td>-8.286***</td>
</tr>
<tr>
<td>newspaper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8.29)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>8.898***</td>
<td>8.968***</td>
<td>9.748***</td>
</tr>
<tr>
<td>(3.67)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State FE</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Demographic and Treatment</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>5636</td>
<td>5636</td>
<td>5636</td>
</tr>
<tr>
<td>r2</td>
<td>0.0637</td>
<td>0.0623</td>
<td>0.0667</td>
</tr>
</tbody>
</table>

Notes: regression relates reported probability of disaster to media usage; * t statistics in parentheses, based on robust standard errors; ** p < 0.05, *** p < 0.01, **** p < 0.001; regression adjusted with survey weights and Huber-robust weights to ensure that sample is representative and independent of outliers, respectively.

disasters on the perceived disaster probability (see Table 2 above). The “Newspaper treatment” shows respondents sections of a USA Today newspaper article on the 2020 wildfire and hurricane season. The “Lagarde treatment” is a recent statement by ECB President Lagarde on the importance of climate change for the ECB’s monetary policy. The “Historic disaster probability treatment” informs respondents that in the past 20 years, there was no disaster in the US that caused damage in the vicinity of 5% of GDP. A variant of this question is our “Historic disaster frequency treatment” which was only asked early on in the survey. It is therefore not included in all subsequent regression analyses. It tells respondents that in the past 20 years, there were two large disasters in the US, both with damages of more than 0.5% of GDP.

Table 5 presents the main results. We find that in response to the newspaper treatment, respondents show a statistically significant, up to a 3 percentage point higher expected probability. When we remove extreme outliers with the top 25% of responses—who report a disaster probability of 50% or higher—the Lagarde treatment also becomes significant. Relaying the intention of the ECB to tackle climate change raises the probability of disaster risk by almost 2 percentage points. The newspaper treatment remains significant. The historic information treatments lower expected probabilities as expected, but not significantly so.

Table C.2 in the appendix shows results for regression on a subsample for respondents with high numerical abilities, that is, for those respondents for with a small error in answering Question 6 (probability of drawing a black ball). In this case we find no effect of the treatment, except in case we provide information about the size of disasters in the past. This lowers
Table 5: Reported Probability of Disaster and Information Treatment

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newspaper (Q3.3)</td>
<td>3.012**</td>
<td>1.865</td>
<td>2.733***</td>
<td>2.402**</td>
</tr>
<tr>
<td></td>
<td>(2.95)</td>
<td>(1.52)</td>
<td>(3.77)</td>
<td>(2.84)</td>
</tr>
<tr>
<td>Historic Disaster Size (Q3.4)</td>
<td>-1.487</td>
<td>-1.597</td>
<td>-0.751</td>
<td>-0.914</td>
</tr>
<tr>
<td></td>
<td>(-1.59)</td>
<td>(-1.36)</td>
<td>(-1.17)</td>
<td>(-1.19)</td>
</tr>
<tr>
<td>Lagarde treatment (Q3.5)</td>
<td>2.013*</td>
<td>1.873</td>
<td>1.929**</td>
<td>1.809*</td>
</tr>
<tr>
<td></td>
<td>(2.04)</td>
<td>(1.57)</td>
<td>(2.73)</td>
<td>(2.17)</td>
</tr>
<tr>
<td>Historic Disaster Freq (Q3.2)</td>
<td>0.537</td>
<td>-0.696</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.58)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate Change Scale</td>
<td></td>
<td></td>
<td>2.248***</td>
<td>1.199***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(16.38)</td>
<td>(13.36)</td>
</tr>
<tr>
<td>Constant</td>
<td>7.255**</td>
<td>0.924</td>
<td>7.217***</td>
<td>2.190</td>
</tr>
<tr>
<td></td>
<td>(3.03)</td>
<td>(0.29)</td>
<td>(4.03)</td>
<td>(0.99)</td>
</tr>
<tr>
<td>State Fixed Effect</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Demographic Controls</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Drop largest 25% prob.</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>N</td>
<td>5636</td>
<td>3468</td>
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<td>2845</td>
</tr>
<tr>
<td>r2</td>
<td>0.0559</td>
<td>0.132</td>
<td>0.0627</td>
<td>0.133</td>
</tr>
</tbody>
</table>

Notes: regression relates reported probability of disaster to information treatment (one treatment per respondent); t statistics in parentheses, based on robust standard errors; * p < 0.05, ** p < 0.01, *** p < 0.001; regression adjusted with survey weights and Huber-robust weights to ensure that sample is representative and independent of outliers, respectively. For the treatments, refer to table 2 or Appendix B. Climate Change Scale refers to question Q4, where respondents are asked to rate the threat of climate change on the US on a scale from 0 to 10.

The reported probability of a large disaster. These findings suggests that respondents with high numerical abilities react more to facts than to suggestive information in assessing disaster probabilities.
3 Disaster Expectations in the New Keynesian Model

In order to analyze the implications of climate-change expectations for monetary policy we rely on a conventional New Keynesian model. We outline the model in Section 3.1. The model is standard except that we introduce a simple Markov structure to capture the key aspects of natural disasters, namely that they are rare but potentially important events. We discuss the shock process in Section 3.2. In section 3.3, we present analytical results which highlight the interdependence between economic outcomes due to households’ disaster expectations and monetary policy.

3.1 Model outline

In what follows, we outline the model structure. Our model is an extension of the textbook model by Galí (2015), with the addition of capital in production, Epstein-Zin preferences and the possibility of rare disasters. Similar models have been proposed by Fernández-Villaverde and Levintal (2018), or, as a real business cycle model without nominal rigidities by Gourio (2012).

A representative household has Epstein-Zin preferences over a consumption basket, $C^i_t$, and labor, $N^i_t$, given by

$$\max V^{1-\sigma}_t = U^{1-\sigma}_t + \beta E_t \left( V^{1-\gamma}_{t+1} \right)^{1-\sigma}. \quad (1)$$

In the expression above $E_t$ is the expectation operator, $\beta \in (0, 1)$ is the discount factor and Period utility $U_t$ is given by $U_t = C_t(1 - N_t)^\nu$, with $\nu$ being the rate to leisure preference. the intertemporal elasticity of substitution (IES) is given by $\hat{\sigma} = \left[ 1 - (1 + \nu)(1 - \sigma) \right]^{-1}$. $\gamma$ gives the degree of relative risk aversion. The consumption basket is a bundle of varieties $C_t(i)$ with $i \in [0, 1]:$

$$C_t = \left[ \int_0^1 C_t(i)^{1-\frac{1}{\sigma}} \, di \right]^{\frac{1}{1-\gamma}}. \quad (2)$$

where $\epsilon > 1$ is the elasticity of substitution across varieties. The household chooses consumption in order to maximize (1) subject to (2) and a flow budget constraint:

$$\int_0^1 P_t(i)C_t(i)di + \int_0^1 P_t(i)X_t(i)di + Q_tB_t \leq B_{t-1} + W_tN_t + R^K_tK_t + D_t, \quad (3)$$

as well as a solvency constraint. Here $P_t(i)$ is the price of good $i$ and $B_t$ is a nominally riskless discount bond which trades at price $Q_t$. $W_t$ are wages, $K_t$ is the capital stock at time $t$, $R^K_t$ gives the nominal return on capital holdings and $D_t$ is the household’s dividend income. The capital stock evolves according to:

$$K_t = (1 - \delta)K_{t-1} + \left( 1 - S \left[ \frac{X_t}{X_{t-1}} \right] \right) X_t e^{d_t \log(1-\psi)} \quad (4)$$

Here, $d$ is a binary random variable which takes the value of 0 if no disaster occurs in period $t$ and 1 if a disaster occurs. The process for $d$ is discussed in more detail below. If a disaster occurs, the fraction $\psi$ of the capital stock is lost. Capital adjustment costs are modeled as in
Christiano et al. (2005) and captured by the term $S \frac{X_t}{X_{t-1}}$. Specifically, we assume that:

$$S \left[ \frac{X_t}{X_{t-1}} \right] = \frac{\kappa_k}{2} \left( \frac{X_t}{X_{t-1}} \right)^2$$  \hspace{1cm} (5)

The parameter $\kappa_k$ governs the rigidity in capital adjustment. Optimality requires the following conditions to be satisfied:

$$\frac{W_t}{P_t} = \nu \frac{C_t}{1 - N_t}$$  \hspace{1cm} (6)

$$Q_t = \beta E_t \left\{ \left[ \frac{C_{t+1}(1 - N_{t+1})}{C_t(1 - N_t)} \right]^{\gamma - 1} \frac{V_{t+1}^{\sigma - \gamma}}{E_t \left[ V_{t+1}^{1 - \gamma} \right]} \frac{P_{t+1}}{P_t} \right\},$$  \hspace{1cm} (7)

$$1 = \lambda_t \left\{ \left[ 1 - S \left( \frac{X_t}{X_{t-1}} \right) \right] - S' \left( \frac{X_t}{X_{t-1}} \right) \right\}$$  \hspace{1cm} (8)

$$+ \beta E_t \left\{ \left[ \frac{C_{t+1}(1 - N_{t+1})}{C_t(1 - N_t)} \right]^{\gamma - 1} \frac{V_{t+1}^{\sigma - \gamma}}{E_t \left[ V_{t+1}^{1 - \gamma} \right]} \lambda_{t+1} S' \left[ \frac{X_{t+1}}{X_t} \right] \left( \frac{X_{t+1}}{X_t} \right)^2 \right\}$$  \hspace{1cm} (9)

where the first condition is typically understood as a labor supply relationship and the second condition is the Euler equation. The other two conditions govern the optimal capital stock and investment. $\lambda_t$ give the marginal utility of an additional unit of capital.

$$P_t \equiv \left[ \int_0^1 P_t(i)^{1 - \epsilon} d\epsilon \right]^{\frac{1}{1 - \epsilon}}$$ is the consumption and investment price index. The optimal allocation of expenditures across varieties implies that the demand function for a generic good $i$ is given by:

$$C_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{- \epsilon} C_t.$$

(10)

There is a continuum of firms, $i \in [0, 1]$; each firm produces a differentiated good while operating under monopolistic competition. The production function of a generic firm $i$ is given by

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

where $Y_t(i)$ is the firm’s output, $N_t(i)$ and $K_t(i)$ are labor and capital employed by firm $i$, $A_t$ is productivity common to all firms and $\alpha \in [0, 1)$. For productivity, we assume the following AR(1) process:

$$A_t = A_{t-1} e^{d_t(1 - \alpha) \log(1 - \psi) + \sigma_A \epsilon_{A,t} + \Lambda_A}$$

Where $\epsilon_{A,t}$ is a $N(0, \sigma_A)$ distributed productivity shock, $\Lambda_A$ is trend growth and the term $-d_t(1 - \alpha) \log(1 - \psi)$ captures the effect of a disaster on productivity, reducing $A_t$ by the fraction $\psi$. Firms are constrained in their ability to adjust prices. In each period a fraction $\theta \in [0, 1]$ is unable to adjust its price. Firms that may adjust face an identical decision problem.
They set the optimal prices $P_t^*$ in order to solve
\[
\max_{P_t^*} \sum_{k=0}^{\infty} \theta^k E_t \left\{ Q_t, t+k | P_t^* Y_{t+k|t} - C_{t+k} (Y_{t+k|t}) \right\},
\]
where, according to (10), $Y_{t+k|t} = \beta^k \left( \frac{C_{t+k}}{C_t} \right)^{-\sigma} \left( \frac{P_t}{P_{t+k}} \right)$. Here this assumption is that firms are ready to produce any amount demanded at the posted prices. The optimal price satisfies:
\[
\sum_{k=0}^{\infty} \theta^k E_t \left\{ Q_t, t+k | P_t^* Y_{t+k|t} - M \Psi_{t+k|t} \right\} = 0,
\]
where $\Psi_{t+k|t} = C_t' (Y_{t+k|t})$ denotes marginal costs and $M \equiv \epsilon_0$ is the markup in steady state. If prices are completely flexible ($\theta = 0$), the optimal price implies a constant markup over marginal costs:
\[
P_t^* = M \Psi_{t|t}.
\]
More generally, the price index evolves as follows:
\[
P_t = \left[ \theta (P_{t-1})^{1-\epsilon} + (1 - \theta) (P_t^*)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}.
\]
(11)

Market clearing requires for each variety $i$:
\[
Y_t(i) = C_t(i) + X_t(i).
\]

We define aggregate output $Y_t \equiv \left( \int_0^1 Y_t(i)^{1-\frac{1}{\Gamma}} \right)^{\frac{1}{1-\sigma}}$, labor market clearing implies
\[
N_t = \int_0^1 N_t(i) \, di = \left( \frac{Y_t}{A_t} \right)^{1-\sigma} \int_0^1 \left( \frac{P_t(i)}{P_t} \right)^{-\frac{\sigma}{1-\sigma}} \, di.
\]
and, lastly, we note that the riskless bond $B_t$ is zero net supply.

### 3.2 Canonical Representation and Disaster Expectations

In order to derive analytical results, we simplify our model outlined in section 3.1. First, we assume capital to be constant over time, i.e. $\kappa_k \to \infty$. Second, there is no depreciation in the model $\delta = 0$. Third, for households’ preferences we assume that $\gamma = \sigma$ and that $U_t = \left( \frac{C^{1-\sigma} - 1}{1-\sigma} - \frac{N^{1+\sigma}}{1+\varphi} \right)$, i.e. that period utility is separable in consumption and labor.\(^5\) Simplifying assumptions one and two guarantee that our model features no investment, i.e. $Y_t = C_t$. Assumption three simplifies our preference structure so that the model is equal to the textbook New Keynesian model of Galí (2015). In section 4 we will relax all assumptions again and show the generality of our results numerically.

A log-linear approximation of the equilibrium conditions around a deterministic steady state AD: Due to the permanent nature of the disaster shock, do we have to log-linearize around

\(^5\)Note that this preference structure enhances the tractability of the model, but is not nested into (1)
a balanced growth path? yields the so-called canonical representation. Specifically, using small-scale letters to denote logs, we obtain the following relationships:

\[
\begin{align*}
\pi_t &= \beta E_t \tilde{\pi}_{t+1} + \kappa \tilde{y}_t, \\
\tilde{y}_t &= E_t \tilde{y}_{t+1} - \frac{1}{\sigma} (i_t - E_t \tilde{a}_{t+1} - r^n_t).
\end{align*}
\]

The first equation is the New Keynesian Phillips curve. It links inflation, \(\pi_t \equiv p_t - p_{t-1}\) to expected inflation and the output gap, \(\tilde{y}_t \equiv y_t - y^n_t\). Here \(y^n_t\) is potential output, that is, the output level that would be realized if prices were perfectly flexible. The second equation is the dynamic IS equation. In addition to the output gap and inflation it features the nominal interest rate, \(i_t \equiv -\log Q_t\), and the natural rate of interest, \(r^n_t\), that is, the interest rate that would obtain if prices were fully flexible.

The model features two exogenous variables: technology and the fraction of output lost to natural disasters. The solution for the natural rate is given by\(^6\)

\[
\begin{align*}
\rho^n_t &= \rho + \zeta E_t \Delta a_{t+1} \\
&= \rho - \zeta (1 - \alpha) E_t d_{t+1} \psi,
\end{align*}
\]

where \(\rho = -\log(\beta), \kappa = \lambda(\sigma + \frac{\sigma + \alpha}{1 - \alpha}), \lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha}, \) and \(\zeta = \frac{\sigma(1+\psi)}{\sigma(1-\alpha)+\alpha+\rho}\). Expression (14) shows that the natural rate increases if productivity is expected to increase, that is, if \(E_t \Delta a_{t+1} > 0\) since \(\delta > 0\). Thus, it declines if \(E_t d_{t+1} \psi > 0\), that is, if a disaster is expected with positive probability.

In what follows, we assume that productivity is constant and focus on (expected) changes in the fraction of output lost to natural disasters. Since our focus is on large natural disasters we assume that \(\psi_t\) evolves according to a n-state Markov chain. Most of the time the damage due to natural disasters is zero or negligible, that is, the economy is in the no-disaster state. But there is a non-zero probability that the economy moves to a disaster state in which there is a non-trivial output loss. Formally, we specify the Markov chain by a transition matrix

\[
P = [P(j,k)] = [P(s_{t+1} = k|s_t = j)], \quad j,k \in \{\text{no disaster}, \text{disaster state 1}, \ldots, \text{disaster state n-1}\}.
\]

Since the model does not feature endogenous state variables, we index all variables with \(s\) and omit the time subscript to ease the exposition. Likewise, we index the fraction of output lost in each state, \(\psi_s\) and assume \(\psi_{\text{no disaster}} = 0\).

For the remainder of this section, we focus on a special case with two states only: no disaster and disaster \((n = 2)\). Moreover, we assume that the probability \(\mu\) of transitioning to the disaster state from the no-disaster state is the same as the probability of remaining in the disaster state. Last, we set \(\psi_{\text{disaster}} = \psi > 0\). In this case our Markov chain is degenerate in the

---

\(^6\)The log-linear approximation of (3.1) is given by \(a_t = a_{t-1} + (1 - \alpha)d_t \log(1 - \psi)\). Due to \(\psi\) being small in all our calibrations, we may approximate \(\log(1 - \psi) \approx -\psi\).
sense that it the probability of disaster $\mu$ is independent of the current state:

$$
\hat{P} = \begin{bmatrix}
\mu & 1 - \mu \\
\mu & 1 - \mu
\end{bmatrix}.
$$

(17)

AD: Given our results in Table C.4 we could look analytically at an alternative specification of the Markov chain where expected disaster probabilities depend positively on past realizations. In our numerical simulations below we will consider alternative specification of the Markov chain and explore the robustness of our results. For now, we stick to the special case and solve the approximate model in closed form assuming alternative specifications for monetary policy.

3.3 Model solution

Throughout we assume that monetary policy follows an interest rate feedback rule. The first possibility we consider is that monetary policy tracks the natural rate, as given by (14). Specifically, we assume:

$$
i_t = r^n_t + \phi_\pi \pi_t.
$$

(18)

In this case, monetary policy stabilizes the economy at its natural level and, in fact, accommodates all possible output loss expectations. The following proposition states this result formally.

**Proposition 1** Consider the model, as represented by equations (12) and (13), and assume that monetary policy tracks the natural rate of interest in line with rule (18). In this case, the unique and stable solution is given by: $\pi_t = \bar{\pi}_t = 0$, that is, producer price inflation is zero and the output gap is closed at all times and in all regimes. The natural rate of interest declines in the expected change of output lost due to a natural disaster: $r^n_s = -\zeta(1 - \alpha)E_t d_{t+1}\psi$. In the two-state special case with the transition matrix $\hat{P}$ given in (17), the solution for potential output and the natural rate is given by

$$
r^n_s = \begin{cases}
-\zeta(1 - \alpha)\mu\psi, & \text{if } s = \text{no disaster}, \\
-\zeta(1 - \alpha)\mu\psi, & \text{if } s = \text{disaster}
\end{cases}
$$

$$
y^n_s = \begin{cases}
0, & \text{if } s = \text{no disaster}, \\
\Xi_\psi\psi, & \text{if } s = \text{disaster}
\end{cases}
$$

where $\zeta > 0$ (see equation (14)) and $\Xi_\psi = -\frac{\sigma(1-\phi)(1-\alpha)}{\sigma(1-\alpha)+(\alpha+\phi)} < 0$. By definition $0 \leq \mu \leq 1$ 

**Proof.** See Appendix A.1. ■

Proposition 1 establishes that the natural rate of interest declines in the probability with which the economy is expected to be in the disaster state within the next period (extensive margin: $\mu$) as well as in the severity of the disaster-related losses (intensive margin: $\psi$). This is because in response to an expected disaster households respond by raising their savings in order to smooth expected consumption across time and states. Since there is no vehicle for savings in our (closed) economy (without government debt and investment, by simplifying assumption), the only way for the asset market to clear is that the interest rate declines.

The solution for potential output also depends on the state. In the absence of a disaster potential output is at the steady state level because in the absence of pricing frictions (a scenario which defines potential output) the economic activity does not respond to changes in the
economic outlook. Instead, in the disaster state, households increase labor supply in order to to make up for some part of the output lost in the disaster. Potential output increases as a result.

Proposition 1 also shows that monetary policy can stabilize inflation and output at its natural level if it tracks the natural rate of interest. This involves lowering the policy rate in response to increasing disaster expectations. However, tracking the natural rate, as implied by rule (18), is a demanding policy, not least because the natural rate is not directly observable. Next, we consider a less demanding rule, given by the following equation:

\[ i_t = \phi \pi_t. \]  

(19)

This rule merely requires monetary policy to adjust interest rates in response to inflation. As a result, monetary policy fails to stabilize the economy at its potential as the next proposition establishes formally.

**Proposition 2** Consider the model, as represented by equations (13) and (12), and assume that monetary policy follows the interest-rate feedback rule given by (19). In this case, the unique and stable solution for the output gap and inflation differs across current realizations of \( \Psi_t \). It is given by:

\[ \tilde{y}_t = \Pi_y r^n_s \quad \text{and} \quad \pi_t = \Pi_\pi r^n_s. \]  

(20)

where \( \Pi_y \geq 0 \) as well as \( \Pi_\pi \geq 0 \). If \( \phi \pi \to \infty, \Pi_y \to 0 \) as well as \( \Pi_\pi \to 0 \). **Proof.** See Appendix A.2. ■

Proposition 2 shows that if monetary policy follows a conventional interest rate feedback rule it fails to fully accommodate the effect of the disaster expectations on economic activity and inflation. In this case, the expected output loss due to a natural disaster is recessionary because the actual interest rate exceeds the natural interest rate. There is a negative output gap as demand falls short of potential output and inflation is negative.\(^7\)

Assume now, as a third case, that monetary policy is at the zero lower bound or unwilling to react to output loss expectations:

\[ i_t = 0. \]  

(21)

**Proposition 3** Consider the model, as represented by equations (13) and (12), and assume that monetary policy follows the interest-rate rule given by (21). Monetary policy stays at the ZLB for another period with probability \( \xi \) and reverts back to rule (19) with \( 1 - \xi \). In this case, the unique and stable solution for the output gap and inflation differs across current realizations of \( \Psi_t \). It is given by:

\[ \tilde{y}_t = \Gamma_y r^n_t \quad \text{and} \quad \pi_t = \Gamma_\pi r^n_t. \]

where \( \Pi_y \geq 0 \) as well as \( \Pi_\pi \geq 0 \). If \( \phi \pi \to \infty, \Pi_y \to 0 \) as well as \( \Pi_\pi \to 0 \). **Proof.** See Appendix A.2. ■

In the limiting case where the response to inflation become arbitrarily aggressive, \( \phi \pi \to \infty \), monetary policy manages to implement the flexible price allocation: any deflationary pressure induces a cut of nominal rates such that the real interest rate becomes perfectly aligned with the natural rate.
Where $\Gamma^U_y, \Gamma^U_\pi \geq 0$. In addition, the following holds:

$$\Gamma^U_y \succ \Pi_y, \quad \Gamma^U_\pi \succ \Pi_\pi.$$

**Proof.** See Appendix A.3. ■

As shown in proposition 3, if monetary policy does not react to expectations about future output losses at all, both the output gap and inflation deviation are maximized. Since the nominal interest rate remains unchanged, the gap between real interest rate and natural rate is maximized. The mechanism causing the outcome to the economy is then in principle the same as discussed above.
4 Quantitative model analysis

We now use the model to assess the quantitative effect of climate change expectations as measured in our survey. For this purpose we rely on model simulations which, in turn, require us to assign parameter values. The model is fairly standard and we assign values in line with the literature.

Table 4 provides a list of all model parameters and provides details on the values used in our simulation. A period in the model corresponds to one year. We set $\beta = 0.98$ to target a real interest rate of 2 percent in steady state. We set the intertemporal elasticity of substitution to unity and inverse of the Frisch elasticity of labor supply to 5. The labor share in production in production is $3/4$, the elasticity of substitution across varieties is set to 9. We set the Calvo parameter to 1/2 which implies an average price duration of two periods. This is a high value given that period in the model represents one year. On the other hand there are several studies which assume a high degree of price stickiness to capture the fact that the Phillips curve is fairly flat (CorsettiEtAl2013). We assume throughout that monetary policy does not adjust the policy rate in response to the natural rate. Instead, it responds to inflation with a reaction coefficient of 1.5.

Next, we use the survey results to parameterize our Markov chain. For this purpose we focus on two questions. First, we use the question regarding the expected output damage of natural disasters (question 2). Second, we the question on the probability of a rare natural disaster (question 3).

In the first case, we set $n = 7$, that is, we allow for seven states in the Markov chain, each corresponding to one of the possible answer bins we asked respondents to assign probabilities to. As we anchored the disaster costs for this year at roughly 1% of GDP p.a., we set $\psi = 1.0\%$ in the “no disaster state”. The upper panel of Table 4 reports results. Here we assess the impact on selected variables in the “no disaster state” due to expectations that the economy may switch to one of the 6 other states where output losses are substantially higher.

We find that expectations depress the natural rate of interest by 70 basis points relative to steady state (assuming a value for the intertemporal elasticity of substitution of unity). Because monetary policy does not track the natural rate directly, policy rate is too high, resulting in an output gap of -0.24 ppts. Inflation declines by 0.25 ppts.

For the second exercise, we use the median probability across respondents when asked
### Table 7: Simulation Results

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<tr>
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<td>0.70pp</td>
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<tr>
<td>$r^n_t$</td>
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<td>-1.78pp</td>
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<td>$\bar{y}_t$</td>
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<td>-0.29pp</td>
</tr>
<tr>
<td>$\pi_t$</td>
<td>-0.25pp</td>
<td>-0.41pp</td>
</tr>
</tbody>
</table>

**Expected prob. of rare disaster (Q 3.1)**

$\text{Prob(Disaster}=1) = 15\%$ (median)

<table>
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</thead>
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<td>$\pi_t$</td>
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<td>-0.44pp</td>
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</table>

Notes: This table gives results for our model given the expectations from survey respondents.

about the probability of a rare natural disaster exceeding which would cause an output loss of 5%. Here, we assume that the economy has only two states ($n = 2$), either there is no large disaster and $\psi = 0$ or a large disaster takes place $\psi = 5\%$. For our exercise we assume that we are currently in the former state, with no large disaster present. As table 4 shows, results are in a similar range as for question 2: the natural rate drops by 75 basis points.

Figure 5 provides a graphical representation of the model. In each panel we show the dynamic adjustment of a selected variable over time, focusing on alternative scenarios for monetary policy. The horizontal axis measures time in years, the vertical axis measures the deviation from steady state. In period zero the economy operates in steady. In period 1, the Markov chain becomes operative and the economy starts off in the no disaster state. Still, for reasons discussed above the natural rate drops immediately. In case monetary policy tracks the natural rate inflation and the output gap remain at their steady state value (of zero). This scenario is represented by the blue dashed lines. The red lines instead represent the case of simple interest rate feedback rule. In this case the policy rate is lowered insufficiently and hence there is negative output gap and inflation declines relative to steady state. These effects are amplified in the zero lower bound scenario for which we assume that monetary policy is temporarily unable to lower policy rates at all.

The thin lines in each panel represent the adjustment of the economy in the disaster state, that is, in case an actual output loss materializes. In this case the natural rate increases and there is a positive output as well as inflation because monetary policy is not sufficiently aggressive unless it tracks the natural rate. However, the main point of our analysis is that the climate change related disaster expectations may impact the natural rate—quite independently of when, if at all, such a disaster materializes. This matters for monetary policy in the absence of a disaster, as Figure 5 is meant to illustrate.
5 Conclusion

Using a representative consumer survey in the U.S., we elicit beliefs about the economic impact of climate change. We find that respondents perceive a high probability of costly, rare disasters due to climate change, but not much of an impact on GDP growth. Salience of rare disasters through media coverage increases the probability by up to 10 percentage points.

Increasing expectations about climate-change related disasters matter for monetary policy because they lower the natural rate of interest. We quantify this importance of the expectational channel in a standard New Keynesian model and find that the natural rate drops by
about 70 basis points. If monetary policy fails to accommodate this drop, inflation and output decline by about 0.5 percent.
References


Figure 4: Impulse Response Functions to a Disaster Shock

Notes: Figure shows impulse response functions to a disaster shock in period 6. Output gap relative to flexible price equilibrium. Inflation, consumption, investment, natural rate of interest and rental rate of capital relative to model without disasters.
Figure 5: Impulse Response Functions to a Disaster Probability Shock

Output gap

Inflation

Consumption

Investment

Natural interest rate

Policy rate

Notes: Impulse response functions to a temporary increase in the exogenous disaster probability from 15% to 16.3%. Output gap relative to flexible price equilibrium. Inflation, consumption, investment, natural rate of interest and rental rate of capital relative to model without disasters.
A Proofs

A.1 Natural Level of Output (Proposition 1)

We can derive the natural level of output, similar as in Galí (2015) by:

\[
\frac{1}{\epsilon - 1} = -(w_t - p_t) + a_t - \alpha n_t + \log(1 - \alpha) \\
= -(\sigma c_t + \varphi n_t) + a_t - \alpha n_t + \log(1 - \alpha) \\
= -(\sigma y_t + \varphi n_t) + a_t - \alpha n_t + \log(1 - \alpha) + \sigma \psi_t
\]

where we use in the third step that \( y_t = c_t + \psi_t \). Note that \( \frac{1}{\epsilon - 1} \) gives the markup under flexible prices, i.e. the desired mark up of firms. We may solve to:

\[
\hat{y}^n_t = \Xi a_t + \Xi \psi_t + \Lambda
\]

where \( \Xi_a = \frac{1+\varphi}{\sigma(1-\alpha)+(\alpha+\varphi)} > 0 \) and \( \Xi_\psi = \frac{\sigma(1-\alpha)}{\sigma(1-\alpha)+(\alpha+\varphi)} > 0 \) as well as \( \Lambda = \frac{(1-\alpha)(\mu - \log(1-\alpha))}{\sigma(1-\alpha)+(\alpha+\varphi)} > 0 \).

We can now use the linearized euler equation:

\[
y_t = E_t y_{t+1} - \frac{1}{\sigma} (i_t - E_t \tilde{\pi}_t + 1 - \rho + E_t \Delta \psi_{t+1})
\]

and our solution for the natural output to solve for the canonical IS equation (??) as well as the natural rate of interest:

\[
r^n_t = \rho + \gamma_y E_t \Delta a_{t+1} - \gamma_y \psi E_t \Delta \psi_{t+1}
\]

where \( \gamma_y = \frac{1+\varphi}{\sigma(1-\alpha)+(\alpha+\varphi)} > 0 \) and \( \gamma_\psi = \frac{\alpha + \varphi}{\sigma(1-\alpha)+(\alpha+\varphi)} > 0 \). The natural rate of interest thus declines if households expect damages to rise within the next period \( E_t \Delta \psi_{t+1} > 0 \). Given the equations (??) and (12) and monetary policy following an optimal interest rate rule as given in (18), the only solution is for all regimes that \( \hat{y}_t = 0 \) and \( \pi_t = 0 \). This follows trivially by inserting the interest rate rule into the equations.

A.2 Taylor Rate Rule (Proposition 2)

If the economy follows a Taylor rule, it holds that the response of output and inflation is given as:

\[
\tilde{y}_t = \Pi_y r^n_t \quad (22) \\
\pi_t = \Pi_\pi r^n_t
\]

with \( \Pi_y = \frac{1}{\varphi + \kappa \varphi} > 0 \) for the output gap and \( \Pi_\pi = \frac{\kappa}{\varphi + \kappa \varphi} > 0 \) for PPI inflation.

A.3 Zero Lower Bound (Proposition 3)

Assuming that we stay at the zero lower bound with probability \( \xi \), the solution is given by:

\[
\tilde{y}_t = \Gamma_y^n r^n_t \quad (24) \\
\pi_{H,t} = \Gamma_\pi^n r^n_t
\]
With
\[ \Gamma_y^U = \frac{(1 - \beta \xi)}{(1 - \xi)(1 - \beta \xi)\sigma - \kappa \xi} \] (26)
and
\[ \Gamma_\pi^U = \frac{\kappa}{(1 - \xi)(1 - \beta \xi)\sigma - \kappa \xi} \] (27)

Following Woodford (2003) it can be shown that the solution is determinate as long as \((1 - \xi)(1 - \beta \xi)\sigma - \kappa \xi > 0\). It can also be shown that
\[ \Gamma_y^U > \Pi_y \] (28)
as long as \(\kappa \phi_\pi > -\xi \sigma (1 - \beta \xi) - \kappa \xi\) which holds for common parameter values and that
\[ \Gamma_\pi^U > \Pi_\pi \] (29)
as long as \(\kappa (\phi_\pi - \xi > \sigma \xi (\beta (\xi - 1) - 1))\) which is true if \(\xi < 1\) and \(\phi_\pi > 1\).
B Survey Appendix

B.1 Demographic Questions

First, we ask all respondents the following demographic questions:

D1: Please enter your age.
D2 Please indicate your gender.

- Male
- Female
- Other

D3: How would you identify your ethnicity? Please select all that apply.

- Asian/Asian American
- Black/African American
- White/Caucasian
- Other
- Prefer not to say

D4: Do you consider yourself of Hispanic, Latino or Spanish origin?

- Yes
- No

D5: Please indicate the range of your yearly net disposable income.

- Less than $10,000
- $10,000 - $19,999
- $20,000 - $34,999
- $35,000 - $49,999
- $50,000 - $99,999
- $100,000 - $199,999
- More than $200,000

D6: In which state do you currently reside?

D7: What is the postal (zip) code for the address of your permanent residence?

D8: What is the highest level of school you have completed, or the highest degree you have achieved?

- Less than high school
- High school diploma or equivalent
- Some college, but no degree
- Bachelor’s degree
- Master’s degree
- Doctorate or Professional Degree

D9: How many children do you have?

D10: What is the percent chance that you will leave any inheritance?
B.2 Questions on climate change

Q1: 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)

Q2: 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.

Q3.1: 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.

Half the respondents were given the treatment (in bold letters) before the question.

Q3.2: 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).

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.

Q3.3: 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 Niña’s 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.
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.

Q3.4: 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).
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.

Q3.5: 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.
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 dis-
aster causing damage of about 5 percent of GDP?
The probability of a large disaster will be ___ percent.

Q4: On a slider from 0 (not important at all) to 10 (very important) how severe a prob-
lem do you consider climate change?

Q5: On a slider from 0 (not important at all) to 10 (very important) how severe a prob-
lem do you consider the COVID-19 pandemic?

Q6: Imagine there are white and black balls in a ballot box. You draw a ball for 70 times. 56
times, you have drawn a white ball, 14 times a black ball.
Given this record, what would you say is the probability of drawing a black ball the next time?
The probability is ___ percent.

B.3 Questions on Media Usage and Political Affiliation
Some respondents were additionally given the following questions:
P1: What would you say is your political affiliation?

- Democrat
- Independent
- Republican
- Other

P2: Please select your preferred news station from the list below: (you might pick more
than one answer)

- ABC
- CBS
- CNN
- Fox
- MSNBC
- NBC
- PBS
- Other
- I do not watch any of these TV/news stations.

P3: Please select your preferred newspaper (print or online) from the list below: (you
might pick more than one answer)

- Washington Post
- Wall Street Journal
- New York Times
- USA Today
- Los Angeles Times
- Other
- I do not read any of those newspapers.
### Table C.1: Cross Section Regressions

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State FE: no yes no yes no yes
N: 3382 3381 2250 2244 1978 1978
r2: 0.0112 0.0458 0.0701 0.109 0.0337 0.0801

Notes: t statistics in parentheses, * p < 0.05, ** p < 0.01, *** p < 0.001; This table presents cross section regression results on the impact of demographics on the climate change expectations. We use weighted regressions with robust standard errors. Weights used are the product of survey weights and calculated Huber robust weights.

### C Tables and Figures

35
## Table C.2: Treatment Regressions High Numerical Ability

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Notes: t statistics in parentheses. *, ** p < 0.05, ***, p < 0.01, *** p < 0.001. This table presents regression results on the impact of several treatments on the expected disaster probability. Only data from respondents who were able to answer Q6 correctly by a margin of 2 percentage points was used. We use weighted regressions with robust standard errors. Weights used are the product of survey weights and calculated Huber robust weights.

### Figure C.1: Disaster Probability and Economic Expectations

![GDP Expectations vs Disaster Probability](image1)

![Inflation Expectations vs Disaster Probability](image2)

Notes: Figures show binned scatter plots for the disaster probability and one year ahead GDP (left panel) and Inflation (right panel) expectations. Black line gives predicted quadratic trend. Gray areas are 96% confidence bounds. We drop the largest 25% of disaster probabilities.
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Notes: regression relates reported probability of disaster to use of specific news stations; t statistics in parentheses, based on robust standard errors; * p < 0.05, ** p < 0.01, *** p < 0.001; regression adjusted with survey weights and Huber-robust weights to ensure that sample is representative and independent of outliers, respectively.
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Notes: regression relates reported probability of disaster to personal experience; t statistics in parentheses, based on robust standard errors; * p < 0.05, ** p < 0.01, *** p < 0.001; regression adjusted with survey weights and Huber-robust weights to ensure that sample is representative and independent of outliers, respectively.