CLI MA TE

DANMARKS NATIONALBANK

8 FEBRUARY 2021 — NO. 3

Are climate change risks priced in the US stock market?

Climate change can have an impact on financial stability

The global financial sector faces risks associated with the green transition and physical climate risks. These risks can be a cause for concern, especially if they are not priced by the market.

Read more

Only very short-term risks are priced in the US stock market

We find that climate change risks are priced only when they reach the domestic political debate; longer-running physical and transition risks do not appear to be priced.

Read more

We use textual analysis to measure different risks

We measure risks stemming from US climate change legislation, international summits, global warming and natural disasters.

Read more

CLI
MA
TE

Climate change

Climate change is impacting society already today and will have further consequences in the future. A successful green transition will require unprecedented efforts, both in Denmark and abroad.

As a case in point, climate change and the transition to a greener economy will impact corporate earnings and economic activity. This may compromise price and financial stability in Denmark, which it is Danmarks Nationalbank's objective to ensure. It is therefore essential that Danmarks Nationalbank increases its knowledge of how, and by how much, the climate challenges will impact various parts of the economy.

Against this backdrop, Danmarks Nationalbank will focus on climate challenges in a series of publications.

ABOUT THIS ANALYSIS

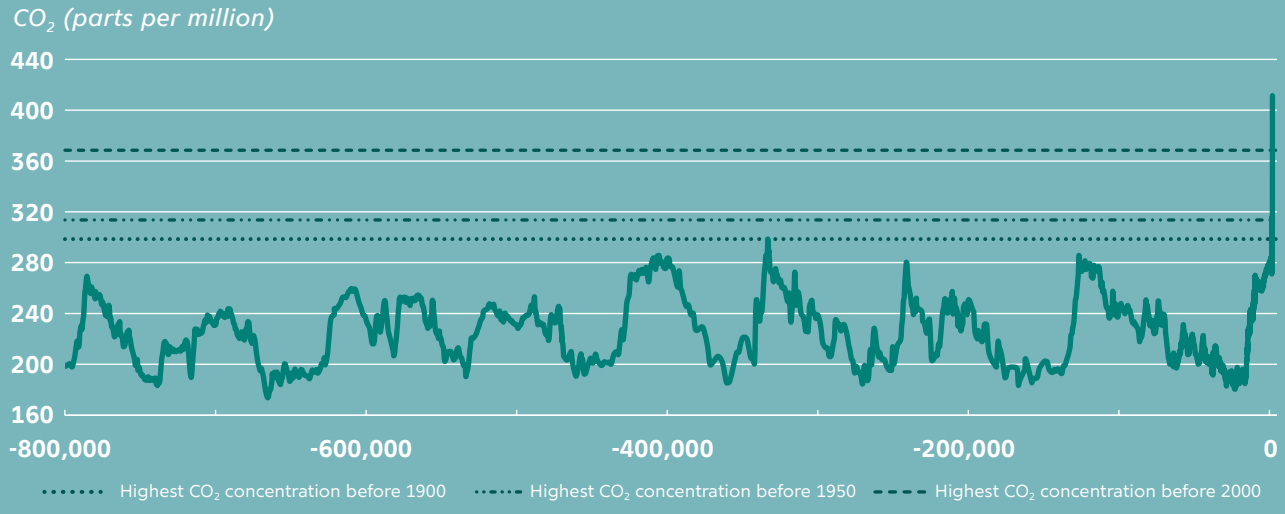
Climate change risk and the stock market

In this analysis, we will focus on how climate change can have an impact on the stock market and thus financial stability by using textual analysis tools. Among main findings are that climate risks started to be priced only very recently in the US stock market. Yet, even over the most recent years, many important sources of climate risk are still not priced.

CO_2 concentration in the atmosphere

800,000 BCE to 2019 ACE

The chart shows the number of carbon dioxide molecules per million molecules of dry air.



DANMARKS
NATIONALBANK

Source: National Oceanic and Atmospheric Administration (until 1957) and National Aeronautics and Space Administration (from 1958).

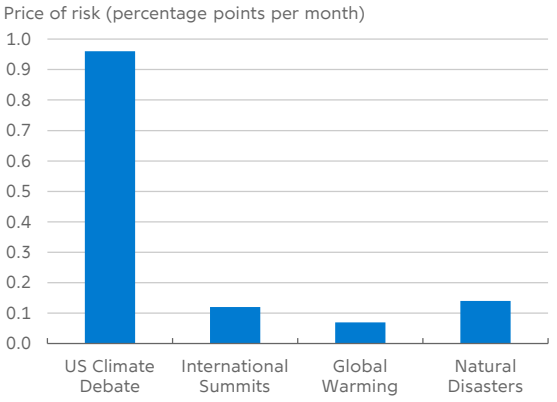
There is scientific consensus that climate change is taking place.[1] The risks from climate change are physical (e.g., hurricanes, rise of sea levels, or forest fires) and transitional (i.e., emanating from the transition to a low-carbon economy). The latter may impose costs on firms due to higher carbon taxation, the emergence of competitive green technologies and changes in consumer preferences. Both physical and transition risks are likely to adversely affect the incomes of some households and firms. This could lead to losses in banks and mortgage credit institutions, and cause systemic financial instability.

In this analysis, we examine US stock prices to understand whether financial investors are aware of climate risks. If they are, then such risks would be reflected in asset prices. Specifically, investors would be willing to hold securities that are more exposed to climate risks only if these assets are comparatively cheaper. In that case, the climate-exposed assets would pay a higher rate of return.

Whether financial investors are aware of climate risks is a question of importance to institutional investors and policymakers. If these risks are not reflected in financial markets, policymakers should intervene and ensure an accurate financial disclosure of these risks. There are also implications for central banks charged with ensuring financial stability. Threats to financial stability typically arise when risks are not properly priced. In fact, in the early 2000s, mispricing of mortgage-backed securities played a key role in fostering the conditions that eventually led to the Great Recession.

A well-functioning financial market could effectively mitigate the build-up of such risks. For instance, if climate risks are properly priced, the market would respond to an increase in transition risks by requiring polluting firms to pay higher interest rates on their loans. The relative worsening of funding conditions for the polluters would lead to a reallocation of capital away from brown firms and into green firms. This would ultimately reduce the climate threats to financial stability. If instead markets fail to properly price climate risks, then policy intervention would be necessary to restore the right financial incentives.

Price of Risk by Topic Chart 1



Note: The price of risk is defined as the difference in expected monthly returns (alphas), expressed in absolute percentage points , between the most risky assets (top 10% decile of US firms listed in NASDAQ, AMEX and NYSE) minus the least risky assets (bottom 10% decile).
Source: Faccini, Matin and Skiadopoulos (2021).

We make use of climate change news articles to disentangle various sources of physical and transition climate risks and investigate whether these risks are reflected in stock returns. First, we classify the news articles via a state-of-the-art textual analysis method.[2] We then compute measures of climate risks for every security listed in the US stock market, based on the sensitivity of their returns to climate news. Finally, to assess whether investors are aware of climate change risks, we check whether riskier assets pay a higher rate of return.

Our main finding is that climate risks started to be priced only very recently in the US stock market. Yet, even over the most recent years, many important sources of climate risk are still not priced. Chart 1 illustrates that only the risks stemming from the political debate are significantly priced. Here, the most risky assets pay a significantly higher rate of return than the least risky ones. Longer-running physical and transition risks, elicited by news on the scientific evidence around global warming and on the occurrence of natural disasters, do not appear to

1 Intergovernmental Panel on Climate Change, 2018.

2 For a thorough description of the method, see Faccini, R., Matin, R. and Skiadopoulos, G., Are Climate Change Risks Priced in the US Stock Market?, *Danmarks Nationalbank Working Paper*, No. 169, February, 2021.

Textual analysis of climate change news

Box 1

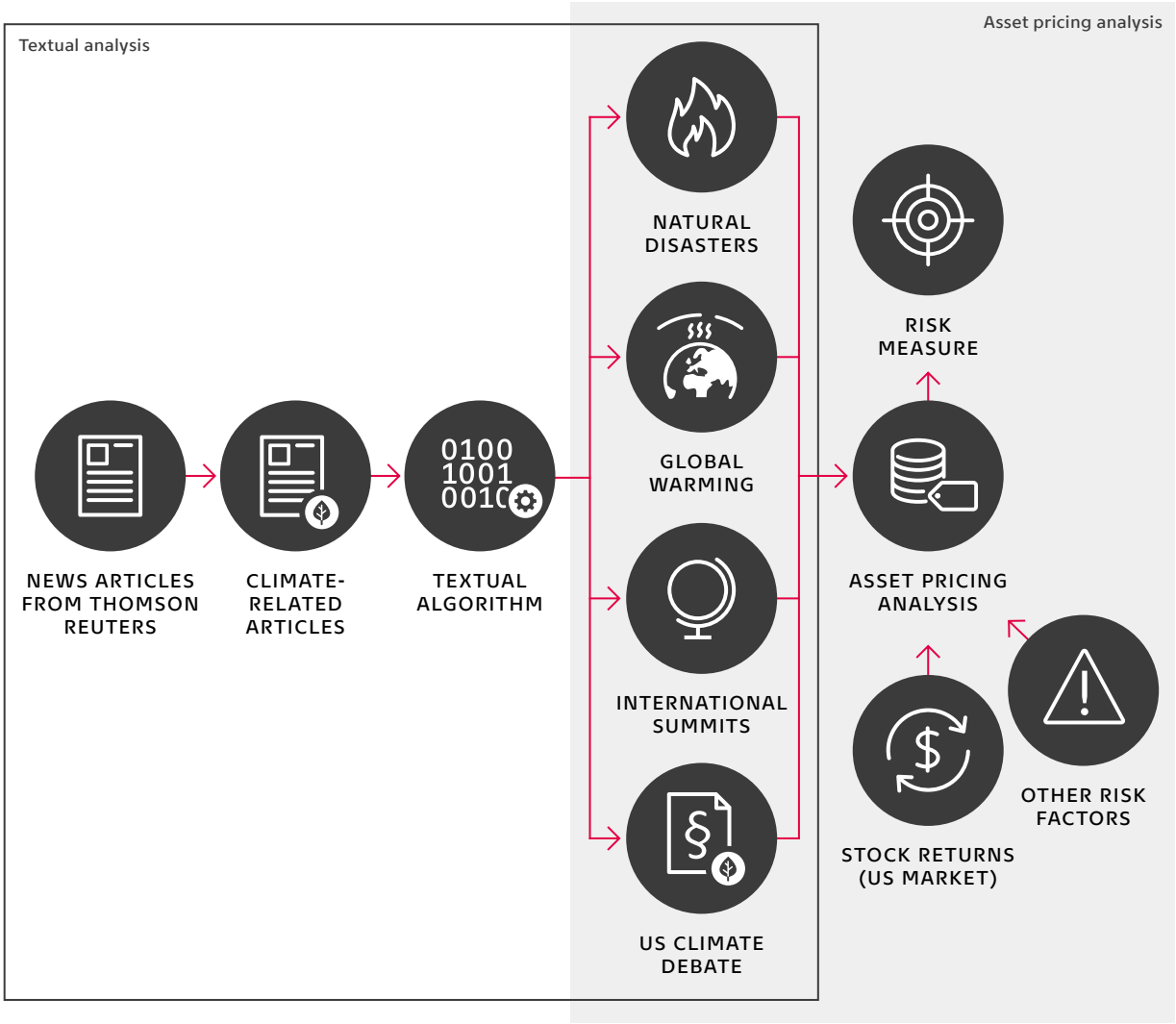
The chart visualises the building blocks of our analysis. We first explain how we break down the entire corpus of articles into four different climate topics of interest, emphasising the different climate risks elicited by each topic (rectangular area on the left). We then focus on the asset price analysis, explaining our approach to assessing whether investors are aware of these risks (rectangular coloured area on the right).

Our initial sample consists of more than 13 million articles from Thomson Reuters News Archive published in the period from 1 January 2000 to 31 December 2018.[1] It contains all news, including entertainment, technology, politics, finance, sports, etc. To filter out the news related to climate change, we only retain those articles that feature the words "climate change". This leaves us with about 34,000 news articles which are broadly related to this topic.

The content of these articles is very mixed. Different subcategories of climate change news may have different relevance for an investor interested in US equities.

Continues

Asset pricing analysis



1. Reuters News reaches one billion individuals each day, and according to corporate sources, its associated trading platform Eikon has a market share of 34%.

Note: Flow chart of the asset pricing analysis.
Source: Danmarks Nationalbank.

Textual analysis of climate change news
Continued

Box 1

Indeed, for someone who is interested in the performance of the New York Stock Exchange, the news that US President Barack Obama in 2008 planned to introduce a system of green taxes and subsidies is potentially more interesting than the news that a hydroelectric power plant is built somewhere in a faraway continent.

We make use of a standard method in textual analysis to break down our heterogeneous set of news into specific climate subcategories.[2] We then label each category based on the frequency and type of words being used in the associated articles. We focus on the four categories of climate change news reported in Chart 1. The categories are: US political debate, international summits, global warming and natural disasters. These topics elicit information on both physical and transition climate risk, at both short-run and long-run horizons.

2. We make use of a methodology called Latent Dirichlet Allocation. For more details we refer the reader to Faccini, Matin and Skiadopoulos (2021).

be reflected in the stock returns. Not even regulatory risks stemming from international summits seem to be priced. This implies that climate risks are only priced with a long lag, which reflects the time that it takes for the evidence on climate change reported in the news to reach the domestic political arena.

While the case of the US is important *per se* for the sheer magnitude of the risks involved and the externality of its emissions, there is a general lesson to be learnt, which extends beyond the US: the failure of financial markets to properly reflect climate risks constitutes a market failure, which is a rationale for government intervention.

Financial markets need clear, comprehensive, high-quality information on the impacts of climate change on businesses. Without it, climate risks cannot be priced. An option available to policymakers is to impose public disclosure requirements in order to foster greater availability of climate-related data. In turn, this should lead to a better assessment of the exposure of businesses to climate-related risks.

Risks elicited by natural disasters and global warming

News about the occurrence of natural disasters and global warming is mostly informative about long-run physical and transition risks. It reveals the direct effects of climate change on current and future production because of rising temperatures and the associated occurrence of extreme meteorological events. These effects are estimated to be disastrous to the planet and the economy.[3] To mitigate these costs, the Intergovernmental Panel on Climate Change (IPCC) called for actions from policymakers to zero net carbon emissions by 2050.[4] As a result, climate change articles relating to natural disasters and global warming are also informative about long-run transition risks. These 'long run' physical and transition risks are not confined to the next century and beyond. Indeed, according to the IMF (2020), the world's temperature will have already increased by 2 degrees Celsius above the pre-industrialised era within the next twenty years, under current policies. This further increase in temperature would map into an expected increase of 700,000 people susceptible to climate change-induced poverty across the globe. Moreover, if policy needs to respond to achieve zero net carbon emissions by 2050, then legislative changes must take place over the next one or two decades.

Risks elicited by the US political debate and international summits

Articles about US climate policy are informative about short-term transition risks. These articles

3 See International Monetary Fund: Mitigating Climate Change Growth- and Distribution-Friendly Strategies, *World Economic Outlook*, pp. 85–113, chapter 3, for a detailed scenario analysis, 2020.

4 Intergovernmental Panel on Climate Change, 2018.

include news on the political debate on climate change, appointments to key positions in organisations like the US Environment Protection Agency, and related laws passed in the US Congress. The articles represent short-run risks because they reflect political intentions and actions over the course of the government's administration, i.e., at most four years; political positions in Congress may radically change with a new round of elections. These positions may well change, even if the same President is re-elected, when there is a shift in the political composition of the Congress; the change in the environmental policy of President Barack Obama's government in its second term is an example.

Articles about international summits are informative about transition risks over a long time horizon. Indeed, agreements reached at international summits take many years to filter through the domestic policy debate, and eventually become law, if they ever do.

Climate change news over time

Having separated the articles according to their topic, we can show how news coverage of a given topic varies over time (Charts 2a, 2b, 2c and 2d). These time series report the average daily occurrence of climate-related articles by topic over each month. Hence, an increase in the series indicates an increase in news coverage.

The series tend to increase around 2007. This is due to the occurrence of many important climate-related events in 2007, as we describe below. It is likely that the media's attention to climate change was also boosted by the award of the Nobel Peace Prize to Al Gore and the IPCC for their efforts to disseminate greater knowledge about man-made climate change. We comment on some peaks in each series by tracing the news that corresponds to them.

News coverage of natural disasters

Chart 2a shows how news coverage of natural disasters varies over time. For instance, in early 2007, the world experienced a series of record-breaking weather events, ranging from flooding in Asia to heatwaves in Europe and snowfall in South Africa. In August 2007, these events became particularly severe, thus the peak in the chart: Hurricane Dean, a category 5 hurricane with a power comparable to Katrina, battered the Caribbean. In August 2008, Eastern India suffered its worst flooding in 50 years, destroying 250,000 houses and affecting about two million people.

In February 2009, there were news reports on the wildfires that raged in Australia, causing hundreds of deaths. In December 2009, in parallel with the Copenhagen conference on climate change, news reports on the increased incidence of natural disasters around the globe, calling for urgent international cooperation. Other news, highlighted in the chart, reflects similar events, including extreme episodes of floods, wildfires, cyclones and pollution.

News coverage of global warming

Chart 2b plots news coverage about global warming. This reflects mostly news on the effects of emissions on global temperatures. This news appears in multiple sources, including reports drafted by governmental and non-governmental organisations, both at a national and international level, publication of scientific studies in academic journals, and articles appearing in non-scientific magazines. Because of its heterogeneity, the global warming factor can be related less often to a significant event, relative to the case of natural disasters. Examples where a strong association can be established include the publication of reports by the IPCC (February 2007, April 2007, November 2007), the UN Panel on Climate Change (December 2009) and the World Meteorological Organization (November 2015). All these documents warned about the impact of global warming and stressed the need to reduce greenhouse gas emissions.

News coverage of international summits

Chart 2c plots the time series of the news on international summits. This reflects the occurrence of international events, where government representatives from around the world meet to negotiate a coordinated intervention to tackle climate change. It also captures how legislation at country level responds to these events. Many of the spikes reported in the chart reflect the occurrence of international conferences on climate change, mostly organised by the United Nations (UN). The conferences of the Hague and Bonn were aimed at gathering the required majority needed to ratify the Kyoto Protocol of 1997, in which countries expressed their joint intention to reduce greenhouse gases by an average of 5% by 2008-2012. The subsequent conferences of Bali, Poznan, Bonn, Copenhagen and Doha were also aimed at achieving further reduction in emissions.

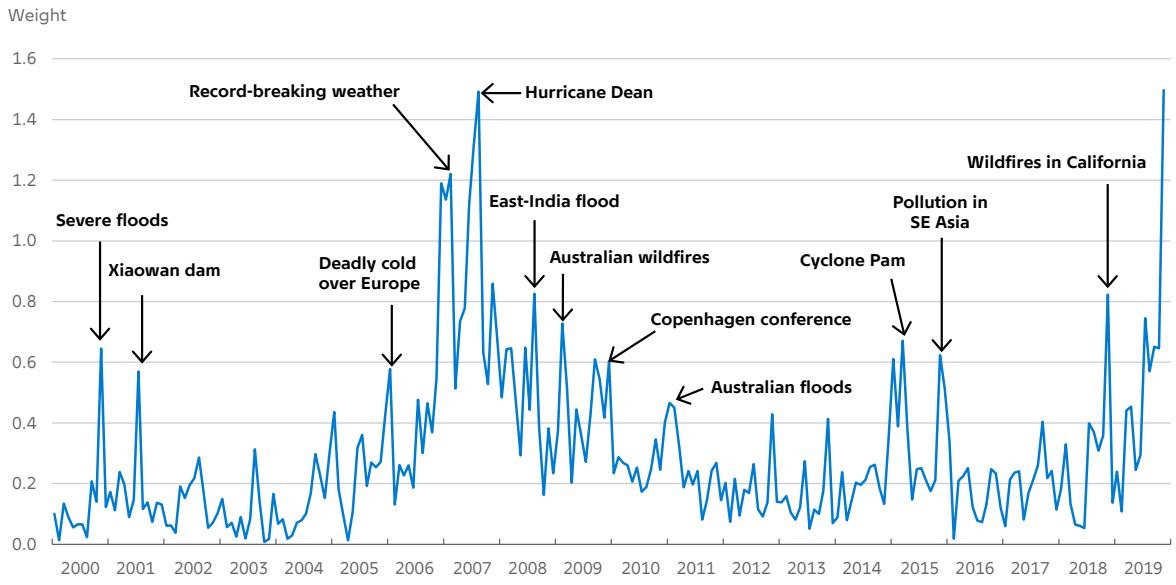
News coverage of the US political debate

Chart 2d plots the time series of the US climate policy news. This series reflects news releases on

presidential speeches, as well as the outcome of elections in the House of Representatives and Senate in the context of their climate-related implications. In addition, the news also reports on environmental bills, the political consequences of natural disasters, and the appointment to key positions of people with well declared views on environmental issues.

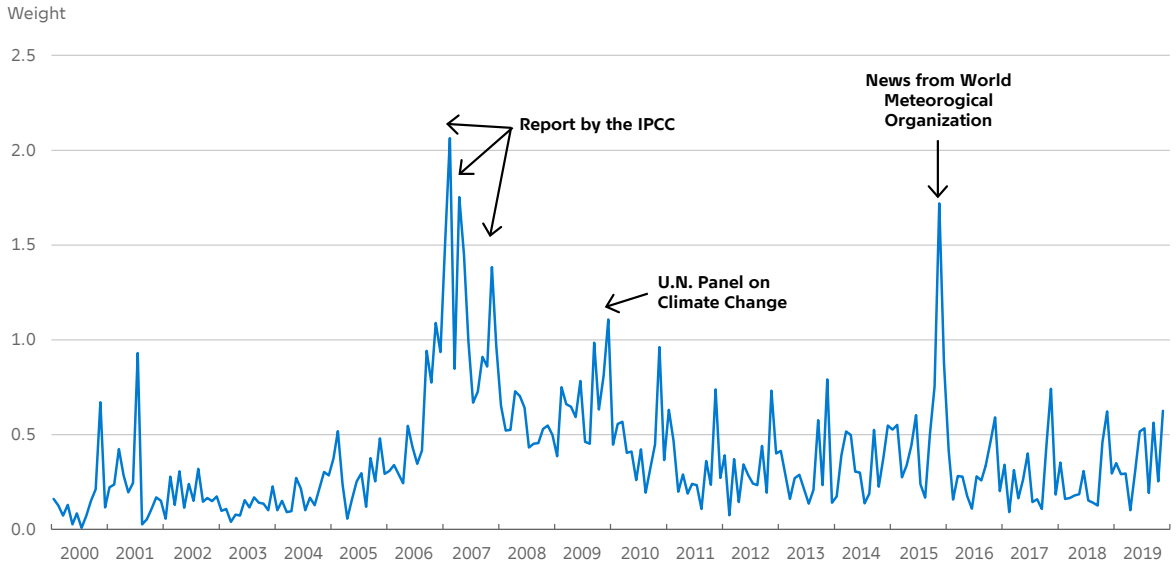
The chart reveals that spikes are often associated with the outcome of elections, which often reshape

Natural Disasters Chart 2a



Note: Time series of Natural Disasters.
Source: Faccini, Matin and Skiadopoulos (2021).

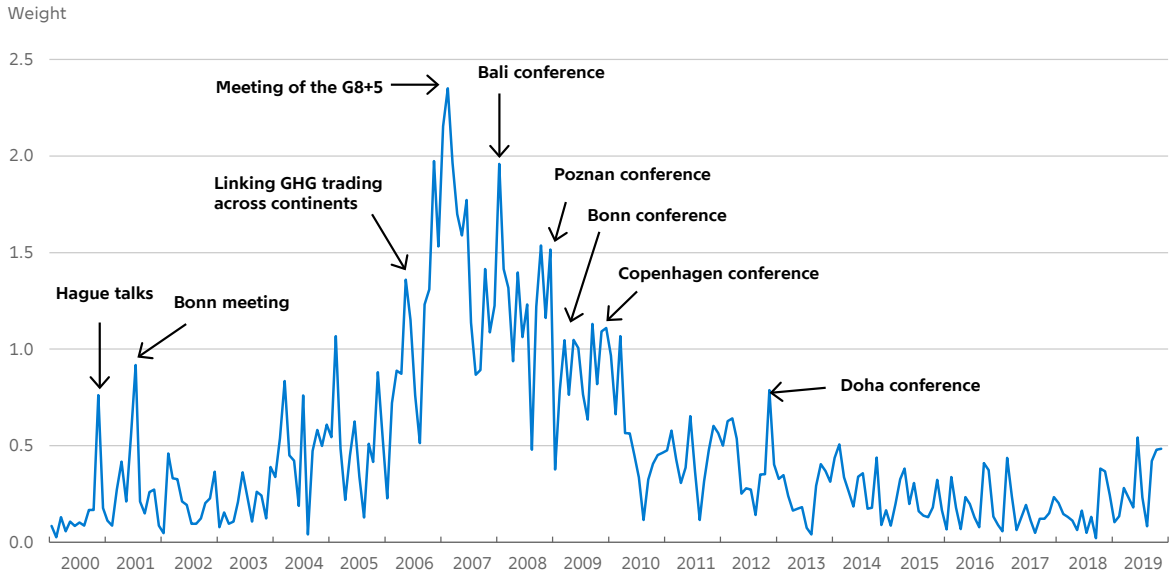
Global Warming Chart 2b



Note: Time series of Global Warming.
Source: Faccini, Matin and Skiadopoulos (2021).

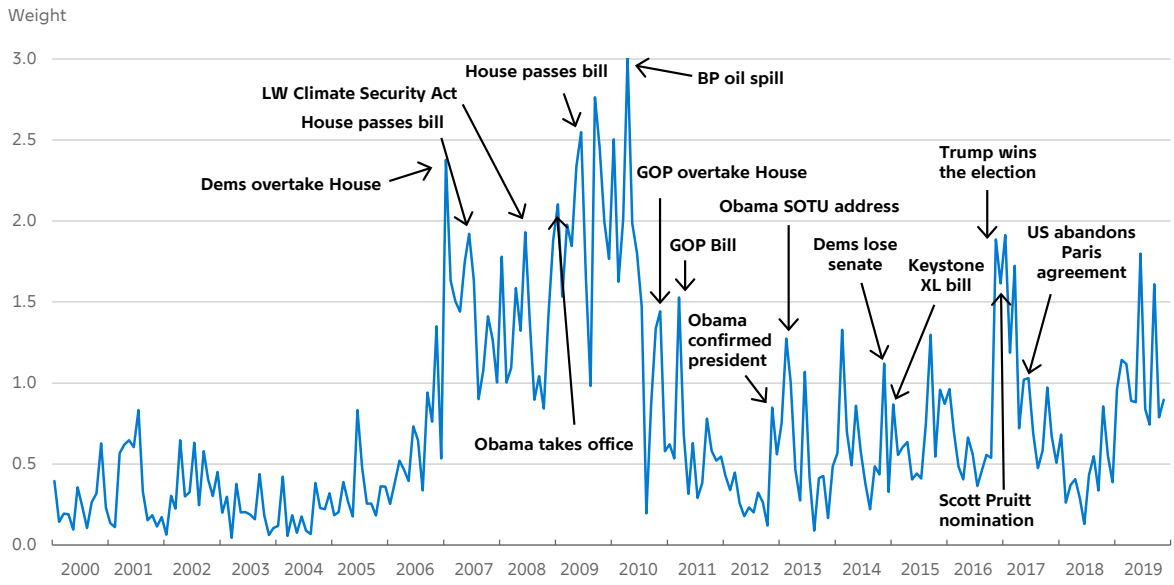
the balance of power between parties, and the prominence of climate change in policy discussions. An important event captured by the time series is the BP oil spill in the Gulf of Mexico (April 2010), which brought the debate on climate issues to the forefront of the political agenda. Also, the decision by President Donald Trump to abandon the Paris agreement is clearly visibly in the time series.

International Summits Chart 2c



Note: Time series of International Summits.
Source: Faccini, Matin and Skiadopoulos (2021).

US Climate Debate Chart 2d



Note: Time series of US Climate Debate.
Source: Faccini, Matin and Skiadopoulos (2021).

Asset pricing analysis

We now turn to analyse whether the risks elicited by the four news topics discussed above are reflected in US stock market prices. The rectangular area to the right of Chart 2 visualises the building blocks of the asset pricing analysis, which takes as input the four series of news depicted in Chart 2, as well as the performance of the US stock market. Specifically, we collect daily stock returns for the NYSE, NASDAQ and AMEX, which implies that for each day we observe on average about 4,700 returns, from a total of 10,498 listed firms in our sample (1 January 2000-31 December 2018).

Stock prices respond to news, including climate news. But each share price will respond in a different way to the same news. For instance, after the news of the introduction of a carbon tax, the prices of businesses that are directly affected should fall in accordance with their carbon emissions. Possibly, the price of some securities may even rise, e.g., if a company produces sustainable energy. Some securities are therefore more risky than others with respect to a given type of news.

Consider two securities that differ only with respect to their sensitivity to one of these topics. Let's also define the security with the larger sensitivity as the riskier asset. If investors are aware of their different sensitivity (risk), then the riskier security should be cheaper. That is, it should yield, on average, a higher rate of return. If this is the case, then we say that the risk is priced, and the difference in returns between the two assets measures the price of their relative risk.

To assess whether climate risks are priced in the US stock market we proceed as follows. First, we measure for each security in our sample the sensitivity of its return to each of the four topics in Chart 2. We consider these measures as an indication of the climate risks faced by each individual security. Next, we group together the securities that are most risky with respect to a specific topic of climate news, and compute the return on this portfolio. Similarly, we group in a different portfolio the securities that are least risky, and compute its return. We then check whether the portfolio of high-risk securities earns a higher return, on average, than the portfolio of low-risk securities. If this difference in returns is significantly different from zero, then we can conclude that climate risks are priced.

There are many reasons why some securities may earn different returns, beyond climate risks. For instance, some businesses are smaller than others, and may find it more difficult to access credit in bad times. When measuring the difference in returns between high- and low-climate-risk portfolios, it is important to account for the role played by other potential sources of risk, and make sure that any estimated difference only arises because of climate risks. The asset pricing literature has indicated many sources of risk that can successfully explain differences in US stock returns. In our analysis, we consider the most important ones, in different combinations.

Taking stock of a multitude of tests, a clear general picture emerges. As illustrated in Chart 1, securities that are more exposed to the risks deriving from the US political debate tend to pay a significantly higher return relative to those that are less exposed. The estimated prices of the risks elicited by the other climate topics depicted in Chart 1 are instead very small. The reason why these estimates are not exactly zero could simply reflect statistical uncertainty. Moreover, the price of risk associated with the political debate is large and beyond statistical uncertainty only in the most recent years, i.e., after 2012. Specifically, with respect to climate policy news, the estimated difference in monthly returns between the top 10% most risky assets and the bottom 10% least risky assets ranges from 0.66 to 1.18 percentage points over the period after 1 January 2012. Our preferred estimates, which are less likely to confound the price of climate risks with other sources of risks, are those towards the bottom of the range, i.e., around 0.66 percentage points per month.

How do our results compare to other findings in the literature? Comparing our results to those of other studies is a difficult task because the literature considers different aspects of climate change risks and uses different methodologies, finding mixed results in terms of whether climate risks are priced. Our measure of risk is derived from the sensitivity of asset prices to climate policy news. Because it is well known that asset prices tend to respond very strongly to news, moving by several percentage points a day if the news is important, it is perhaps no surprise that our measure of risk delivers results that lie at the upper end of the estimates reported in the literature.

The closest term of comparison to our work is the study by Hsu, Li and Tsou (2020), who approximate climate risk by the level of emissions. The underlying idea is that firms that pollute more are also more exposed to the risk that policymakers will respond to climate change by taxing emissions. They use the same methodological approach discussed above, and only provide results for the difference in returns between the top 20% most risky assets and the bottom 20% least risky assets. They find an annual differential return of 4.0 percentage points. Our preferred estimates, computed using their same classification of stocks, range between 5.0 and 5.6 percentage points per annum.

To sum up, we find that only the climate risks stemming from the domestic political debate are reflected in US stock market prices. This implies that financial investors are only aware of, or only care about, the very short term risks. Hence, substantial sources of longer-running climate risks may not be adequately priced.

Literature

Faccini, R., Matin, R. and Skiadopoulos, G. (2021), Are Climate Change Risks Priced in the US Stock Market?, *Danmarks Nationalbank Working Paper*, No. 169, February.

Hsu, Po-Hsuan, Li, Kai and Tsou, Chi-Yang (2020), The Pollution Premium, Hong Kong University of Science and Technology, Mimeo.

Intergovernmental Panel on Climate Change (IPCC). 2018a. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, edited by V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea,P. R. Shukla, A. Pirani and others, In press.

International Monetary Fund (2020): Mitigating Climate Change – Growth- and Distribution-Friendly Strategies, *World Economic Outlook*, pp. 85–113. Chapter 3.

Appendix A: The Asset Pricing Model

This Appendix provides an overview of the methodology used in this analysis. For further details, we refer to the Working Paper.[5] In a first step we regress

$$r_{i,t} - r_t^f = \alpha + \beta_i^\tau F_t^\tau + \boldsymbol{\gamma_i X_t} + \varepsilon_t, \qquad (1)$$

where $r_{i,t}$ denotes the daily return of a given security *i* at time *t*, r_t^f denotes the risk-free rate, as proxied by the return on a three-month government bond. F_t^τ is the time series of a particular textual factor depicted in Chart 2, and indexed by superscript τ, $\boldsymbol{X_t}$ is a vector of variables that have been found to explain the cross-section of US stock returns and ε_t is a standard error term with zero mean. We note that the coefficient β_i^τ in equation (1) measures the sensitivity of a given security *i* to the textual factor. As such, β_i^τ carries information about the risk of each individual security with respect to the climate change risks elicited by the textual variable F_t^τ. Under the assumption that an increase in news coverage captures an increase in risk, negative betas identify risky assets, that is, the assets that tend to experience a fall in returns when risk increases. The more negative the beta, the riskier the asset.[6]

We estimate the coefficients β_i^τ for all the securities in our sample and overlapping three-month periods. That is, at the end of every month, we estimate equation (1) recursively, using a rolling window consisting of daily observations over the previous three months. We roll forward the starting date of the window by one month at each iteration. At the end of every month, we rank the estimated betas from the smallest to the highest, and then sort securities in portfolios according to their beta, creating quintile and decile portfolios. For each portfolio, we compute the average monthly return by weighting the return of every asset by the market capitalisation of its underlying company. Next, we compute the return on the spread portfolio, which is defined as the difference in returns between the top percentile and the bottom percentile portfolio. Lastly, we estimate

$$r_{s,t} = \alpha + \boldsymbol{\gamma_s X_t} + \eta_t, \qquad (2)$$

where $r_{s,t}$ is the monthly return on the spread portfolio, η_t is a standard error term with zero mean and $\boldsymbol{X_t}$ is the same vector of variables that was used in equation (1). The price of risk is given by the estimated coefficient α, which measures the return on the spread portfolio that cannot be attributed to the standard sources of risk captured by the variables $\boldsymbol{X_t}$.

5 Faccini, Matin and Skiadopoulos, Are Climate Change Risks Priced in the US Stock Market?, *Danmarks Nationalbank Working Paper*, No. 169, February, 2021.

6 For a discussion of the relationship between news coverage and risk for each individual climate factor, we refer to Faccini, Matin and Skiadopoulos, 2021

PUBLICATIONS

NEWS

News offers a quick and accessible insight into an Analysis, an Economic Memo, a Working Paper or a Report from Danmarks Nationalbank. News is published continuously.

ANALYSIS

Analysis from Danmarks Nationalbank focuses on economic and financial matter. Some of the analyses are published with a regular frequency e.g. *Outlook for the Danish economy and Financial stability*. Other analyses are published continuously.

REPORT

Report comprises recurring reports and reviews of the functioning of Danmarks Nationalbank. For instance Report includes the *Annual report* and the annual publication *Danish government borrowing and debt*.

ECONOMIC MEMO

Economic Memo is a cross between Analysis and Working Paper and it often shows the ongoing study of the authors. The publication series is primarily targeted at professionals. Economic Memo is published continuously.

WORKING PAPER

Working Paper presents research projects by economists in Danmarks Nationalbank and their associates. The series is primarily targeted at professionals and people with an interest for academia. Working Paper is published continuously.

The analysis consists of a Danish and an English version. In case of doubt regarding the correctness of the translation the Danish version is considered to be binding.

DANMARKS NATIONALBANK
LANGELINIE ALLÉ 47
DK-2100 COPENHAGEN Ø
WWW.NATIONALBANKEN.DK

This edition closed for contributions on 26 January 2021

Renato Faccini
Deputy Head of Research
rmmf@nationalbanken.dk
ECONOMICS AND MONETARY POLICY

Rastin Matin
Senior Quantitative Risk Analyst
rma@nationalbanken.dk
FINANCIAL STABILITY

CONTACT

Ole Mikkelsen
Communications and Press Officer
omi@nationalbanken.dk
+45 3363 6027
SECRETARIAT AND COMMUNICATIONS

DANMARKS NATIONALBANK