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# Climate Risks and Financial Markets: The Role of Financial Regulators in the UAE and Around the World

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**Abstract**

Rising global temperatures and an increased frequency and intensity of extreme weather events pose physical climate risks to communities and economies around the world. At the same time, policies to reduce carbon emissions constitute transition climate risks for high-emission economies. These effects are likely to be felt particularly in oil producing countries in the Middle East, a region characterized by already high baseline temperatures. This paper summarizes the state of knowledge on how physical and transition climate risks can affect economic activity, asset values, and potentially financial stability, with particular references to the case of the UAE. We provide suggestive evidence consistent with real estate markets in the UAE at least partially incorporating physical climate risks into the pricing of properties. We also describe a variety of tools that financial regulators might use to better measure and manage climate-related financial risks and, depending on their mandates, to support a green transition.

**Keywords:** Climate risks, financial regulators, United Arab Emirates.

**JEL Codes:** G12, Q54

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# Contents

# 1 Introduction

A central challenge facing the world is the rapid increase in global temperatures and the associated rise in extreme weather events. Beyond the wide-ranging social implications of these developments, it is increasingly clear that both changes in the climate as well as global policy efforts to reduce carbon emissions might affect economic activity, asset prices, and financial stability. While these risks are generally global in nature, their effects are likely to be felt particularly strongly in the Middle East, a region with high baseline temperatures and many economies that are substantially dependent on the oil and gas sectors. The objective of this paper is to provide an overview of an emerging body of research that explores the effects of various climate risks on financial institutions, and to outline some of the tools that financial regulators have used to assess and manage any potentially resulting threats to financial stability.[1] Related discussions can be found, for example, in Litterman et al. (2021) and Bank for International Settlements (2022).

To facilitate this discussion, Section 2 discusses the increases in global temperatures and in the frequency of natural disasters, and describes various policy responses to address climate change, both in the United Arab Emirates (UAE) and around the world. Section 3 then summarizes an empirical literature that finds that the physical manifestations of climate change ("physical risks"), and as well as regulatory actions to mitigate carbon emissions ("regulatory transition risks") already influence economic activity and valuations across a wide range of asset classes, from equities, to fixed income, to real estate. To complement this existing evidence, we also present a new analysis that suggest climate risk may already be priced in some UAE housing markets.

Through affecting economic activity and asset values, climate risks can subsequently affect a wide range of firms in the financial sector, including asset owners and managers, banks, and insurance companies. We review some of these exposures of the financial sector in Section 4, focusing on the climate risk exposures of banks. For example, we highlight that banks with loan exposures to sectors with high carbon emissions may see higher default rates in their loan books in response to realizations of regulatory transition risks that substantially reduce the repayment abilities of these firms. Similarly, extreme weather events that lead to widespread destruction of real assets can lead to defaults on both corporate loans and mortgages.

[1] We focus our discussion on the possible roles of financial regulators tasked with guaranteeing the stability of their financial systems. Depending on their mandates, other financial regulators and policy makers may want to consider climate-related risks for reasons beyond their possible implications for financial stability. For example, the potential implications of various climate-related risks on the rate of inflation could lead monetary policy authorities to consider climate factors in their monetary policy decisions.

In light of these potential effects of climate risks on firms in the financial sector, regulators and policymakers around the world have begun to take a more active role in shaping financial institutions' response to climate change and emissions regulation. For example, financial regulators are increasingly devising guidelines and stress tests to assess climate-related financial risks and encourage prudent risk management practices. They are also pushing for greater climate-related disclosures from both firms and financial institutions, ensuring that financial institutions adequately assess and disclose their climate risks. We review some of these possible roles for financial regulators in Section 5, and describe some of the measures taken in particular by the Central Bank of the UAE.

# 2 The Changing Climate and Regulatory Responses

## 2.1 The Changing Climate

According to National Oceanic and Atmospheric Administration (2023), average global temperatures have risen by about 0.08 degrees Celsius (0.14 degrees Fahrenheit) per decade since 1880, or about 1.1 degrees Celsius in total. This trend has recently accelerated, with the rate of warming since 1981 being more than twice as fast, at 0.18 degrees Celsius (0.32 degrees Fahrenheit) per decade. The year 2022 was the sixth-warmest year on record, and the 10 warmest years in history have all occurred since 2010.

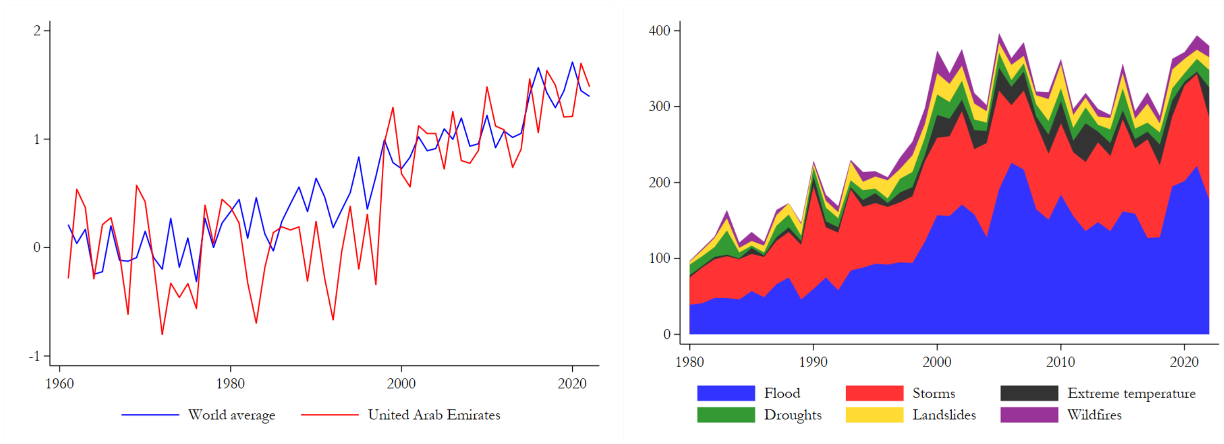
Similar to much of the rest of the world, the UAE has also experienced significant temperature increases in recent decades. Based on data from the National Center of Meterorology (2023), temperatures have shown a consistent upward trajectory, with average temperatures gradually climbing and frequently exceeding 45 degrees Celsius (113 degrees Fahrenheit) during the summer season. Figure 1a illustrates the trajectory of temperature changes in the UAE and the average for the world relative to the base period of 1951–1980. Both lines exhibit a strong upward trend over this period.

These rising temperatures have been accompanied by an increase in the frequency and intensity of extreme weather events around the world. As illustrated in Figure 1b, the frequency has increased particularly for floods and storms, even though some stabilization seems to have occurred in the last 15 years. The Intergovernmental Panel on Climate Change (2023) emphasized that such extreme weather events pose substantial risks to human communities, ecosystems, and economies. For example, in the UAE, rising temperatures lead to increased energy demand for cooling, greater strain on water resources, potential health and productivity risk due to extreme heat. They also raise the possibility of tropical cyclones forming in the Arabian Gulf. Moreover, as a low-lying coastal nation, the UAE is particularly vulnerable to sea-level rise and its effect on real assets located on the coast, an aspect we come back to in the next section.

Figure 1: Global temperatures and frequency of extreme events

(a) Temperature change (Change in degrees Celsius)

(b) Frequency of natural disasters (Events per year)



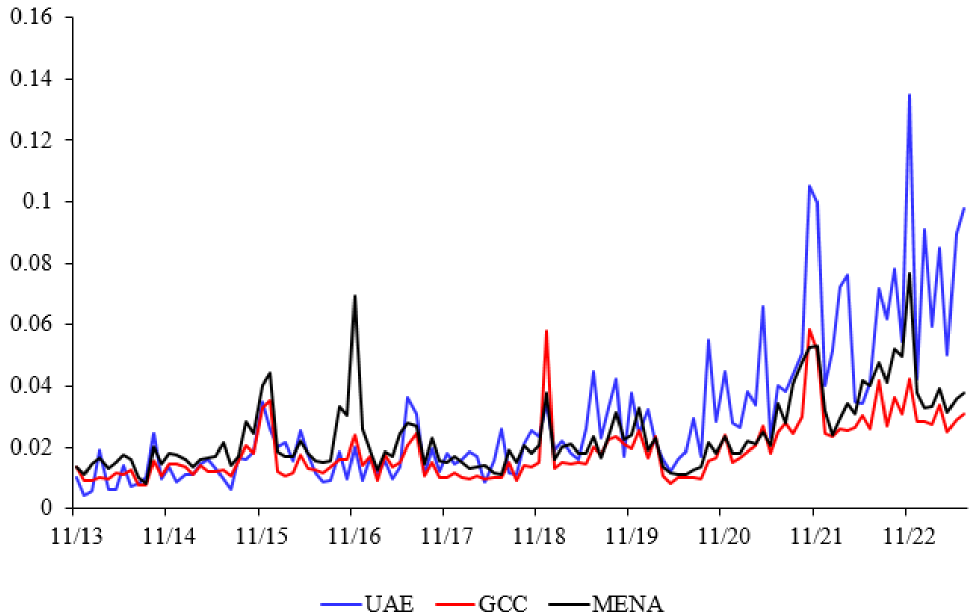

**Notes:** Panel 1a shows the change in the average surface temperature (expressed in degrees Celsius) with respect to the period 1951–1980 for the world and the UAE. For the world, a simple cross-country average is used. Data is from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). Panel 1b reports the number of extreme climate-related disasters per year by subcategory. Data is from the International Monetary Fund Emergency Events Database (EM DAT).

The challenges from rising temperatures and extreme weather events for the UAE have been highlighted, among others, by the International Monetary Fund (2023), which concluded that "the UAE is exposed to physical risks from climate change, particularly through rising temperatures." They have also led to heightened media attention towards climate-related issues. Figure 2 shows how media attention towards climate risk issues evolved in the Middle East and North Africa (MENA) region, as gauged through the frequency of news articles on the topic (see Sisco et al., 2017; Engle et al., 2020; Bonato et al., 2023, for related approaches to measuring attention to climate risks). Media attention to climate risks has increased significantly over time, in particular in the UAE, reflecting an intensification in the frequency and severity of climate events as well as a growing awareness of climate-related risks in the region.

## 2.2 The Global Policy Response

Faced with a changing climate and heightened attention to the resulting challenges, policymakers and regulators around the world are increasingly taking actions to guide their

Figure 2: Climate risk attention
(News count per month, normalized)




**Notes:** The figure shows the number of news articles per month related to "climate change" and "global warming" normalized by the number of articles within the month. The news articles are obtained from the Bloomberg News Feed, a comprehensive archive of news stories and social media posts of more than 150,000 sources. The methodology for the construction of the news count index follows Bonato et al. (2023), applying it to the period November 2013–June 2023. For country aggregates, the figure reports the average. MENA = Middle East and North Africa, GCC = Gulf Cooperation Council.

economies away from carbon-intensive industries and energy production and towards a lower-carbon economy. The adoption of formal carbon pricing mechanisms has become increasingly common as part of efforts to combat climate change. For example, the European Union's Emissions Trading System (EU ETS) places a cap on greenhouse gas emissions of a broad spectrum of industries, enabling companies to trade emission allowances to achieve a total targeted emissions reduction at the lowest economic cost. The EU's introduction of a "carbon border adjustment mechanism" (CBAM) will eventually require EU importers to pay the difference between the amount that "embedded emissions" in the imported products would be charged in the EU and whatever carbon price they paid in the origin country. The CBAM thus creates incentives for producers outside the EU to reduce their emissions, and puts pressure on other economies to implement their own carbon pricing mechanisms in order to collect the revenues themselves.

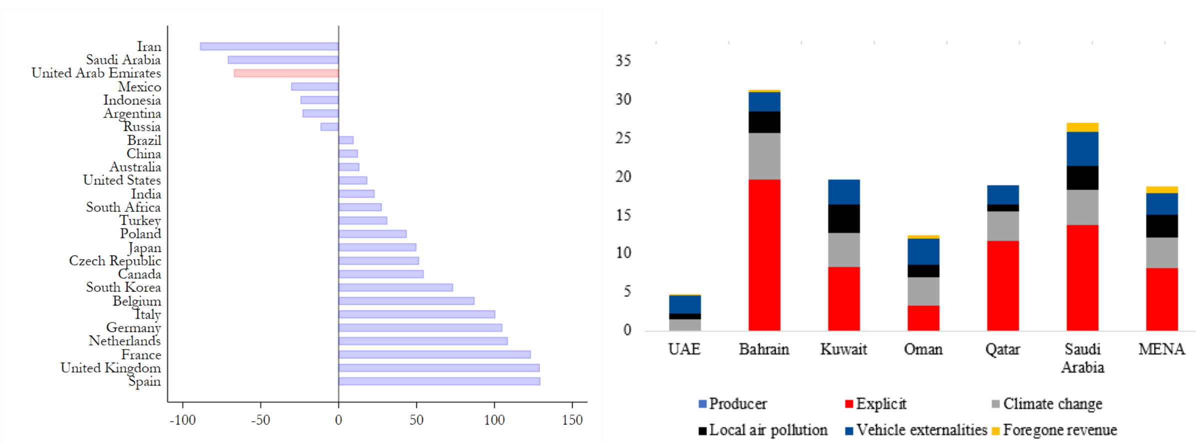
In addition to Europe, several U.S. states have instituted their own carbon pricing initiatives. For example, the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade system, specifically targets emissions from the power sector across multiple northeastern states. Moreover, China, the world's largest emitter of greenhouse gases, introduced its national carbon trading system in 2021, initially focusing on the power sector. This proliferation of formal carbon pricing mechanisms across jurisdictions reflects the increasing recognition of the role of carbon pricing in fostering climate action and facilitating the transition to a low-carbon economy on a global scale.

A variety of other national or local measures to complement carbon pricing schemes are also common around the world. These include emissions caps for buildings; renewable energy portfolio standards or mandates that require utilities to source a certain percentage of their energy from renewable sources; various subsidies for renewable energy generation; and incentives for electric vehicle adoption, such as tax credits and rebates.

Figure 3: Climate policies around the world

(a) Carbon prices in 2021 (USD per metric ton of CO2)

(b) Explicit and implicit fossil fuel subsidies (Percent of GDP)




**Notes:** Panel 3a reports numbers from the Kepos carbon price barometer, which summarizes the price in USD per metric ton of CO2 emissions implied by emissions reduction policies and subsidies. Panel 3b reports the size in percent of GDP of explicit and implicit fuel subsidies (i.e., undercharging for environmental costs and forgone consumption tax revenues). For MENA, the figure reports the average. MENA = Middle East and North Africa. Data is from the IMF's Fossil Fuel Subsidies dataset, 2023 update.

One attempt at summarizing the many direct and indirect regulatory interventions is provided by the Kepos carbon barometer. The barometer provides a country-level price per metric ton of CO2 emissions for 25 countries accounting for 83% of the global emissions. The price reflects inputs related to 7 policy categories that include tariffs and subsidies. A higher barometer price indicates that emitters in that country must pay a higher cost per unit of carbon emissions while a negative barometer price reflects subsidies supporting fossil fuels. Figure 3a reports this metric in 2021 for a range of countries, including the UAE. European countries, with their long-standing efforts in regulating emissions, have relatively high implied carbon prices. The negative carbon price in the UAE and other oil exporting countries reflects estimated subsidies for oil, gas, and electricity products and highlights the potential for substantial changes in the cost of carbon emissions and therefore the presence of climate transition risks to the economy.[2]

## 2.3 The Climate Transition Agenda in the UAE

Similar to other countries, the UAE has identified a series of policy goals to guide the country's climate transition over the coming decades, which constitute a source of transition risk for local firms. Notably, the UAE was the first country in the MENA region to commit to net-zero emissions, which are targeted by 2050. The guiding principles of the UAE's strategy are described in the *Net Zero by 2050* initiative, the *UAE Green Agenda 2015–2030* and the *National Climate Change Plan of the UAE 2017–2050*; together with the *UAE Vision 2021* and *UAE Vision 2071*. In addition, in September 2022 the UAE updated its plans to achieve the targets set out in the Paris agreement. Specifically, the emission reduction target was set to 31% relative to "business as usual" for the year 2030, which corresponds to an absolute emission avoidance of 93.2 million tons. A recent report by the Ministry of Climate Change & Environment (2023) provides an overview of the various proposed actions and plans for each sector. The following paragraphs summarize some of these actions and plans.

Overall, electricity generation is set to contribute 66.4% of total planned emissions reductions by 2030. Key to this is a plan to build the UAE's clean power capacity to reach 14 GW by 2030, from just above 100 MW in 2015 and 2.4 GW in 2020, mostly by increasing electricity production from solar and nuclear sources. The UAE is also investing in clean hydrogen (Ministry of Energy & Infrastructure, 2023). As of May 2023, total investment in clean energy projects locally was above $40 billion, in addition to $16.8 billion in renewables ventures across 70 countries. In 2022, the UAE pledged to invest an additional $50 billion by 2032 to scale up climate action by deploying clean energy solutions both in the UAE and abroad.

In the oil and gas sector, one stated policy focus has been to adopt more climate-friendly industry practices. For example, the national oil company has developed a car-

[2] Figure 3b highlights that, according to the latest update of the IMF's Fossil Fuel Subsidies data summarized in Black et al. (2023), the UAE's subsidies in 2022 consisted exclusively of *implicit* subsidies, representing 4.8% of GDP. These correspond to undercharging for environmental costs and forgone consumption tax revenues, and therefore occur when the retail price fails to include external costs, inclusive of the standard consumption tax. Implicit subsidies in the UAE are accounted for by vehicle externalities (congestion, accidents, and road damage), climate damage (approximated by the fuel's emissions times the value per ton of emissions), and local air pollution (produced by the combustion of fossil fuels products). *Explicit* subsidies, which are common in other GCC countries, were fully phased out by the UAE in 2015.

bon capture, utilization, and storage network with a current installed capacity of 800,000 tons per year, a number that is planned to grow to 5 million tons per year (0.4% and 16% of UAE's carbon emissions in 2022, respectively). Also, the company became the first oil and gas producer in the world to source 100% of its grid power from nuclear and solar energy. In the transportation sector, the UAE reformed the fuel pricing system in 2015 by linking gasoline and diesel prices to international market prices, thus removing direct subsidies to fuel consumption. In addition, the UAE has been investing to expand its public transport options. For example, the Etihad Rail has been operational for freight movement since January 2016, and is scheduled to begin other operations in 2023. Also, the Dubai Metro, a rapid transit rail system, complemented a bus service and a short-range tram network.

# 3 Climate Risks and Asset Prices

A key reason financial regulators are concerned about the possible effects of climate risk on financial stability is that these risks can have a substantial effect on a range of asset values, which can, in turn, feed back into the health (and possibly even the viability) of financial institutions. In the following subsection, we describe the evidence on the various channels through which climate-related risks affect valuations across a range of asset classes. In subsequent subsections, we then discuss the channels through which these shifts in asset values might affect financial stability.

Climate-related risks to the economy—and thus to asset prices and possibly to financial stability—are commonly categorized into two types: *physical risks* and *transition risks* (e.g., Financial Stability Board and NGFS, 2022; Stroebel and Wurgler, 2021). Physical risks refer to the effects on economic activity and asset values that come from the direct manifestations of climate change, such as heat waves, floods, droughts, and wildfires. For example, sea level rise and coastal flooding can cause economic damage by destroying residential properties and factories in affected areas. Similarly, heat stress can threaten agricultural activities and depress worker productivity. The term "transition risk" refers to the economic effects of changes in policies, technologies, or preferences during the transition to a less carbon-intensive economy. The effects of transition risk realizations can differ substantially across industries, with risk realizations benefiting some industries while hurting others. For example, consider the introduction of carbon pricing as an example of a transition risk realization. Such policies could reduce the profitability and even the viability of fossil-fuel firms, but improve the profitability of firms producing renewable energies (see van Benthem et al., 2022). Both physical and transition climate risks are perceived as important by financial market participants, with transition risks—and in particular regulatory transition risks—generally perceived as the most immediately relevant risk category (see the survey results presented in Krueger et al., 2020; Stroebel and Wurgler, 2021).

**Transition Risks in the UAE.** Transition risks are particularly relevant in oil exporting countries like the UAE, where about a quarter of GDP is attributed to oil-related activities and which is thus affected by changes in both national and international regulations of carbon emissions. Noting such risks, the International Monetary Fund (2023) highlighted that "ensuring long-term resilience to the impacts of climate change mitigation policies abroad will be a key challenge [for the UAE], underscoring the importance of continued preparations for a low-carbon global economy." As an example of such risks, initiatives such as the EU's CBAM expose firms in other countries to regulatory transition risks, since such policies can raise the cost of carbon-intensive production processes even outside of the European Union. Beyond raising the costs of carbon-intensive exports to the EU, the CBAM might also induce other countries to adopt their own carbon pricing strategies to prevent the EU from benefiting from taxing their emissions (Beaufils et al., 2023).

**Physical Risks in the UAE.** As noted above, rising sea levels are an important physical climate risk in the UAE due to its low-lying and shallow-sloping geography (Melville-Rea et al., 2021). Since 1880, global average sea levels have risen 21–24 centimeters (8–9 inches), posing potential threats for the UAE's high-value coastal real estate. Indeed, the UAE's real estate sector has experienced significant growth over the past decade, and real estate and construction activities accounted for 14.1 (20)% of GDP (non-oil GDP) during 2013–2022. In response to the increasing threats of physical climate risks related to rising sea levels and recognizing the real estate sector's importance to the economy, the UAE has put in place several climate adaptation strategies. These focus on enhancing the resilience of properties against environmental threats by developing properties at higher elevations, strengthening buildings to withstand extreme weather, and adopting sustainable building practices.

## 3.1 Existing Empirical Evidence

We next review a growing body of empirical work that documents that both physical and transition climate risks are already priced across a range of asset markets today. This review is not intended to be complete, and we direct the interested reader to a more comprehensive discussion in Giglio et al. (2021a) and elsewhere.

**Equities.** In recent years, a variety of research papers have shown that transition climate risks have begun to affect equity valuations. For example, Bolton and Kacperczyk (2023) find higher stock returns for companies with higher carbon emissions, suggesting that investors perceive lower valuations for these high-emissions firms, presumably at least in part due to the transition risk exposures of these firms. Similarly, Engle et al. (2020) and Alekseev et al. (2022) document that stocks with lower climate risk exposures outperform in periods with bad news about climate risks (also see Faccini et al., 2023). Choi et al. (2020) document that stocks of carbon-intensive firms underperform firms with low carbon emission in periods when investors pay particular attention to climate risks, which tends to happen in abnormally warm weather.

Acharya et al. (2022) study the pricing of physical climate risks in equity markets and conclude that firms with higher exposure to heat stress have higher expected returns. Similarly, Bua et al. (2022) show that both physical and transition climate risks are priced in euro area equity markets, and increasingly so in recent years. Consistent with these findings, Reggiani (2022) and Cuculiza et al. (2021) show that sell-side equity analysts incorporate climate news in their earning forecasts.

**Corporate Bonds.** Climate risks also affect valuations across a range of fixed income markets, including corporate bond markets. For example, Seltzer et al. (2022) show that changes in aggregate transition risk have greater effects on bond credit ratings for firms with a worse environmental performance. Similarly, Huynh and Xia (2021) find that bonds that are more negatively exposed to climate change risk earn higher returns, and Acharya et al. (2022) find that an increase in heat stress exposure raises sub-investment grade bond spreads for S&P500 corporates.

**Sovereign Bonds.** Sovereign debt yields are also likely to be affected by various climate risks. Transition risks pose potential threats to the repayment ability of countries with substantial oil and gas industries, while countries with large physical climate risk exposures are more likely to default (Cevik and Jalles, 2022), in particular in the aftermath of major weather disasters.

**Municipal Bonds.** In many countries including the United States, municipal bond markets provide opportunities for sub-national municipalities (states, counties, cities, and the like) to access capital markets. Due to the spatial concentration of the tax base, these municipal bonds are particularly likely to be affected by concerns about physical climate risks. Consistent with this assessment, Painter (2020) and Goldsmith-Pinkham et al. (2023) show that the cost of issuing municipal bonds is affected by the issuing government's exposure to sea level rise, while Acharya et al. (2022) find that exposure to heat stress is also priced in municipal credit spreads.

**Real Estate.** A large literature has documented that physical climate risks such as sea level rise and wildfires have a negative impact on real estate prices. For example, Giglio et al. (2021d) show that during periods of increased climate risk attention, the relative valuation of more exposed residential properties declines. In related work, Bernstein et al. (2019) show that in the US, coastal homes that are vulnerable to sea level rise are priced at a discount relative to similar homes at higher elevations. Baldauf et al. (2020) find that houses located in a flood zone sell for less than an identical house located outside a flood zone. Similar effects are also found in commercial real estate markets. For example, Addoum et al. (2021) show that New York commercial properties exposed to flood risk trade at a large persistent discount following Hurricane Sandy, an event that likely raised the salience of New York's climate risk exposure to real estate investors.

## 3.2 Climate Risks in UAE Real Estate Markets

Motivated by the growing evidence that climate risk is priced across several global real estate markets, this section provides an empirical assessment of whether climate risks are also priced in housing markets in the UAE. Specifically, we examine if buyers of properties that are less exposed to physical climate risks pay a price premium. The analysis builds on a data set comprising the universe of real estate sales transactions in the Emirate of Dubai during the period March 2013–June 2023 provided by the Dubai Land Department. The data includes information about the properties' sales price as well as property and transaction characteristics. We construct a measure of a property's exposure to rising sea levels as the shortest distance in km between the geographical center of the administrative area where it is located and the coast, such that a longer distance is generally correlated with less exposure to rising sea levels.[3]

One challenge with using distance to the ocean as a measure of physical risk exposure is that it is likely correlated with other characteristics at the property area level. For example, more exposed properties are also likely to have better beach access, which would affect property values independently of any climate risk exposure. In one attempt to account for such confounders, we use information on whether the purchase involved a freehold agreement—which delivers permanent ownership of the land the property sits upon—or a leasehold agreement—which instead delivers only the right to occupy the property for a given number of years (see Giglio et al., 2015, 2016, for a description of

[3]We only observe a property's location at the second administrative level, referring to government divisions two levels below the national level. Our data covers real estate transactions in 64 distinct areas. Our analysis assigns each property in the same administrative region the same "distance to the sea". Some property areas are right on the coast, which case the distance recorded is zero.

this contract structure in other countries). The key assumption is that, since physical climate risks will disproportionately materialize in the more distant future, they should particularly affect the valuation of freehold properties. To the extent that other area-level characteristics affect freeholds and leaseholds similarly, exploring how the freehold premium over leaseholds varies with the distance to the coast provides an indication of whether climate risk is priced into the sale transaction. Concretely, we estimate the following hedonic regression:

$$log(price_{i,t}) = \alpha_{a,t} + \beta freehold_{i,t} + \gamma freehold_{i,t} \times distance_a + \delta X_i + \varepsilon_{i,t} \tag{1}$$

where $log(price_{i,t})$ is the log price paid by the buyer for property $i$ in month $t$, trimmed at the top and bottom 2.5% of the distribution to exclude outliers; $freehold_{i,t}$ is a dummy variable that takes value one if the property is sold with a freehold agreement and zero if it is sold with a leasehold agreement; and $distance_a$ is the shortest distance from the center of the area $a$ where the property is located to the coast. The specification also includes a vector of controls $X_i$, which features dummy variables for the size of the apartment, the type of property being sold (either apartment or villa), for whether the transaction involved an off-plan property or an existing one, for whether the property has a balcony or parking, for the number of rooms or type of unit, and for the closest landmark, the closest metro station, and the closest mall.[4] The specification also includes area-month fixed effects, $\alpha_{a,t}$, to capture time-varying factors common to all properties in an area.

In a related analysis, we explore whether the freehold premium varies with attention to climate risks, measured using the climate change attention index based on news counts presented in Section 2.[5] The conjecture is that property sales involving a freehold agreement should feature a smaller premium when there are concerns about climate risks, again due to the fact that climate change risks are only likely to materialize in the relatively distant future.[6] To test this hypothesis, the following equation is estimated:

$$log(price_{i,t}) = \alpha_{a,t} + \beta freehold_{i,t} + \phi freehold_{i,t} \times attention_t + \delta X_i + \varepsilon_{i,t} \tag{2}$$

where $attention_t$ is a the three-month moving average of the climate change attention

[4]The analysis includes 50 dummy variables for property size; 10 dummies for the number of rooms or type of unit (e.g., studio, one bedroom, two bedrooms, penthouse, etc.); 13 dummies for the nearest landmark, 35 dummies for the nearest metro, and 5 dummies for the nearest mall.

[5]To take advantage of the full sample length (March 2013–June 2023), we use the index based on the number of news articles related to climate change and global warming instead of its normalized version. The results, however, are robust to the use of the normalized version of the index.

[6]We cannot explore whether the effect of distance to the coast varies with climate attention, since that variation is fully absorbed by the area × time fixed effects.

index standardized to have zero mean and a standard deviation of one.

Table 1: Regressions of property sales prices

| | Baseline results | | | Log of distance | 12m MA of attention |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Freehold | 0.176*** | 0.144*** | 0.113*** | 0.121*** | 0.086*** |
| | (0.018) | (0.017) | (0.018) | (0.020) | (0.020) |
| Freehold × distance to coast | 0.002*** | | 0.006*** | 0.013** | 0.019*** |
| | (0.001) | | (0.001) | (0.005) | (0.005) |
| Freehold × climate attention | | -0.090*** | -0.095*** | -0.091*** | -0.122*** |
| | | (0.003) | (0.003) | (0.003) | (0.004) |
| Observations | 528,092 | 528,092 | 528,092 | 528,092 | 528,092 |
| $R^2$ | 0.838 | 0.839 | 0.839 | 0.839 | 0.839 |
| Area-month fixed effects | Yes | Yes | Yes | Yes | Yes |
| Controls | Yes | Yes | Yes | Yes | Yes |

**Notes:** The sample includes the universe of real estate sales in the Emirate of Dubai between March 2013 and June 2023. All regressions include dummies for the size of the property, the property type, its usage, the nearest points of interest, whether the property is existing or off-plan, and property characteristics (parking, balcony, and number of rooms); and area-month fixed effects. Columns (1) to (3) use the distance to the coast in km and a 3-month moving average of the climate attention index. Column (4) uses the log of the distance to the coast. Columns (5) uses a 12-month moving average of the climate attention index. In each case, the climate attention index is standardized to have zero mean and a standard deviation of one. Robust standard errors are reported in parentheses. ***, **,* denote statistical significance at 1, 5, and 10 percent levels.

Table 1 reports the results of estimating equations (1) and (2), as well as specifications that include the interaction of the freehold indicator with both the distance to the coast and with our measure of climate attention. The results in column 1 suggest that freeholds trade at a premium to leaseholds, but that this premium is smaller for properties closer to the coast. This finding is consistent with the idea that exposure to sea level rise should disproportionately reduce the valuation of those assets with cash flows in future periods when sea levels rises are more likely to have occured. Similarly, column 2 suggests that the freehold premium is smaller in periods when attention toward climate change is elevated, consistent again with the idea that relatively distant climate disasters should disproportionately affect the values of freeholds, which include a claim to the more distant cash flows from the property. These findings also hold when both interaction terms are included in the same specification as shown in column 3. Using the estimates in column 3, the analysis suggests that the freehold premium is 0.6 percentage points higher for properties located 1km further from the coast. The analysis also suggests that the freehold premium is 9 percentage points smaller when attention to climate risks increases by one standard deviation.

As a robustness test, we next estimate a similar specification as column 3, but replacing the distance to the coast in km with its log (column 4) and replacing the 3-month moving average with a 12-month moving average for the standardized climate change attention index (column 5). The results are similar to the ones of the baseline specifications.[7, 8] All in all, these results provide initial suggestive evidence consistent with the UAE's real estate market at least partially incorporating physical climate risk exposure into the pricing of properties. Future work exploring property-level variation in physical climate risk exposure driven by localized variation in elevation, or work that explores the pricing of leaseholds with different maturities, could provide more conclusive findings.

## 3.3 Are Climate Risks Priced Adequately?

The prior sections summarize a body of research that has shown both physical and transition climate risk exposures to already affect valuations across a range of asset classes. This research effort has largely focused on rejecting the null hypothesis that climate risks have no effect on asset prices. However, while asset prices have been shown to incorporate various types of climate risk exposures to some degree, it is much less clear whether they do so *adequately*. Indeed, answering this question is much harder: using standard asset pricing frameworks, an assessment of the adequacy of climate risk pricing for a particular asset requires taking a quantitative stand on (i) the cash flow implications at different horizons under various climate risk scenarios, (ii) the likelihood of the various scenarios, and (iii) the marginal utilities in those states of the world.

Each of these steps involves many complications. For example, on the physical risk side, it is challenging to assess the current likelihood of various extreme weather events in a particular geography given that climate change has made past frequencies uninformative about current risks (Levin et al., 2023). Assessing future probabilities is substantially harder, requiring analysts to assess the likelihoods of various paths of future emissions, their effects on the global climate, and the resulting effects on the frequency of extreme weather hazards in the locations relevant for the asset's cash flows.

On the transition risk side, it is important to realize that future risk realizations—and in particular future regulatory risk realizations—are inevitably the outcome of an interplay of a political process and technological advances that determine how quickly

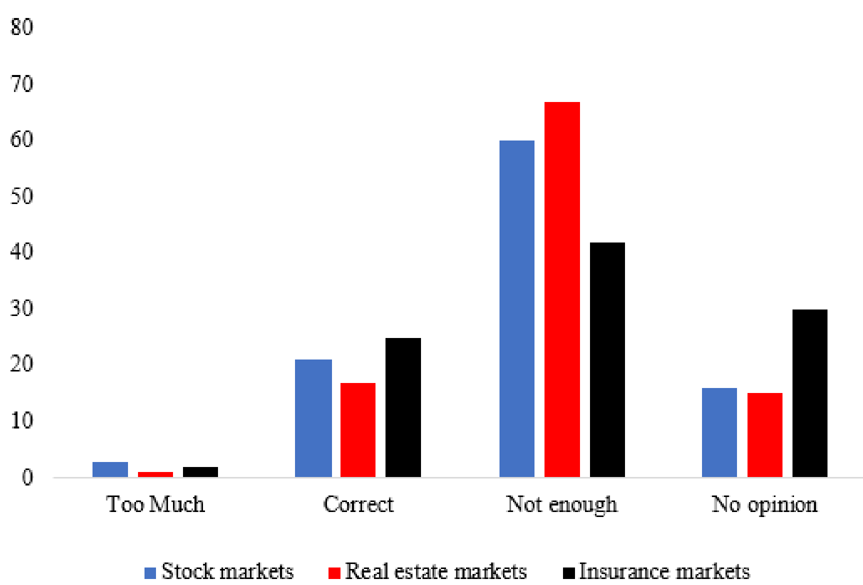
[7] To avoid losing the observations for properties located in areas with zero distance to the coast, in the regressions with the log of the distance to the coast we calculate $log(distance) \approx log(1 + distance)$.

[8] One concern is that the results might be driven by the generalized decline in property sales prices observed during the COVID-19 pandemic, during which climate attention increased significantly. However, excluding the period January 2020–April 2022 returns similar results to the ones presented in Table 1.

carbon-intensive processes can be replaced by alternative technologies. Both the technological processes and the political economy dynamics would need to be formally modeled to assign probabilities to different paths of transition risk realizations.

Yet, despite these complications, assessing the adequacy of the pricing of climate risks is important, and should become a key focus area for future research. In particular, if climate risks are not currently priced adequately, there is a risk of large-scale future changes in asset prices even without any actual risk realizations such as large-scale weather disasters or carbon taxes, and without any changes in the true underlying probability distributions. For example, if households were to currently underestimate the risk of tropical cyclones in the Arabian Gulf, house prices of coastal properties in the UAE and other affected regions would be too high: the risk from tropical cyclones would not be adequately priced. If households were to subsequently learn the true probabilities, this would lead house prices to fall, even without the occurrence of an actual tropical cyclone or a change in the climate that would further raise the probability of such storms. As we discuss in the next section, through such shifts in asset values, climate risks might affect financial stability in the short run even without the occurrence of any immediate physical or transition risk realizations that affect cash flows today.

Figure 4: Opinions on pricing climate risks by market
(Percent of survey responses)




**Notes:** The figure summarizes the results in Table 3 of Stroebel and Wurgler (2021). Participants were asked: "In the $X$ most familiar to you, how do prices currently reflect climate-related risks?", where $X$ is either stock markets, real estate markets, or insurance markets. The total number of respondents is 861.

Absent reliable quantitative estimates of the adequacy of climate risk pricing across asset classes, surveys can provide a snapshot of market participants' perspectives on this question. For example, Stroebel and Wurgler (2021) asked several hundred individuals—including academics, public sector employees, and individuals employed in the financial sector—whether they believed that equity markets, real estate markets, and insurance markets adequately priced climate risk. Figure 4 shows that, in the survey, 60% of respondents reported that, in their view, climate risk was insufficiently priced in equity markets, 21% believed that it was correctly priced, and 3% believed that it was overpriced (the remaining respondents did not have an opinion on this matter). Respondents working in the private sector were particularly convinced that climate risks were not yet adequately reflected in equity prices. Similarly, 67% of respondents believed that real estate valuations underpriced climate risks, compared with 17% of respondents who thought they priced climate risks adequately, and 1% of respondents who thought they overpriced these risks.

## 4 The Effects of Climate Risks on Financial Institutions

Through their effects on economic activity and asset values, physical and transition risks can affect a wide range of financial market participants. In this section, we provide a high-level overview of some of the mechanisms through which financial institutions might be affected, focusing our discussion on the various ways in which climate risks affect banks. Acharya et al. (2023) provide a more detailed overview.

**Banks.** Climate risks can affect banks in several ways, including through their loan books ("credit risk channel"), their financial asset portfolios ("market risk channel"), and their liquidity positions and funding costs ("liquidity risk channel"). We discuss these channels in more detail in the following paragraphs.

First, realizations of climate risk may affect the ability of borrowers to repay their outstanding loans. Consider a bank's mortgage lending operations. Physical climate risk realizations such as floods or wildfires can lead to substantial increases in mortgage default and associated credit losses for banks (e.g., Gete and Tsouderou, 2022; Issler et al., 2020).[9] Similarly, regulatory interventions such as carbon taxes might affect the repayment ability of firms in sectors such as coal-powered utilities that would see their operating costs rise dramatically (Jung et al., 2023). However, for climate risks to affect a bank's health through such a credit risk channel, these risks would need to materialize with substantial

[9] The sharing of losses between homeowners, mortgage lenders, insurance companies, and other mortgage participants—such as Fannie Mae and Freddie Mac in the United States—might differ across markets.

cash flow implications during the life of the outstanding loans. Since loan maturities vary across loan types (with typically longer maturities for mortgages, and shorter maturities for corporate debt), any attempt to quantify the climate risk exposure of banks through their loan book should focus particularly on longer-maturity loans—after all, the actual cash flow realizations of transition and in particular physical climate risks are likely to increase over time. To assess the credit risk implications for shorter maturity loans that may or may not be rolled over by banks, it is important to better understand the decisions of banks to dynamically adjust their lending behavior in response to climate risks.

While the largest cash flow implications of climate risk realizations will likely occur at longer horizons—with perhaps smaller effects on firms' and households' repayment abilities in the immediate future—-the previous discussion showed that any changes in actual or perceived climate risks in the future can lead to sizable effects on asset values today. This can affect bank health through the value of a bank's trading book even in the absence of any actual climate risk realizations. Depending on the degree of the mispricing of climate risks—a question on which little reliable research exists—such repricing events could be substantial in magnitude, with implications not just for the health of individual financial institutions, but potentially also for financial stability more broadly.

Beyond these credit and market risk channels, climate risks can also be a source of liquidity risk. For example, following large disasters such as floods or wildfires, households might withdraw their deposits in order to fund rebuilding activities at exactly the time that demand for loans would be high (Brei et al., 2019; Cortés and Strahan, 2017). Both of these events might reduce a bank's liquidity buffer and raise its funding cost.

**Other Financial Institutions.** Beyond banks, other firms in the financial sector might also be affected by various climate risks. For example, asset managers are exposed to market risk in much the same way as banks are. Similarly, insurance companies can be affected by climate risk in various ways. First, insurance companies likely face a rising claims and payouts due to the increased frequency and severity of climate-related extreme weather events, and the extent to which they can pass these rising costs onto policy holders is unclear. In addition to such risks on the liability side, insurance companies typically hold investment portfolios to generate income and meet their financial obligations. As discussed in prior sections, the value of these assets can vary with climate risk realizations. The fact that such losses on the asset side may coincide with substantially higher payouts on their liability side—in part because both can be driven by the same extreme weather events—further increases the threat to financial stability from these events.[10]

[10] Central Bank of the UAE (2023a) provides an assessment of the awareness of the UAE's insurance sector of climate change risks. The survey-based evidence of this report suggests that attention and awareness of

# 5 The Role of Financial Regulators

Given the various ways in which climate risks can affect the health of financial institutions, it is unsurprising that these risks are a key focus of financial regulators and policy makers around the world. For example, in October 2021, Federal Reserve Governor Lael Brainard said that *"Climate change is projected to have profound effects on the economy and the financial system, and it is already inflicting damage. [...] It will be important to systematically assess the resilience of large financial institutions and the broader financial system to climate-related risk scenarios."* Similarly, in a September 2023 speech, ECB Executive Board Member Isabel Schnabel explained that: *"Climate-related and environmental risks are now an important focal point for supervisors."* And in October 2021, His Excellency Khaled Mohamed Balama, Governor of the Central Bank of the UAE, said that: *"The UAE, represented by the Central Bank and its regulatory and government agencies, is committed to achieving sustainable economic growth by engendering qualitative change and innovation in the financial sector, boosting financial inclusion, and adopting strategies, regulations and policies that mitigate the effects of climate change."*

In the following, we summarize several ways in which financial regulators can encourage and facilitate prudent climate risk management in the financial sector. Which of these and other tools might be appropriate for any particular policymaker depends on both the nature of the particular climate-related risks to their local economies as well as any constraints on their activities imposed by their particular mandates. In this respect, since the Basel Committee on Banking Supervision has clarified regulatory expectations (Bank for International Settlements, 2022), the UAE Sustainable Finance Working Group has developed and launched the Principles for Effective Management of Climate-Related risks in November 2023 (Central Bank of the UAE, 2023b).

## 5.1 Encouraging Disclosure

Since it is hard to manage a risk that you cannot measure, an important step to facilitate better climate risk management in the financial sector is for regulators to encourage firms to provide more detailed and transparent disclosures of their climate risk exposures. Improved climate risk disclosures by firms will, in turn, allow financial institutions to better assess and mitigate their own exposures to climate-related risks, in particular when the firm-level disclosures are structured in such a way that they could be easily aggregated by financial institutions to the portfolio levels. However, while regu-

climate-related risks were already on the rise in 2021. It also points to a growing understanding of the opportunities associated with climate change within the sector.

latory demands for more measurement and disclosures of climate-related risks are very common, there are many challenges to a successful implementation of any disclosure framework. Addressing such challenges is a key focus of work by groups such as the Task Force on Climate-Related Financial Disclosures (TCFD), which was recently completed, and the International Sustainable Standards Board (ISSB), which is working on developing sustainability- and climate-related accounting standards such as IFRS S1 and IFRS S2.

On the physical risk side, a key challenge to better climate risk disclosures relates to the difficulties with assessing the frequencies of relevant extreme weather events that constitute key sources of physical risk (Levin et al., 2023), in particular for risk assessments that require estimates of how these frequencies vary across relatively small geographies. While various commercial vendors offer data products that aim to assess the physical climate risk exposures of various firms, academic research has shown that the assessments of different data providers often diverge substantially (Hain et al., 2022). Without a more transparent and reliable modeling of extreme weather hazards, it will be inherently difficult for firms to understand and ultimately disclose their physical risk exposures; it will also be hard for these firms to take actions to mitigate those exposures, either through purchasing insurance or through physical adjustments to their facilities.

It is similarly difficult to comprehensively measure and subsequently disclose a firm's transition risk exposure. While reporting frameworks and technologies for greenhouse gas emissions are improving at least for scope 1 (i.e., direct greenhouse emissions that occur from sources that are controlled or owned by an organization) and scope 2 emissions (i.e., indirect greenhouse emissions associated with the purchase of electricity, steam, heat, or cooling), a firm's overall transition risk exposure is also influenced by a range of considerations that are much harder to pin down. For example, an oil company with a plan to transition into renewable energies is very differently exposed than another oil company with a similar emissions profile today but no plans to expand renewable capacity (see van Benthem et al., 2022). However, whether a particular transition plan is credible and thus will lead to a medium-run reduction in exposure to transition risks is an inherently subjective judgement, and a simple announcement of a net-zero target without a clear and credible plan to achieve that target might not indicate a reduction in a firm's transition risk exposures.

## 5.2 Climate Stress Tests to Assess the Effects of Climate Risks on Financial Market Participants

Once a framework for measuring and disclosing different assets' climate risk exposures is in place, financial regulators can assess the resilience of the financial system to various climate risks through conducting *climate stress tests*. Stress tests are quantitative assessments of the resilience of individual financial institutions and the financial system to severe but plausible realization of adverse events, and their use to assess the resilience of the financial system against various economic shocks has become common in recent years (see Acharya et al., 2023). Even if regulators choose not to adjust bank capital and other regulatory requirements based on the outcomes of climate stress tests, these exercises can be valuable. In particular, to conduct climate stress tests, banks would be required to build internal capabilities to measure and assess their climate risk exposures, allowing them to more effectively target reductions in these exposures over time.

Like all stress tests, climate stress tests start from the definition of a set of stress scenarios—in this case, combinations of physical and transition climate risk realizations combined with estimates of the associated economic effects, including for variables such as carbon and energy prices—that sketch out a range of extreme but plausible paths of the economy. Financial institutions are then asked to model how they would be affected by the various stress scenarios, considering, among other things, the effects through their loan and trading books. The results of the stress test would then be a set of projected outcomes such as possible bank capital shortfalls under the stress scenario.

The Network for Greening the Financial System (NGFS) has played a key role in the development of a set of climate risk scenarios to serve as a common starting point for different regulators (Network for Greening the Financial System, 2023). Such standardization of risk scenarios has the benefit of improving the comparability of stress tests across different banks and regulators. However, there is substantial value in constructing additional scenarios that reflect the particularities of the economies under consideration. For example, certain transition risk realizations such as a global carbon tax or a technological breakthrough in energy storage technologies would have much larger effects in countries with substantial oil exports. As a result, oil exporting countries benefit from considering a wider range of transition risk scenarios than those proposed by the NGFS. A starting point for the design of such scenarios could be energy transition scenarios developed by the Dutch Central Bank (Vermeulen et al., 2018).

The Central Bank of the UAE has started to integrate climate-related risks into its supervision and financial stability analysis. In 2022 and 2023, it conducted top-down and bottom-up stress tests on the transition risks using three NGSF scenarios (i.e., Net Zero 2050, Delayed Transition, and Current Policies).[11] Looking forward, the Central Bank of the UAE plans to conduct additional UAE-specific climate risk stress tests that consider shorter time horizon and the physical climate change risk. This would involve collecting granular data from UAE banks and developing UAE-specific climate risk stress testing scenarios.

### 5.3 High-Frequency Assessment of Market Participant Sentiment

As discussed in prior sections, sudden shifts in investors' concerns or sentiment related to climate risk can lead to large swings in the values of assets exposed to climate risks. While investor sentiment is inherently hard to forecast, financial regulators could use relatively high-frequency surveys to measure the sentiment of market participants towards various types of climate risks.[12] As in Stroebel and Wurgler (2021), these surveys could, for example, elicit the distribution of investors' perceptions of the current pricing of these risks in an attempt to quantify the scale of a possible repricing in response to shifts in market sentiments. Such data would also allow researchers to better understand—and eventually anticipate—the determinants of swings in climate-risk sentiment.

## 6 Conclusions

In recent years, investors and policymakers have increasingly come to realize that climate-related physical and transition risks can have strong effects on economic activity and asset values. Through these channels, climate risks have the potential to affect financial institutions—for example through their loan or trading books—and ultimately the health of the financial system. Financial regulators in the UAE and elsewhere have therefore begun to encourage and require better climate risk measurement, disclosure, and management in the financial system, including by asking financial institutions to conduct various climate risk stress tests and scenario analyses.

While these activities are ongoing, many open questions remain, calling for an increased effort by researchers and policymakers to better understand the complex interac-

[11] The results of the top-down stress tests indicate that aggregate corporate default rates would increase by 21% in the Net Zero 2050 scenario and by 27% in the Delayed Transition scenario compared to the Current Policies scenario in the five years following the shocks. See Central Bank of the UAE (2022) for more information.

[12] As an example, in 2017 Vanguard began to survey its retail investors every two months regarding their expectations for stock market returns, GDP growth, and other macroeconomic outcomes (see the description in Giglio et al., 2021b,c, 2023a).

tions between climate change, economic activity, and financial markets. For example, a clearer understanding of the adequacy of climate risk pricing across different asset classes is a key ingredient to better assess the risks to financial markets from sudden shifts in investor perceptions of climate risks. Similarly, interdisciplinary work that combines more accurate forecasts of extreme weather events with better estimates of the economic losses from such events can allow for an improved understanding of the financial implications of physical risk realizations. Such research will allow for the further development of realistic climate stress scenarios to better understand the potential financial stability implications of climate risk. Finally, market participants and policymakers have been broadening their interest in the interactions between economic activity and the health of our planet that go beyond climate risk to include topics such as biodiversity loss (Giglio et al., 2023b). Prudent forward-looking financial policymakers should consider investing in their ability to measure biodiversity-related risks to allow them to assess any potential implications for financial stability.

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