

Flying Blind: What Do Investors Really Know About Climate Change Risks in the U.S. Equity and Municipal Debt Markets?

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ABSTRACT

We assess how rising concerns about climate change are affecting disclosures to financial markets by looking systematically at 10-K filings from the 3000 largest U.S. publicly traded firms over the last 12 years and samplings of Official Statements from all U.S. municipal bonds. For equities, disclosure has risen sharply. Today, 60% of publicly traded firms reveal at least something about climate change, but the largest volumes of information are skewed heavily toward a few industries (e.g., electric utilities, oil & gas, mining) and concern valuation risks due to possible transition away from fossil fuels. By contrast, there is much less disclosure around the physical risks of climate change. In municipal finance, disclosure of physical risks is even weaker, although many municipalities are highly exposed to flood, fire, heat stress, and other perils that could both destroy infrastructure and undermine the tax and income bases essential to repayment of long duration bonds. Innovations in climate science over the last decade make it possible to assess these physical risks at fine geographical resolution (counties), but we find no relationship between such measures and municipal disclosure. Although policy makers and investor ESG frameworks have focused klieg lights on the financial risks that might accompany transitions away from fossil fuels, the real mispriced finance risks appear to lie with the raw physical risks of a changing climate. Remedies include infrastructure audits and new analytical capabilities that can help lower the cost and raise utility of meaningful disclosure along with stronger regulatory rules and industry norms. New practices at credit rating agencies and rethinking of liability rules could rapidly accelerate best practices. Details are presented in a "Supplemental Information" (SI) appendix.

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Introduction

For more than three decades, there have been sustained, global diplomatic efforts to address the perils of climate change. Over that period, global emissions have risen by nearly two-thirds. That consistent failure in public policy has inspired a search for new solutions, including efforts by some activists, investors, and central bankers to improve disclosure about climate-related risks. Greater disclosure, in theory, could lead to investment and operational decisions that better reflect climate risks that investors and other market players could not, on their own, discover. In turn, better pricing of risks with appropriate reflection in asset valuations and credit rating could improve the ability of financial regulators to understand and respond to possible systemic disruptions that might arise if markets suddenly realize that investments previously thought to be highly valuable, such as in fossil fuel companies, are suddenly distressed or worthless (Carney, 2015). For investment managers, investors, and issuers of securities, better disclosure is about prudence and fiduciary responsibility. For central bankers and regulators, disclosure could be vital to the stability of the financial system. For credit rating agencies, disclosure could have a huge impact on what they know and how they evaluate risk. And, importantly, for the public and politicians, better disclosure could reveal the scale of vulnerabilities to climate change and, thus, focus policy solutions.

The disclosure movement has generated a massive amount of activity. Central bankers in several countries have proposed or conducted stress-tests of their financial sector to climate risk (Vermeulen et al, 2018). Rating agencies have threatened to downgrade municipalities if they do not prepare for climate change. Large institutional investors like BlackRock have threatened to take action, including voting against companies that do not disclose climate risks (Fink, 2019). It has been reported that more than 400 mandatory and voluntary disclosure frameworks currently exist, encompassing everything from NGO campaigns to ratings schemes to legal standards.¹ The most influential include the Task Force on Climate-Related Financial Disclosures (TCFD), the Carbon Disclosure Project (CDP), the Global Reporting Initiative (GRI), and the Principles of Responsible Investment. Today, the TCFD framework for disclosure is supported by more than 1000 organizations with \$12 trillion in capitalization (TCFD, 2020). The CDP has seen a 36-fold increase in the number of companies engaged with their disclosure surveys since 2003 (CDP, 2019). And climate-related disclosures have become a central part of the environmental, social, and governance (ESG) frameworks that have surged in popularity as the keystone to “responsible investing” and purportedly help explain the long-term financial performance of companies (Hayat and Orsagh 2015).² Although there has been some convergence around a few prominent frameworks such as the TCFD and the CDP, this Cambrian explosion of reporting systems has generated enough variation in methods and data quality that it remains difficult for market participants to determine which frameworks and what information are most valuable.

This paper looks at whether these efforts are bearing fruit both in terms of the volume of disclosure and whether the information reflects the actual risks associated with climate change. While there is much

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1. From (OECD, 2015). Included in this list are advocacy campaigns, platforms for registering sustainability commitments, guidance, policies, ratings schemes, laws, and tools for measurement.
2. The financial impacts of CSR/ESG investing strategies and the importance of non-shareholder stakeholder considerations are discussed further in this handful of papers: (Eccles et al, 2011), (Cerin and Belhaj, 2009), (Dhaliwal et al, 2011), (G&A, 2012), (Borgers, 2013), (El Ghoul, 2018), (Griffin, 2012), (Fulton, 2013), (Chang, 2018), and (QMA, 2018).

attention and many studies on the need for disclosure, very little existing research is rigorously empirical or focused on the key question: Has disclosure helped the markets learn anything that has inspired changes in behavior? While looking at every dimension of potential disclosure is difficult, this paper offers a down payment, outlines what is already apparent empirically, and suggests research and policy directions.

We look at two kinds of information that lie at the center of the disclosure movements. One is information about *transition risks*, the risks introduced by the shift away from carbon polluting activities in today's economy to greener industries of the future. The other is information about the *physical risks* of climate change to assets such as roads, buildings, and public transport systems that could be damaged or to local tax bases eroded as climate impacts lead to migration.³ Empirically, we look at the U.S.-based investments in equities (the full Russell 3000 list of roughly 3000 exchange-traded stocks) and debt issuance (samples of municipal bonds). While this sampling strategy does not cover all U.S. financial instruments, they focus on the places where disclosure patterns should be most meaningful because easily tradable assets should, if markets are informed, most readily reflect climate risks. Municipal bonds, and corporate debt and equities account for one third of household net wealth in the United States and essentially all the readily tradeable wealth (Federal Reserve, 2019). Equities and municipal debt are where climate exposures are most material to personal wealth and financial stability, and also most visible.⁴

Because disclosure practices are still fluid, and it is hard to pin down how the disclosure movement has affected the supply of useful information, we triangulate our empirical approach. First, we look at the rules and expectations around disclosure and the patterns of climate-related disclosure in equities and municipal debt. Second, we examine where and how credit rating agencies and other analytical organizations have used disclosure and other climate-related information to alter how they evaluate the creditworthiness of investments. Third, we briefly survey the existing literature that has looked empirically at whether climate-related information has altered market behavior.

We make two central arguments.

First, the quality of disclosures is highly uneven and generally lousy. There are some signs that while the volume of disclosure from corporate equities rose sharply over the last decade, anecdotal evidence suggests quality has gone down. More firms are disclosing more general information that is essentially of no utility to the marketplace. Moreover, outside of a few industries (e.g., insurance and agriculture), disclosure has disproportionately focused on transition risk. Yet most of the information being released through these disclosures on transition risk is already readily available to any sophisticated market participant. Disclosures of climate-related information for equities occur in risk sections of 10-Ks. Such disclosure occurs mainly through frameworks that companies use to tabulate and release information about environment, social, and governance (ESG) factors that affect their operations. Traditionally, the “G” in ESG has played an outsized role, as investors have learned how variation in governance quality can yield variation in valuations. Rising concerns about climate change are elevating the “E” element. (There is no agreement on how to measure many of the key elements of ESG—more about this below.) Meanwhile, in

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3. For more general information on climate change risks and finance, see (Center for Climate and Energy Solutions, 2020), (The Economist Intelligence Unit, 2007), (Covington, 2015), and (Breitenstein, 2019).
4. We are mindful that there are at least two categories of concern that arise from improper disclosure and mispricing of risk from the marketplace. One set of concerns is systemic and related to overall market functioning. The other is particular to other trade instruments and whether they are properly valued. Obviously, these two types of risk interact, and while this paper is focused on the particular risks disclosed in public documents, we stress that focusing on these will plausibly make it easier to describe the systemic risks.

municipal finance, there appears to be almost no meaningful disclosure of climate-related risks. Using some of the latest science projecting spatially resolved potential climate impacts, we show that there is no detectable difference in the level of municipal disclosure between communities most at risk from climate change and those least exposed to physical impacts.

Second, it is possible to achieve much greater levels of useful disclosure around the physical risks of climate change by deploying new analytical tools, regulatory incentives, and business practices. While it has been argued widely that the failure to disclose more information about physical risk is due to analytical barriers, in fact a large number of tools already exist that make it possible to offer more useful information about potential climate exposures. These tools can lower the cost of analyzing and revealing potential exposures to and impacts from the physical risks of climate. A central challenge seems to be not analysis but imagination, because the scenarios by which climate impacts affect equities and municipalities involve complex chains of cause-and-effect. Obvious impacts, such as a hurricane slamming into Florida, are widely known (and there is some evidence that municipalities in coastal areas therefore reveal a bit more information about climate risks when compared with the heartland). More pernicious, however, are those that involve repeated impacts on communities—floods, heat waves, fires—that threaten to erode tax bases and could raise default risks. In conclusion, we identify some implications for corporate governance and investment management (e.g., on how firms assess compliance and disclosure to mitigate errors and omissions and director and officer liability), for policy (e.g., on the need for more serious attention to physical disclosure), and for analysts (e.g., on the value of demonstrating how physical risk impacts can be quantified to impact the valuation of assets and creditworthiness of issuers).

Patterns of Disclosure: Legal Requirements and Actual Practice

In principle, the legal authority to require climate-related disclosure already exists. Issuers of municipal bonds are required to release an Official Statement; all publicly traded companies must make an annual public disclosure to the Securities and Exchange Commission (SEC) known as a 10-K. Both of these are governed by the 1934 Securities Exchange Act, which requires issuers to report on their financial standing and health and disclose any "material" exposure to financial risks. Through practice and legal challenge, the materiality standard has come to mean any information that, if not widely visible, would create a "substantial likelihood" of altering the deliberations of a "reasonable shareholder" (Wasim, 2019).⁵ While the definition of materiality is left to issuers, its application in climate change has been litigated. Peabody in 2015, for instance, settled a lawsuit by the New York State Attorney General brought for failures to disclose the company's exposure to climate policy in SEC filings (*In the Matter of Investigation by Eric T. Schneiderman, Attorney General of the State of New York of Peabody Energy Corporation*, 2015). Peabody, the world's largest publicly traded coal company, was in a high emissions business, yet argued that they could not model the risks of climate change and public policy to their company, even though it did that modeling for internal decision-making processes. Since 2010, the SEC has published guidance on climate change risk disclosures, aimed at aligning with the general SEC approach of ensuring that disclosures are "consistent, reliable and comparable" (SEC, 2010; Lee, 2020).

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5. Interesting work has been done on the impact of ESG materiality standards and stock price informativeness; for more, see (Grewal et al, 2020).

In practice, guidance for municipal issuance is less rigorous and precise than for equities, although the broad concept of materiality still applies. As a practical matter, one way the SEC applies its influence with municipal issuers, who are legally exempt from federal securities registration, is by regulating underwriters who bring bonds to market, and requiring these underwriters to obtain the Official Statements that we sample in this paper (SEC, 2018).

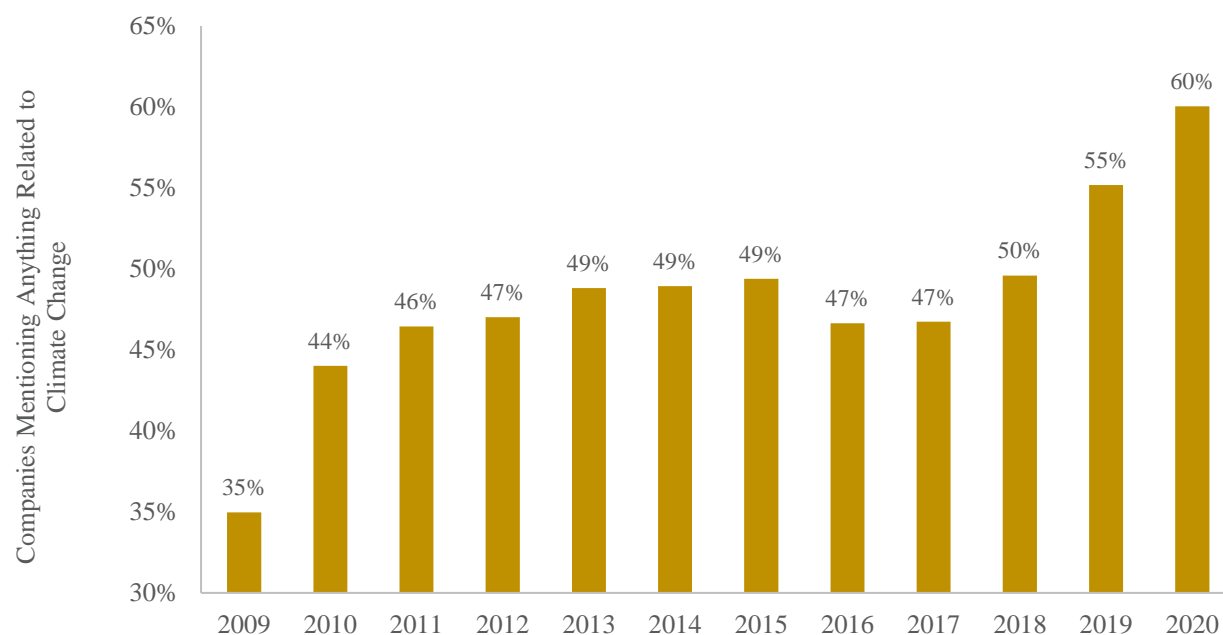
As attention to disclosure has risen, in particular, over the last 15 years, how have enterprises required to disclose responded? To answer this question, several organizations have sampled 10-K and other filings. For example, the TCFD used an AI algorithm to scrape the SEC filings and sustainability reports of roughly 1,000 companies; Ceres has sampled the SEC filings of S&P 500 firms for a few select years; C2ES has done the same for a few select companies; and the CDP has offered answers by sampling results of their independent disclosure framework.⁶

In assessing corporate disclosure practices, it is possible to do a lot better. For equities, all 10-Ks are public documents and readily searchable.⁷ Ceres, a leading sustainability nonprofit, has helpfully compiled those documents into a single database, searchable with a Ceres tool that we use for the full universe of significant publicly traded firms: the Russell 3000 list of equities. Because the Ceres tool is an intermediary, we are constrained by its methodology (keyword searching) and extent (2009 through 2020). With guidance from industry and climate experts, Ceres identified a set of climate-related keywords that power its search index.⁸ To offer the most expansive view of climate disclosure, we use the full set of Ceres keywords—an approach that is, of course, upwardly biased, because terms like “hurricane” and “flood” are included as a discussion of climate change even if in the context of prose that is unrelated to transition or physical risks of climate change. The results for all firms are shown, over time, in Figure 1; even with a method designed for upward bias, today 40% of firms say nothing about climate change (in the SI Appendix, we tabulate the data for this analysis broken down by risk-mention category). A logical next step for research of this type would be to machine-learn the searches so that context can be identified with greater precision and, perhaps, full text could be used to identify variations in quality.

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6. For these reports, see (TCFD, 2019), (Center for Climate and Energy Solutions, 2020), and (Ceres, 2012).
7. We are aware that the general consensus among industry practitioners is that 10-Ks have limited efficacy to comprehensively capture risks, given the purposeful opaqueness of language to avoid litigation. However, as a practical matter, 10-Ks are the best available data source to assess market-wide equity disclosures at a large scale.
8. The Ceres' SEC Sustainability Disclosure Search Tool was created in collaboration with Cook ESG Research, including Jackie Cook and University of Melbourne researchers Henk Berkman, Jonathan Jona, and Naomi Soderstrom, and is powered by Morningstar text analysis. This tool was a collaborative effort to compile a list of words deemed relevant to climate change. Other studies using different methods find broadly similar patterns with regard to which industries report the most about climate change in 10-K filings but find much different rates for overall disclosure because they mine the 10-Ks differently. For example, a blog by (Rozin, 2019) using a proprietary search tool finds that just 30% of the Russell 3000 companies discuss climate change as a risk, with only 3% of companies including that discussion in their management discussion and analysis of financial condition and results of operations (MD&A).

Figure 1. Share of Russell 3000 firms mentioning climate risk in their annual 10-K filings has increased since 2009

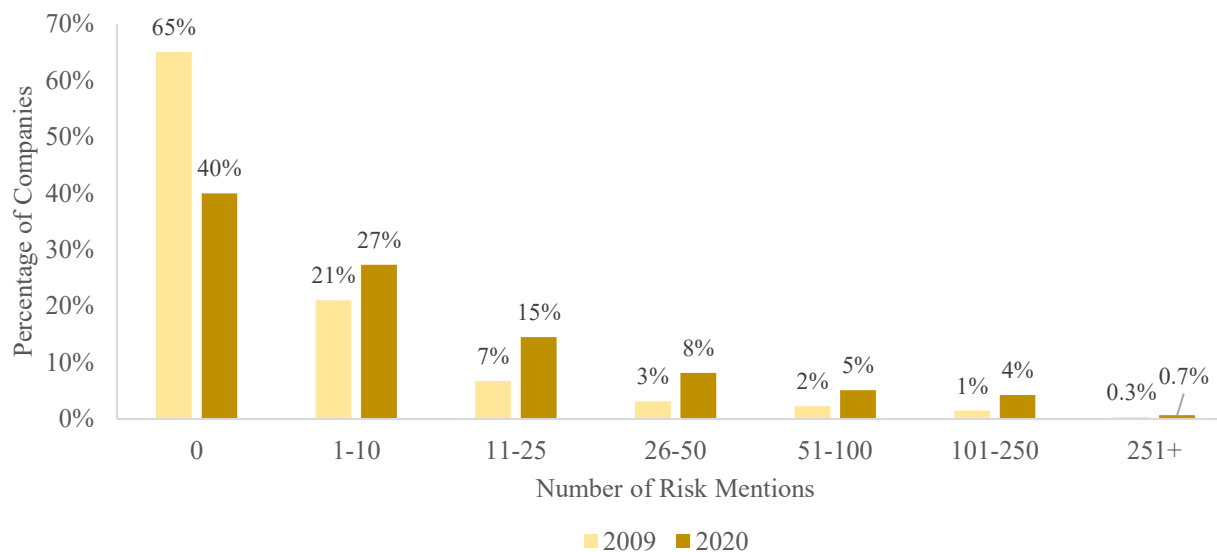


Note: The dataset for the figure above was generated by scraping a Ceres webpage that catalogues and performs a key-word analysis on SEC filings. Because the Ceres system is a keyword searcher and not using the context of the passage, words like “hurricane” and “drought” will be flagged as relevant to climate change even if the passage or entire document makes no mention of climate change directly. As such, the numbers above, if anything, are overly generous. Nonetheless, there has been a noticeable (78%) increase in the numbers of firms mentioning climate-related risks in their filings.

Source: Ceres/Cook/Morningstar 10-K Database (see footnote 9) and analysis by authors

Not only are more firms likely to say something in the later years, they are likely to say more than they did before. In 2009, the average firm mentioned climate-related risks 8.4 times in their 10-K. In 2020, that number was 19.1 times. An obvious question that arises from this fact is, what is driving the increase—is it more firms saying something, or a few vocal firms saying even more? One way to answer this question is to look at a distribution of risk mentions by amount for multiple years. We present such an analysis in Figure 2. From those plots it seems clear that the causal mechanism is the former—more firms saying something at all. This finding is further buttressed by breaking down the analysis of Figure 2 by sector. We present this sectoral analysis in the SI.

Figure 2. More companies mention climate-related risks more frequently over time



Note: For each histogram, the buckets are the number of risk mentions in a 10-K. So, for instance, the figure above says that nearly 65% of firms in 2009 say nothing regarding climate change in their 10-K. It is clear from the above figure that the increase in total mentions between 2009 and 2019 is not being driven by a few firms saying even more. The average is primarily being brought up by many quiet firms being more vocal.

Source: Ceres/Cook/Morningstar 10-K Database and analysis by authors

We then refine the analysis in two ways. First, we match each firm to its industrial sector and to its market capitalization in 2019.⁹ Second, we identify the types of disclosure—whether “transition,” “physical,” or general “non-specific”. Whereas in Figure 1 the unit of analysis was the firm, with a binary determination of whether the firm discloses anything about climate change at all, for this next analysis the unit of analysis is the individual disclosure. Thus, we will be counting types of disclosures (physical, transition, general) and showing averages by sector. (In the SI, we show more data on the distribution of the sample.)

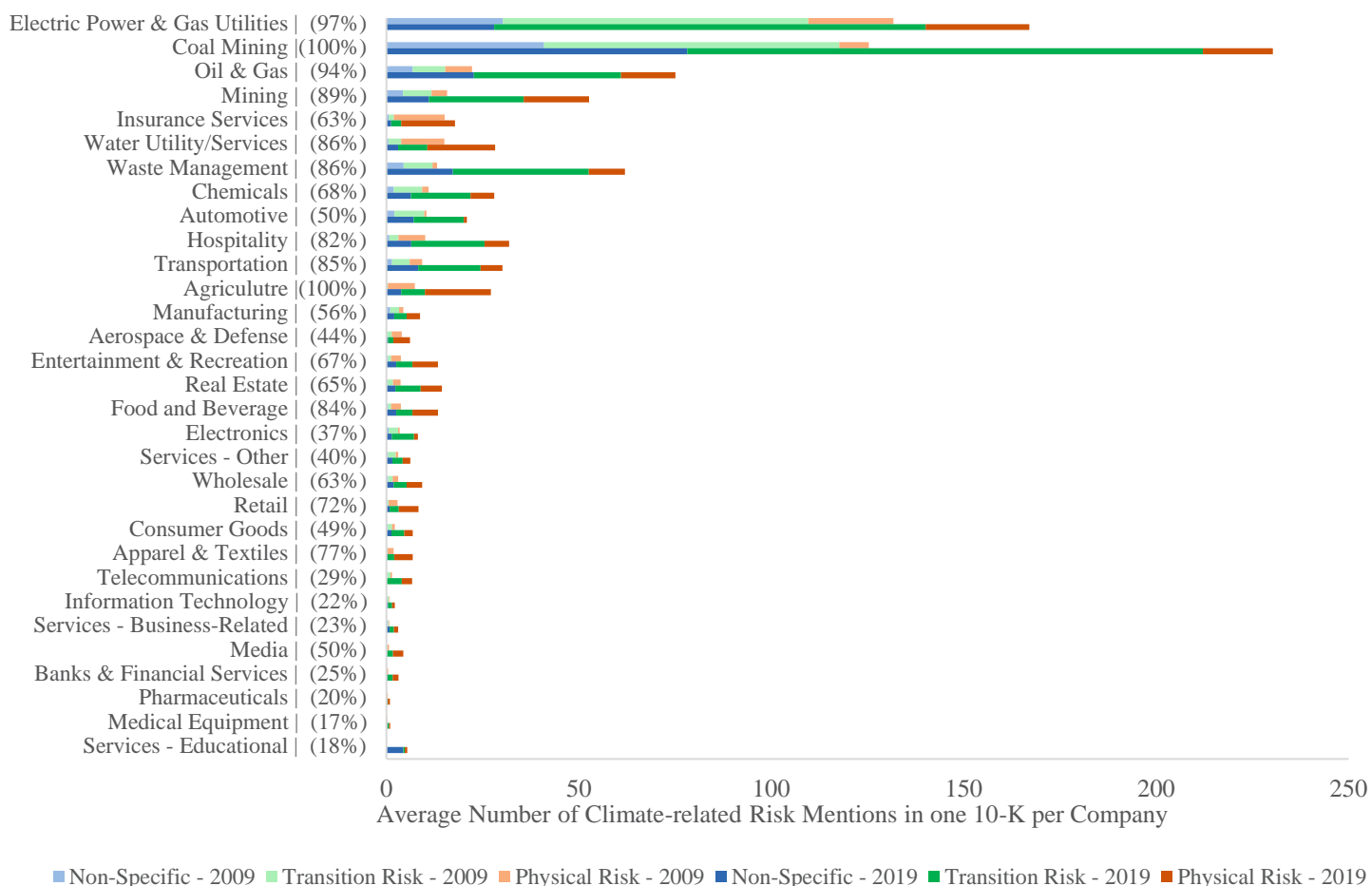
Figure 3 shows these data (in the SI, we tabulate this data) for the start and end of our time series (i.e., 2009 and 2019). Not surprisingly, firms in the four industries related to extracting and using fossil fuel energy talk the most about climate change: oil and gas, power utilities, coal mining, and other mining. Nearly all the disclosure from these firms relates to transition risk and to general climate change issues (in the SI, we show the full breakdown of risk-mention categories for all 12 years). Indeed, across those four industries, only 15% of disclosures in 2019 were related to the physical impacts of climate change. Additionally, the four industries mentioned above constitute only 8% of the Russell 3000 (by count), but 58% of all mentions of climate-related risks in 2019. Other industries with high levels of exposure—real estate, insurance, and water utilities—are noticeably quieter, accounting for 13% of the firms on the Russell 3000 and an identical portion of all climate risk disclosures. The industries that account for the bottom two-thirds of Figure 2 say almost nothing about climate change, although in a few industries at least two-thirds of firms say at least something (and usually that something is about physical risk):

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9. The Ceres search tool catalogues each firm by an assigned sector; this information was pulled when the company’s name was scraped from their site. Market capitalization data is from 2020 and was pulled from Finviz, a stock market screener.

Entertainment and Recreation (67%), Food and Beverage (84%), Retail (72%), Apparel and Textiles (77%). What may bind these industries together are strong brand identities for the largest and most visible firms. Brand-sensitive firms are among the most highly engaged with ESG reporting systems and corporate governance. Similarly, big firms also do a lot more reporting. In 2019, the largest 10% of firms by market capitalization (\$20 billion - \$1.6 trillion) were 36% more likely to mention climate change-related risk at least once in their disclosures and, on average, mentioned the risks 38% more times than the smallest 10% of firms (less than \$120 million in valuation). Figure 4, below, visualizes how skewed the total set of risk mentions is to just a few firms and sectors.

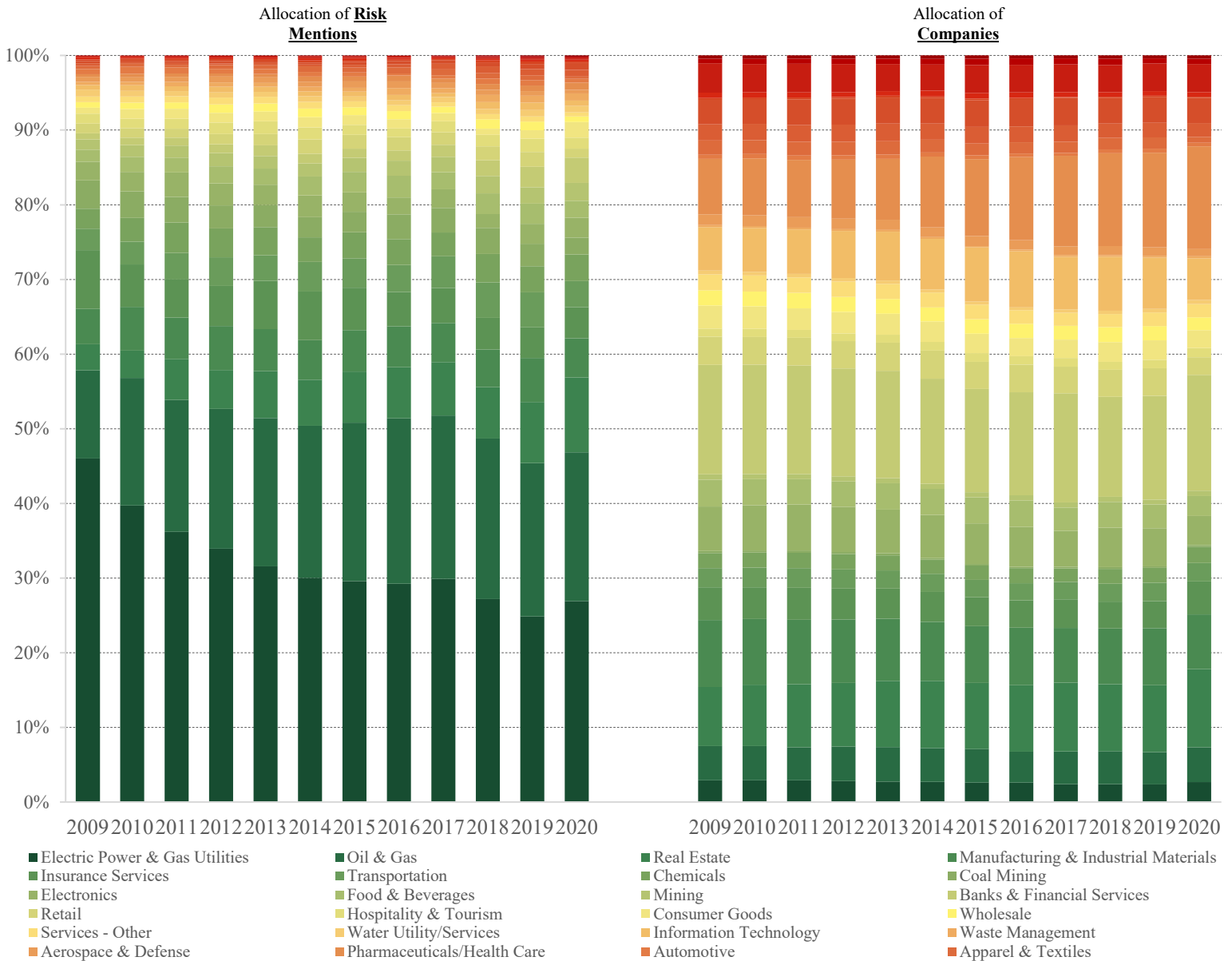
Figure 3. Climate risk discussion is dominated by three industries that primarily discuss transition risk



Note: The graph above was produced by using the Ceres tool mentioned in Figure 1. Ceres groups language in the 10-Ks that they determine is germane to climate change into four categories: non-specific language, regulatory risk, clean and renewable energy, and physical risk. For the purposes of this analysis, clean energy and regulatory risk were lumped together into the category of transition risk. The percentage next to each sector is the percent of firms in that sector that at least mentioned climate-related risk one time in their 2019 SEC filing. Two things stand out from the above figure: (1) transition risk dominates the discussion of most industries, and (2) the top four industries constitute more than the preponderance of all risk discussion.

Source: Ceres/Cook/Morningstar 10-K Database and analysis by authors

Figure 4. A relatively small number of sectors and firms account for most mentions of climate risk

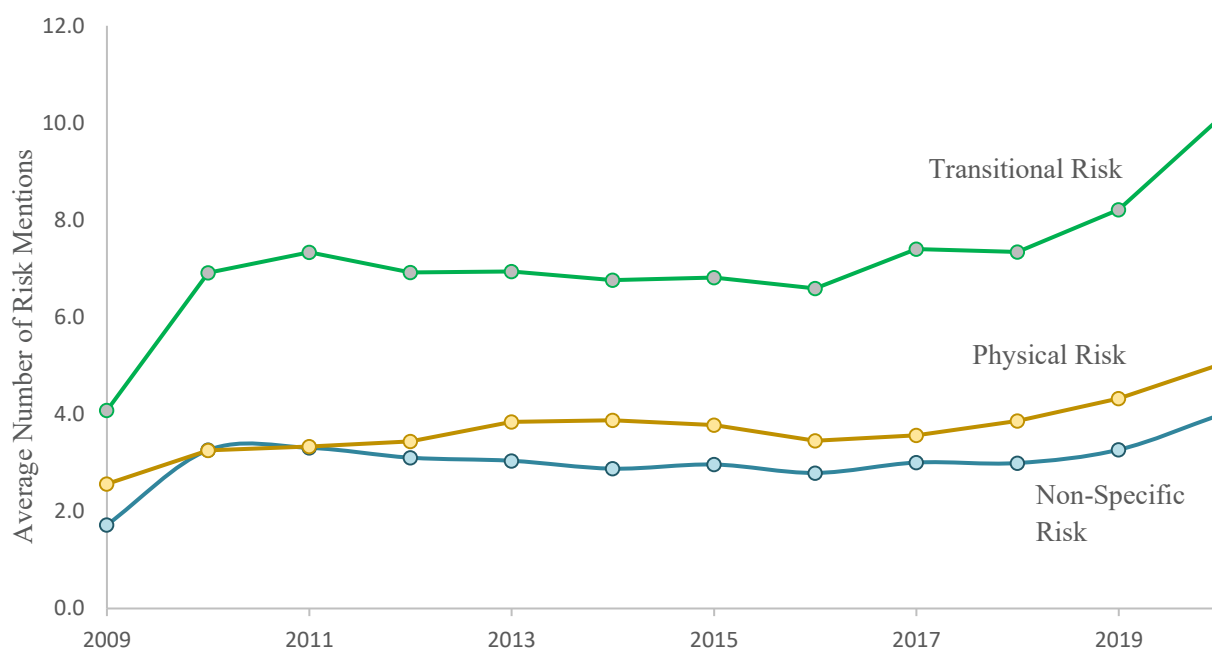


Note: On the left side of the figure, the bars represent all climate risk mentions and the percentage that comes from each sector. On the right side of the figure, the bars represent the totality of firms in the Russell 3000 that year and the percentage each sector makes up. As can be seen in the yellow-shift from the left to the right, the vast majority of risk discussion is dominated by 3-4 sectors that make up a tiny proportion of the number of companies in the Russell 3000. Oil & Gas and Electric Power & Gas Utilities, for instance, make up more than 50% of all risk discussion between 2009 and 2017, while accounting for roughly only 6-7% of the Russell 3000 in those same years.

Source: Ceres/Cook/Morningstar 10-K Database and analysis by authors

Measuring the quality of disclosure is very difficult, and to date there have been few attempts to study that question. Some academic work suggests that disclosure is symbolic and not aimed at quality; the TCFD has attempted to assess quality, but that remains a work in progress (Michelon, 2015). While this report does not fill that analytical gap, it does offer suggestive answers from three perspectives. First, we can look at types of disclosure over time (Figure 5). Over this period (2009-2020), about half of firms said at least something about climate change. Half of all the mentions about climate change relate to transition risk (top line of Figure 5). From 2009 there was a huge surge, lasting a year, in reporting on transition risk; since then, reporting levels have hardly changed for climate risks of any type. The big surge in transition risk reporting from 2009 is plausibly due to Congressional effort that year (the first year of the Obama presidency, with Democrats in power in the House, the Senate, and the White House), where climate change and health care were the top two legislative priorities once a massive economic stimulus was passed early in the year. (Climate change efforts failed, but health care succeeded.) That visible effort, along with others, such as a 2018 lawsuit by the New York Attorney General against two energy firms (AES and Xcel) charging they failed to disclose transition risks, may have made the dangers of non-disclosure palpable.

Figure 5. Transition risk has historically and continues to dominate risk discussion in 10-K filings



Note: The methodology for gathering this data is explained in Figure 1 and Figure 3. The figure above looks at the average number of risk mentions by category in one 10-K per company by year. It is clear from the chart above that transition risk has historically and continues to dominate climate risk discussion. There is an open question about why the amount of disclosure spiked between 2009 and 2010. It is possible that the 2008 New York AG lawsuits against Xcel and AES played a role. It seems probable that the TCFD report in 2017 spurred the inflection seen in the graph for the years 2017-2020.

Source: Ceres/Cook/Morningstar 10-K Database and analysis by authors

A puzzle that needs further investigation is why reporting about climate exposure is so heavily weighted to transition risk. As shown in our analysis of disclosure from traded corporate equities, transition risk gets double the mentions of physical risk. It is hard to believe that physical risks are, indeed, only half as important as transition risks. While it is true that legislation and litigation over the last decade have drawn attention to transition risks, many destructive events should have had similar effects in focusing attention on physical risk. Such events include heatwaves (every year during the past decade in the U.S., except 2015), Category 5 hurricanes that had U.S. landfall (2016, 2017, 2018, and 2019), lesser hurricanes and storms that caused exceptional damage (e.g., Sandy, which hit NYC metro area in 2012, and Harvey, which hit Houston in 2017), and wildfires (e.g., the Camp Fire in California in 2018, the biggest and deadliest in state history). All plausibly could have had the same salience and impact as transition risk disclosure, but they didn't. All these perils are expected to become more common with climate change; a growing field of research has demonstrated the improving ability to attribute such events to climate change itself.¹⁰ Economic analysis of transition costs and impacts provide no evidence that transition will be more onerous than physical damage—most, in fact, arrive at the opposite conclusion (Stern, 2007). While more work is needed on this topic, plausible explanations are rooted in how the investor community has been talking about climate change, and the fact that investors have been talking about transition risks at least since the Kyoto Protocol (1997), whereas discussion of physical impacts has followed along later. Disclosure began with a few industries that, indeed, were highly exposed to transition risk (the top four mentioned earlier), and today most investor discussion of climate risks and disclosures occurs through ESG frameworks. Those frameworks have almost exclusively focused on emissions (i.e., transition risk).

A second perspective on reporting quality comes from varied efforts to look more granularly at what companies report. Here the literature is all over the map and consists mainly of semi-systematic anecdotes. For example, a 2017 KPMG study found 130 of the world's largest 250 firms acknowledge the financial risks of climate change (a finding exactly in line with the results reported in our study), but only five quantify the risks, and 3% (roughly eight firms) discuss if or how they use scenario analysis to model risk (KPMG, 2017). By 2020 even a task as straightforward as computing emissions has, for the most part, been ignored by a large portion of firms. A study by *The Economist* in 2020 found 33% of S&P 500 companies and 21% of Euro Stoxx companies do not disclose emissions from their own operations, known as “scope one” emissions (Economist Briefing, 2020). A higher proportion, 60% and 50% respectively, do not disclose emissions that arise after customers purchase their product—for example, the emissions from jet fuel sold to an airline that burns the fuel (known as “scope three” emissions). Perhaps most disturbing is that the firms that self-select into engagement with the TCFD—those most likely to take climate change seriously—do not disclose how they integrate climate change into their risk management strategy. Only 17% of these firms actually discuss their integration strategy, and 9% discuss the resilience of their business models to climate change (TCFD, 2019). Anecdotally, firms that are highly exposed to transition risks rooted in the behavior of fossil fuel markets have been castigated for reliance upon models that have a long history of poorly representing those markets (Carbon Tracker Initiative, 2016; 2018).

A third way to examine the quality of disclosure is to look, company by company, at what is said and whether that information was already available to the market. Here, Peabody's 10-Ks are instructive because the firm has already been sued for nondisclosure. Here is how Peabody frames the risks in its latest (December 2019) 10-K:

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10. For more on event attribution, see (Differbaugh, 2020).

"The enactment of future laws or the passage of regulations regarding emissions from the use of coal by the U.S., some of its states or other countries, or other actions to limit such emissions, could result in electricity generators switching from coal to other fuel sources. Further, policies limiting available financing for the development of new coal mines or coal-fueled power stations could adversely impact the global supply and demand for coal. The potential financial impact on us of such future laws, regulations or other policies will depend upon the degree to which any such laws or regulations force electricity generators to diminish their reliance on coal as a fuel source. That, in turn, will depend on a number of factors, including the specific requirements imposed by any such laws, regulations or other policies, the time periods over which those laws, regulations or other policies would be phased in, the state of development and deployment of CCUS [Carbon Capture, Utilization, and Storage] technologies as well as acceptance of CCUS technologies to meet regulations and the alternative uses for coal."

While the 195-page 10-K offers more detail on particular initiatives, none of what is revealed extends beyond what any person reasonably knowledgeable about energy policy would already know. Indeed, while ESG frameworks offer a lot of detail around how to disclose emissions, estimating those emissions is not particularly challenging. Other studies that utilize independent sources of information are already revealing that information (Griffin, 2017); (Climate Action 100, 2020). Disclosure offers more detail from the perspective of the firm itself, but no investor would be surprised to learn that oil and gas companies have large emissions from their operations and even larger emissions linked to the sale of their products. Meanwhile, private investors and corporations are largely unaware of the looming costs needed to adapt to climate change—costs that will accrue both to private firms and municipalities (Goldstein et al, 2019).

Turning now to municipal finance, the materiality standards outlined above to guide disclosure are similar, but the practice of disclosure is *much* worse. While smaller than the corporate equity market, municipal debt—with a valuation of roughly \$3.9 trillion (MSRB, 2019)—is incredibly important to some individual investors and mutual funds. Municipal bonds have historically very low default rates and offer notable tax advantages.¹¹ For our purposes, this market is particularly important because, in principle, it should be a place where the physical effects of climate change are most evident. Much of what municipalities do with funds raised from these bonds (e.g., infrastructure) is vulnerable to physical impacts; looking to the future, even more infrastructure spending (e.g., sea walls) will be needed to ameliorate climate impacts, and localities will be expected to pay for some of that. Moreover, the revenue supplied to assure bond repayment (e.g., property, sales, and income tax) is itself potentially vulnerable to climate change if repeated climate-related events (e.g., floods, fires, and heat waves) lead to outward migration and loss of local appeal and wealth (Deese, 2019).

Municipal finance comes mainly in two kinds. General Obligation (“GO”) bonds, or bonds that are backed by the full taxation power of a governmental entity whose tax base may be threatened by climate change. The other is revenue bonds—instruments tied to specific projects that may face losses from perils such as flooding, sea-level rise, or wildfires. Small changes in damages could have big effects on historically low (near zero) default risks that are the bedrock assumption for the whole municipal finance market. Indeed, analysis and risk modeling by BlackRock and the Rhodium Group concludes that under a scenario where emissions of warming gases are not controlled, "within a decade, more than 15% of the

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11. Between 1970 and 2016, the default rate of investment-grade municipal bonds was 0.18%—nearly ten times less than the default rate of investment-grade corporate bonds of 1.74% (MSRB, 2019).

current S&P National Municipal Bond Index (by market value) would be issued by MSAs [metropolitan statistical areas] suffering likely average annualized economic losses of up to 0.5% to 1% of GDP [from climate change]"(Deese, 2019). Over longer time horizons those damages could be significant, and while there are substantial uncertainties in climate impacts, the risks are large enough that they should, in principle, be reflected in prices of GO and especially revenue bonds.

On the municipal bond side, there is no publicly available equivalent to the Ceres keyword search. All municipal bonds are available on a centralized site ("EMMA," maintained by the Municipal Standards Rulemaking Board [MSRB]) but they must be pulled one at a time with no search index pre-processing. Worse, there is no widely agreed-upon method for identifying which municipalities are at risk. (That lack of agreement is the root of a common refrain in the industry that even where concerns about climate change may exist, it is not possible to quantify them. We will show that is incorrect.) With large systematic data sets hard to obtain and methods for assessing risk in flux (at best), much of the discussion about how climate impacts affect municipal finance has been anecdotal yet illuminating. Some of the most at-risk municipalities in the country—New Orleans, Los Angeles, Charleston, SC, and Mobile, AL, among them—do not mention the term "climate change" once in their most recent bond offerings.¹²

There is some evidence that municipalities simply don't pay attention to climate change when it comes to their financial offerings even when they are focused on dangers of climate in other areas of policy. Oakland, for example, has organized a common law nuisance lawsuit against BP (because the oil giant's emissions are linked to climate change), claiming big impacts to the city from climate change, yet at the same time raising funds in the municipal debt market with disclosures silent about climate change.¹³ In the lawsuit (*City of Oakland vs. BP*, 2020), Oakland states:

"Storms with their attendant surges and flooding occur on top of and super imposed on sea level rise, causing storm surges to be greater, extend farther inland, and cause more extensive damage—including greater inundation and flooding of public and private property in Oakland. A 100-year flood event is, an event that—without global warming—normally has a 1% chance of happening every year. But by 2050, a '100-year flood' in the Oakland vicinity is expected to occur on average once every 2.3 years and by 2100 to occur 44 times per year—or almost once per week. Similarly, the 500-year storm surge flood would occur 13 times per year by 2100."

Yet in their 2020 general obligation bond (which borrows out to 2042) Official Statement, the City maintains a different stance:

"The City is unable to predict whether sea level rise or any other impacts of climate change will occur, the extent to which they will occur, when they may occur, and, if any such events occur, [and] whether they will have a material adverse effect on the financial condition of the City and the local economy." (City of Oakland General Obligation Bond, 2020)

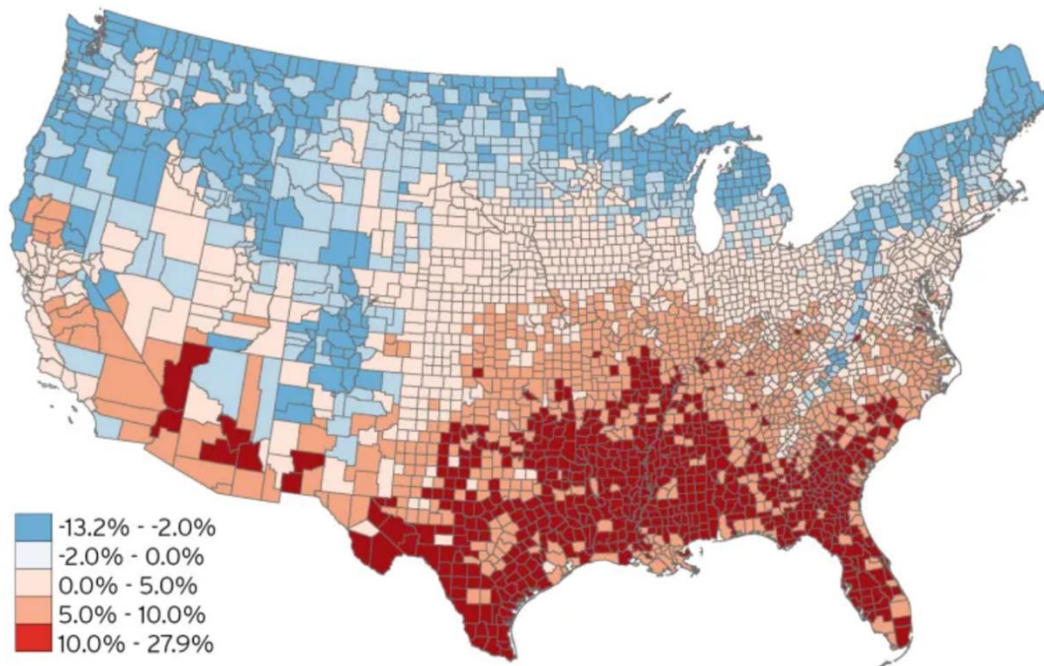
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12. We include links to these recent bond offering Official Statements in the references.

13. For more on municipal rebuttals to legal challenges in these lawsuits stating they intentionally did not disclose climate impacts, see (Rhodes and Magrini, 2019). Cities held that not every risk may be material to each bond offering, that not every risk is fully understood at the time of offering, and that mitigation efforts may prevent damages.

While it is hard to obtain systematic data on climate impacts and link that to bond issuance, it is possible to do better than pretending the task is impossible. We use a widely cited study of climate impacts that offers estimates at fine geographical resolution—down to the levels of counties in the U.S. This study from the Climate Impact Lab (CIL), a consortium of researchers working with leading-edge data techniques to quantify physical risks, estimates damages for eight major perils: crop yields, mortality, changes to low-risk labor, changes to high-risk labor, property crime, violent crime, energy expenditures, and coastal damage. These different perils are modeled for the time period 2080 to 2099 and then converted into common currency (discounted U.S. dollars), with results as presented in Figure 6. From the perspective of economics, two effects dominate the results: in parts of the Atlantic and Gulf coasts, strong cyclonic storms; across all the hot parts of the country, the effects of additional heat. Nationwide, heat stress—which affects worker productivity and mortality—has the largest economic effect. Most of the plausible scenarios that run from climate change to municipal distress involve physically damaging climate impacts, although in some communities (e.g., in coal-dominated municipalities such as Gillette, WY, or across Appalachia) there are impacts that run from lost tax revenues and real estate valuation, due to abandonment of high carbon fuels, to municipal distress (Morris, 2019).

Figure 6. Projected 2080 income loss from climate change by U.S. county



Note: This figure shows projected climate impacts measured by county level income change as a share of 2012 income by 2080. Regions of the south are heavily impacted, with income losses up to 27.9%, while regions of the Pacific Northwest and Northeast show net increases in county income. The data behind this figure, which also form the basis for our analysis of municipal bonds, is from the Climate Impacts Lab, and demonstrates that high degrees of geographic specificity are possible in evaluating climate impacts.

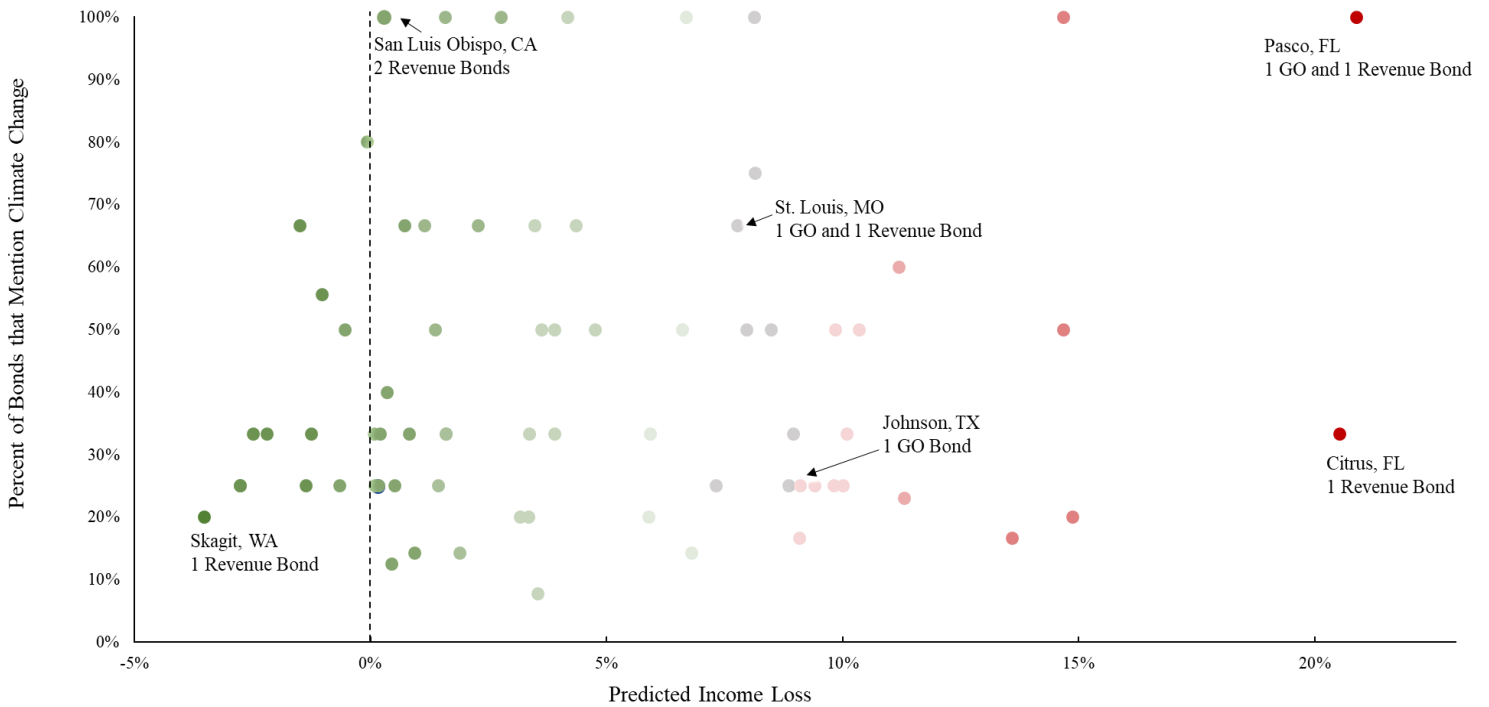
Source: Climate Impact Lab and analysis by Mark Muro, David G. Victor, and Jacob Whiton (2019)

Using the CIL data, we rank all 590 U.S. counties with populations over 100,000 by climate exposure, from least to most exposed.¹⁴ For “exposure,” we use CIL’s county-level estimate of net economic damages due to climate change, for the period 2080-2099, under a scenario that assumes emissions are not much affected by global policy. We are mindful that impacts in 2080 are not material to many bond issuances in 2020, especially those with short maturity. Using a 2017 sample of 350,000 bonds collected by Marcus Painter of Saint Louis University, we calculate that the average maturity of outstanding bonds is 13 years; however, given that 41% of bonds have a maturity of 15 or more years and 23% have maturities of 20 years or more, the CIL county-level estimates are highly likely to be correlated in both direction and magnitude with nearer-term impacts. For instance, the places most likely to suffer extreme heat stress in 2080 are also, relative to other counties, more likely to suffer that peril earlier. Moreover, the CIL estimates are medians, and given the uncertainties in climate warming (e.g., warming is already happening faster than the IPCC estimated two years ago), the tail effects are likely to be important by the 2050s or earlier. Other work has argued that those effects, in much of the country, will be apparent over the next decade (Rhodium Group, 2019). As such, our use of the CIL 2080 median estimates should not be viewed as a prediction for distress in the bond market but rather as a method for identifying at-risk counties. Having ranked these counties, we then sample recent bond issuances and the corresponding Official Statements looking for language about climate change. For 590 studied counties, we looked at the Official Statements of bonds from 2010 to the present. For larger counties with hundreds of bonds in that range, we selected 15-20 bonds to stay consistent with the smaller counties, and chose the most recent bonds where Official Statements were accessible. For each bond, we looked to see if the Official Statement mentioned (1) climate change; (2) plans for adaptation; (3) a discussion of reports or modeling techniques used to understand exposure; and (4) a quantification of their risk. (The SI reports the full data set and the types of bonds sampled.) This leads to a matrix that crosses these two variables—climate exposure and engagement with climate disclosure—as shown in Figure 7.

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14. This method of looking at counties over a threshold population may introduce a minor bias into our results as the full set of less populated counties has a slightly higher exposure to climate impacts. (For more details, which suggest there is no meaningful bias, see SI.)

Figure 7. There is no significant difference in reporting quantity or quality between high-risk and low-risk municipalities



Note: The data above was gathered from sampling 590 counties and nearly 1,500 municipal bonds. These bonds were made up of general obligation (GO) and revenue bonds from the most at risk and least at risk municipalities with populations > 100,000, using risk rankings from the Climate Impact Lab, which measure predicted county income loss as share of 2012 income by 2080. This figure shows no relationship between predicted income loss and the percent of a county’s bonds that mention climate change. Outliers include large coastal counties, which may face well-understood risks from sea level rise, or have large affluent or liberal populations. The number and types of bonds called out in the above figure are the bonds for that municipality that mentioned climate change, not the total number of bonds checked for that municipality.

Source: Climate Impact Lab, Municipal Securities Rulemaking Board, and analysis by authors

The data on Figure 7 show essentially no relationship between economy at risk (as assessed by CIL) and engagement of climate change (as reported by municipalities in their bond disclosures). In the SI, we report these data aggregated; we also, as a robustness check, used the same method but with estimates of climate impacts derived from 427, a company now owned by Moody’s. (The results, with a smaller sample than reported here, are aligned.) Additionally, in the SI we explore the relationship between climate risk exposure, bond maturity length, and disclosure. Again, we find no relationship between the three variables.

At the extremes (see the left-most and right-most bins on Figure 7), there are modest differences in reporting on climate change. That effect appears to be dominated by counties in coastal states—in Florida

and the Carolinas (where the CIL data show substantial impacts due to hurricanes) and California. (In the SI, we report geographical patterns at the state level.)

Further research should assess multivariate relationships between plausible causal factors (e.g., objective exposure, partisan identification, income, and other factors that prior research has shown to form attitudes about climate change and thus plausibly may form attitudes about reporting on climate change). One pattern that is apparent is the difference between GO bonds (42% of our sample) and revenue bonds (57%). Because GO bonds have general backing from a municipality, they are plausibly less at risk, which is consistent with the patterns we observe: 10.5% of revenue bonds include a mention of climate change, but that same mention is present in just 3.8% of GO bonds. In the SI, we include a table that breaks down—among low and high-risk counties—the number of bonds and counties checked, the percent of GO and revenue bonds that mention climate change, and a quantification of the overrepresentation of coastal communities in climate disclosure. The credit stress from the physical impacts of climate change is yet another factor that amplifies default risk factors that investors are already aware of, such as underfunded pension liabilities.

The failure to say much about climate change in municipal finance, even as public debate about climate impacts was soaring over the last decade and disclosure practices in equities embraced the climate agenda, is puzzling. We see three interrelated explanations rooted in a) analytical tools; b) imagination; and c) terrible policy that allows self-interest (avoiding disclosure that might drive up borrowing costs) to outweigh market needs, alongside policies that create moral hazards by inviting communities to risk exposures that the federal government will backstop. In the conclusion, we elaborate on these in more detail, since they apply, as well, to other topics that we address in the next sections.

Credit Rating Agencies and Other Analytical Organizations

Whether poor disclosure is material to market behavior depends not simply on what companies and municipalities say about climate risks but also how pivotal actors in the markets aggregate and assess information (including information from disclosures, but typically a lot more). Disclosure could be terrible, yet markets could still price risks appropriately if large traders, credit rating agencies, and others found alternative ways to incorporate climate-related information. As a practical matter, some very large investors do their own assessments of risk. Thus, the question of disclosure may be of paramount importance for segments of the investor community that include smaller retail investors and those that rely heavily on opinions, notably from the credit rating agencies. How these agencies form their assessments is the subject of this section, and whether the markets care about that information and disclosure is addressed in the next section.

Looking to global financial institutions, the data are not encouraging. A 2019 Oliver Wyman survey of 45 global financial institutions—including Capital One, Goldman Sachs, JPMorgan Chase, and Wells Fargo—found that just two explicitly factor climate change into their credit risk-assessments. One third do not consider it at all.¹⁵ A growing number of investment groups claim they are focusing on climate change in their risk assessments and in redlining certain areas against investment (e.g., coal production). But that work nearly always looks at “climate” through an ESG framework. All ESG frameworks that include climate change include a focus on transition risk, and the most important ESG frameworks have increasingly detailed standards for emissions reporting and assessment of transition risk. The major ESG

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15. Oliver Wyman did not identify which two institutions addressed climate explicitly. For more, see (Colas et al, 2019).

frameworks also include, in principal, attention to physical risks, but systematic methods for assessing those risks remain elusive. Thus, in practice, climate disclosure through the utilization of ESG frameworks has meant focus on transition risk.

A few central banks appear to be doing better, but as of this writing, that progress is hard to fully assess. Notable are efforts to apply stress tests that can gauge the resilience of banks and other institutions to large systemic shocks, and model impacts on capital reserves, credit availability, and other indicators during near-term events like recessions (Adrian et al, 2020). There have been several efforts to begin stress testing climate-related factors—transition and physical risks—particularly through EU banks and several other jurisdictions (Cadman, 2020), and the Commodity Futures Trading Commission (CFTC) has called on U.S. regulators and banks to undertake similar stress test efforts (CFTC, 2020). The Bank of England has undertaken a comprehensive climate stress test of their holdings, including both physical and transition risks, but has postponed releasing the results due to coronavirus.¹⁶

The actors who play a pivotal role in managing complex risks are the credit rating agencies. Fitch, Moody's, and S&P account for nearly 95% of the global market share for credit rating (Ronsberg, 2011), and thus we focus on them. (In some industries, other credit rating agencies also play key roles, such as A.M. Best and Kroll for the insurance industry. We see no evidence that the patterns of engagement around climate change for those more specialized agencies are much different from what we will summarize for the big three here.) In recent years, all three agencies have invested in analytical capabilities and issued reports on the matter.¹⁷ Our interest, though, is in materiality—have climate risks affected what the credit rating agencies do?

We answer this question from two perspectives. First, we look, where possible, at the actual work of the credit rating agencies: ratings. This is difficult because the credit rating process remains a difficult one for outside analysts to peer inside and understand from a practical perspective of replicating outcomes and results. (Whether this is a good practice or whether the agencies should be subjected to more extensive regulation and disclosure requirements is beyond the scope of this paper [Rivlin and Soroushian, 2017]. In subsequent research, we will look directly at that topic with regard to physical impacts of climate change.)

There are encouraging signs from the credit rating agencies that efforts are emerging to incorporate climate risk into their credit considerations, although the transparency of these efforts varies.

Moody's has published regular overview reports on both their ESG methodology, and in particular, how they address environmental risks, including climate change (see Moody's 2016, 2017a, 2018, 2019b and 2020a). Their approach sees climate-related risks arising over different time horizons and includes transition and physical risks. With regard to physical risks:

“Direct environmental trends such as those arising from climate change (for example, rising temperatures) are typically incremental, developing over very long time frames, with diffuse

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16. While the results are unreleased, physical variables proposed included heat stress and increased storm severity, among others. Transition risk variables proposed included carbon pricing, renewables development, and changing consumer preferences. See (Bank of England, 2019).
17. Moody's acquired 427 and Vigeo Eiris, and S&P recently acquired RobecoSAM—groups whose analytical capabilities are oriented around climate change. Collectively, the three big credit rating agencies have released over 1000 pages of documents discussing climate change (usually in the context of ESG) and appear to have substantially more material for clients (behind paywalls) on these topics. These materials vary in what they say about how climate change—either as a source of systemic change, or its impact on particular events that might distress municipalities—is factored into their decision-making processes.

consequences and *limited immediate impact on ratings*. High impact environmental hazards such as hurricanes or cyclones, wildfires or floods are episodic; they can be severe, concentrated in their impact and can sometimes have an immediate impact on ratings” (Moody’s 2019b, page 7, emphasis added).

In 2020 Moody’s added more detail on how they utilize scenario analysis for both transition and physical climate risk. That study emphasized the evolving methods for assessing physical risk:

“As climate-related hazards increase in severity and frequency, we expect them to have more adverse economic and social ramifications for issuers, such as impaired asset values, costs to repair and rebuild infrastructure, lost economic opportunity, business disruption, health and safety risks, food insecurity and population displacement. These all have the potential to hurt credit outcomes, although the actual impact will vary significantly across regions” (Moody’s 2020a, page 9).

There is anecdotal evidence that points to varied impacts of these analytical approaches on ratings themselves. Recently Moody’s downgraded a municipal utility district in northern California due to wildfire risk—a risk that recent wildfire events made tangible—and also downgraded multiple Texas municipalities after Hurricane Harvey revealed greater vulnerabilities to flooding (Moody’s, 2019c; Moody’s, 2017b). As suggested above in the quote from its 2019 framework, these actions were justified by specific events that revealed the hazard, rather than ex ante evaluation of the long-term, cumulative, and diffuse possible effects of warming.

As a practical matter, the Moody’s attention to climate (reflecting the broader market, as we discuss above) is more concentrated on transition risk than physical risk. Two-thirds of their 2020 scenario analysis report concentrates on the former, with more detailed analytical frameworks, compared with just one-third on the latter.¹⁸ A major challenge for any rating agency when it assesses government issuance, in particular, is the need to evaluate the interplay of two factors: a) whether there is a public sector backstop on losses that might be incurred (see our discussion of FEMA below, for example); b) whether jurisdictions can minimize any risk of default through continued strong economic fundamentals (e.g., tax base) and adaptation strategies (see Moody’s, 2016 page 1; Moody’s, 2019b page 7).

While there are good reasons for credit rating agencies not to fully reveal their methods—so that issuers won’t game the system and competitor agencies won’t gain undue commercial advantage—at present there is no way for external stakeholders to ascertain the materiality of climate change on ratings. That makes it harder for issuers, especially those where risks may be greatest, to know how to behave. It makes it hard for investors to understand how different methods or expectations might cause different material impacts on an asset, which is important because climate models do not agree in detail on some of the most important projections for local harm. It also makes it hard for people and political leaders living in a municipality to understand how to balance their own investments in adapting to climate risks.

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18. This is based on a page count of the Moody’s (2020a) analysis covering transition and physical risks, from pages 4-12. The discussion of transition risk includes, for example, assessments of exposure for 20 automakers along with links to numerous Moody’s reports on particular aspects of transition risk (many of which are behind subscriber walls). The discussion of physical risks, understandably, looks broadly at possible impacts and points to ongoing development of “approaches and frameworks to assess the ways in which such physical risks will transmit into credit implications...” Those approaches appear to be most advanced for U.S. electric utilities and for sovereign risks related to sea level rise (Moody’s 2020a, p.12).

Development of the methods for obtaining the relevant information and making rating assessments is at early stages.¹⁹

The other two agencies, S&P and Fitch, have also begun articulating more fully their approach to climate change impacts, although their information points to essentially the same conclusion: climate change, for ratings purposes, is currently mostly immaterial to ratings decisions. In both cases, like Moody's, the agencies lump climate change concerns with other factors such as ESG—an act that may, inadvertently, lead the agencies to focus on emissions and transition risk even though, for municipal finance, the bigger risks may be physical. In 2017, S&P retroactively looked over their 9,000 corporate credit rating updates and issuance from 2015 to 2017 and found that in only 106 (or 1.2%) of all their decisions were climate and environmental factors (E&C) a key driver of their decision (S&P Global, 2017).²⁰ Of those 106, only 43 were downgrades (only 0.5% of all decisions). In 2019, Fitch did their own retrospective evaluation of whether climate change affected (over an unstated period) ratings related to public finance and infrastructure projects.²¹ Even given the broadness of the ESG category, Fitch found that such factors were only relevant to about 5% of all rating decisions regarding infrastructure projects and public finance. Only one-quarter of that 5% concerned environmental factors at all. Of that tiny portion, climate change was the relevant environmental factor in only one third of the cases. Thus, looking across the entire Fitch sample, the agency determined that any aspect of climate change was material to a rating just 0.03% of the time (Fitch, 2019).

Figure 8 shows what these two agencies learned from their retrospective analyses. Where possible, we have tried to apply the same categorical concepts across the two agencies (reflected in colors on the chart). Among many of the differences, the two agencies apply screens in different ways. For the S&P analysis, the question of whether an environment-related factor was determinative of a rating was applied early in the sample (the second, yellow pie) with the ultimate aim of explaining whether the screen would affect a rating upward or downward. By contrast, for Fitch, the determinative screen was applied at the end of the analysis, and no information is supplied on whether the ratings went up or down.²²

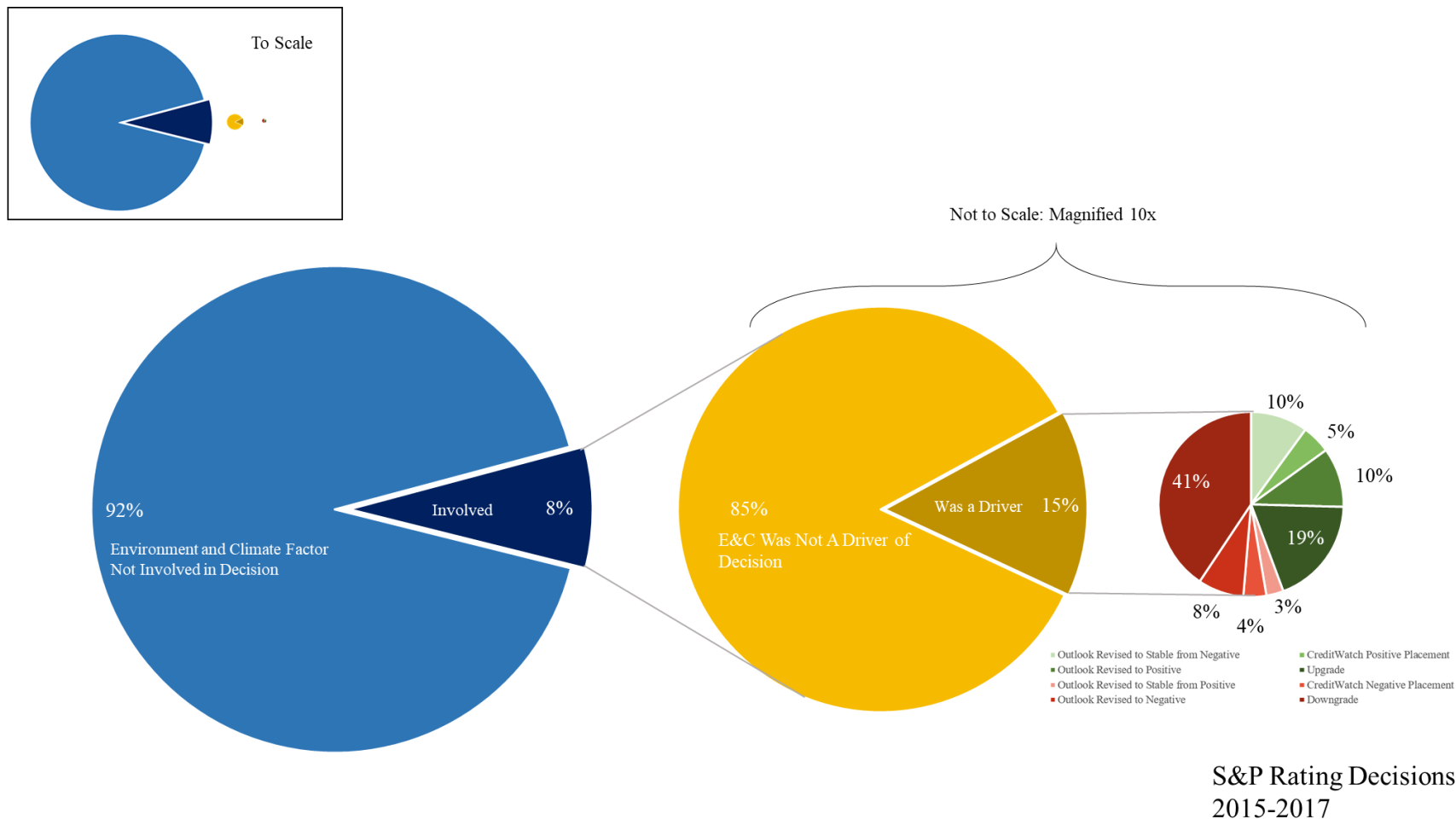
19. Indeed, even in places that have binding requirements for such assessments along with strong public and government support, actual practice lags behind. In France, a binding law has not been met with required disclosure (see Evain, 2018).

20. In 717 cases, E&C factors were considered an important consideration. But in a separate blog post, S&P refers to those 717 cases as examples where E&C factors were just "relevant" to their decision.

21. Methodologically, however, it lumped all of climate change within the ESG category—indicating that it considers it germane to corporate social responsibility. It thus paired climate change with energy management, waste management, and hazardous waste management considerations—in practice, topics related to emissions and pollution, not physical risk.

22. It appears that Moody's has done a similar materiality analysis, available behind a paywall and reported on publicly to examine the materiality of ESG in general. The public release notes that 88% of ESG mentions are about governance; 16% cite environmental issues. Looking across all of 2500 rating actions where it found ESG to be material, in 19% of cases the impact was negative, 12% positive, and 69% neutral (Moody's 2020b).

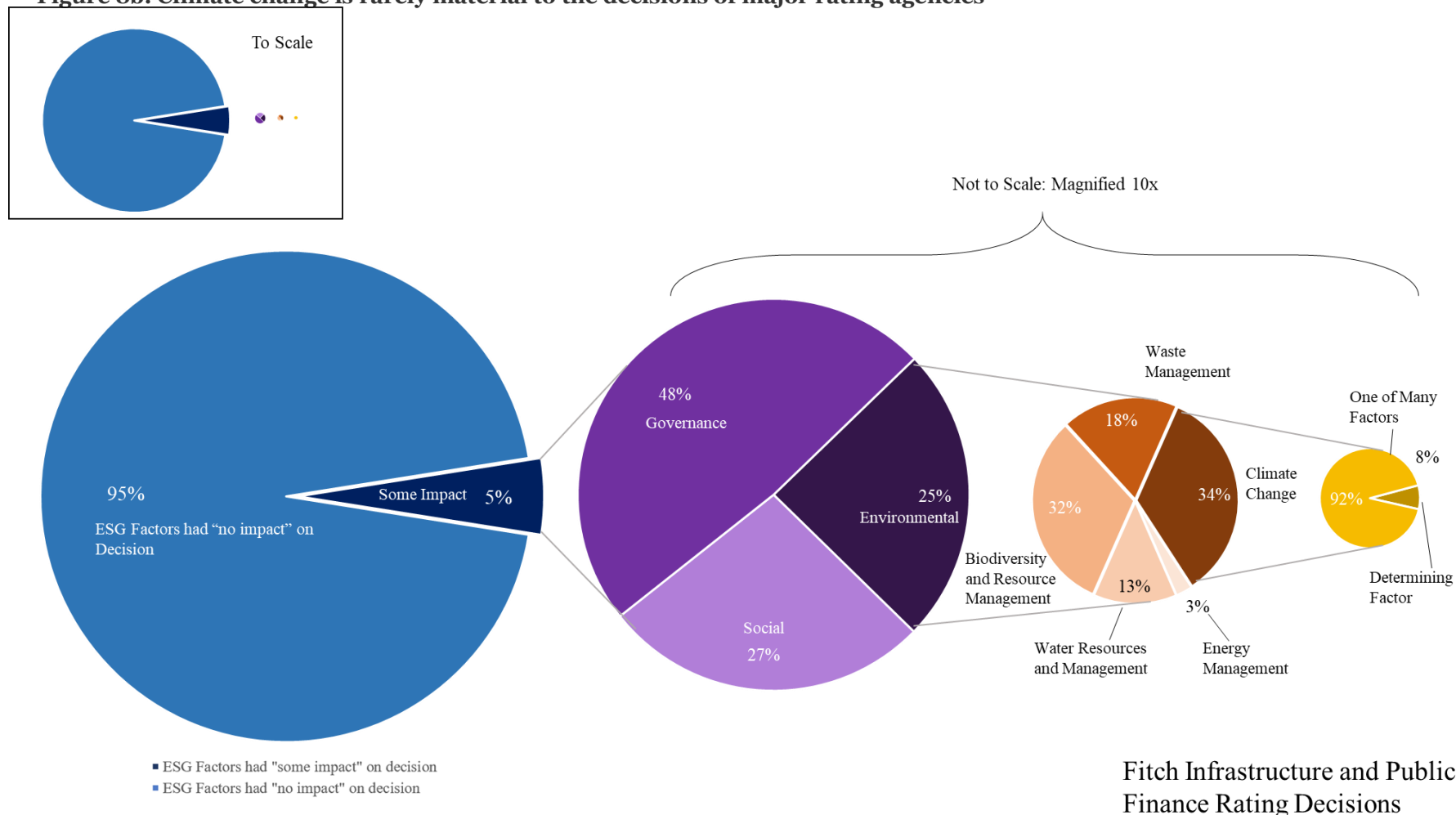
Figure 8a. Climate change is rarely material to the decisions of major rating agencies



Note: The data for the above figure was pulled from the publicly available reports by S&P. It is clear from the figures that climate change is almost never materially relevant to their decision. Only 0.5% of all decisions by S&P were a rating downgrade because of climate change.

Source: Standard and Poor's

Figure 8b. Climate change is rarely material to the decisions of major rating agencies



Fitch Infrastructure and Public Finance Rating Decisions

Note: The data for the above figure was pulled from the publicly available reports by Fitch. It is clear from the figures that climate change is almost never materially relevant to their decision. In only 0.03% of all infrastructure and public finance decisions by Fitch was climate change a determining factor in their decision.

Source: Fitch Ratings

One could conclude that the rating agencies have determined, so far, that climate does not have a material impact on ratings. However, whether that observation is robust is hard for anyone outside those agencies to assess. The methods they have used to evaluate their own ratings process rely heavily on ESG-like criteria that might focus attention on emissions rather than physical risk.

Since the perspective of asking credit ratings agencies to report on how climate affects their work is necessarily incomplete, we take a second perspective that is much more anecdotal. We look at two cases—one corporate, one public finance—where perils were, for any knowledgeable expert, clearly within the scope of climate-related impacts, but were ignored until after the peril was manifest and the impacts were clear. We suggest that in both these cases the failures to reflect climate perils reflect a failure of imagination. As climate change unfolds, its impacts may not be readily computed just by looking, for example, at assets at risk. Will a hurricane wipe out a bridge, for example? Instead, the pernicious impacts of climate change require more imagination. For example, a shift in the probability of a peril can interact with corporate behavior in ways that magnify the risk—as evident with wildfires in California where climate-related drying of biomass (along with poor forest management and other factors) interacted with an aging power grid infrastructure managed by the utility PG&E.²³ Similarly, better imagination will be needed to see that, perhaps, the big physical risks from climate change for municipal finance lie with erosion of the tax base—not simply destruction of uninsured publicly funded property or the need to build new infrastructures to protect a municipality from storm surges or other perils. These systematic impacts create cascading effects, that, while hard to measure, we can grasp in the same way we triangulate municipal exposures—through the extremes.

One such example is PG&E. Not one of Moody's PG&E credit rating decisions before the 2017 fires mentioned climate change as a relevant risk factor to the utility. Yet almost every single rating decision after the fires mentioned climate change, as heightened wildfire risk alongside California's inverse condemnation laws that hold utilities liable for wildfire damage regardless of negligence could lead to long term credit impairment (Moody's, 2020c). PG&E, in vastly underestimating its climate exposure, is an instructive bellwether of potential future extreme events. After the 2017 and 2018 fires PG&E entered bankruptcy filings and began an extensive restructuring of its debt with California state oversight. The utility has paid out billions in subrogation claims to insurers and had trouble obtaining insurance for continued operation. It will exit bankruptcy still deeply indebted with a bond package rated Baa3 by Moody's and BBB- by (Wiltermuth, 2020).

Another extreme example is Puerto Rico—perhaps the most dire American example of how climate change (extreme cyclonic storms and flooding) can interact with the tax base to alter repayment risks. Puerto Rico was already deeply economically distressed before the climate-linked hurricane made landfall. It is an indicative story of how climate change risks may have their greatest impacts on society—not as single blockbuster events that arrive overnight but as a stressor, often repeated, that undermines communities already in financial distress. In Figure 9, we show the progression of ratings (Moody's) for Puerto Rico's GO bonds along with one revenue bond: for Puerto Rico's Aqueduct and Sewer Authority (PRASA).²⁴ We begin in October 2013 with a fresh downgrade, inspired by a slowing economy (but no

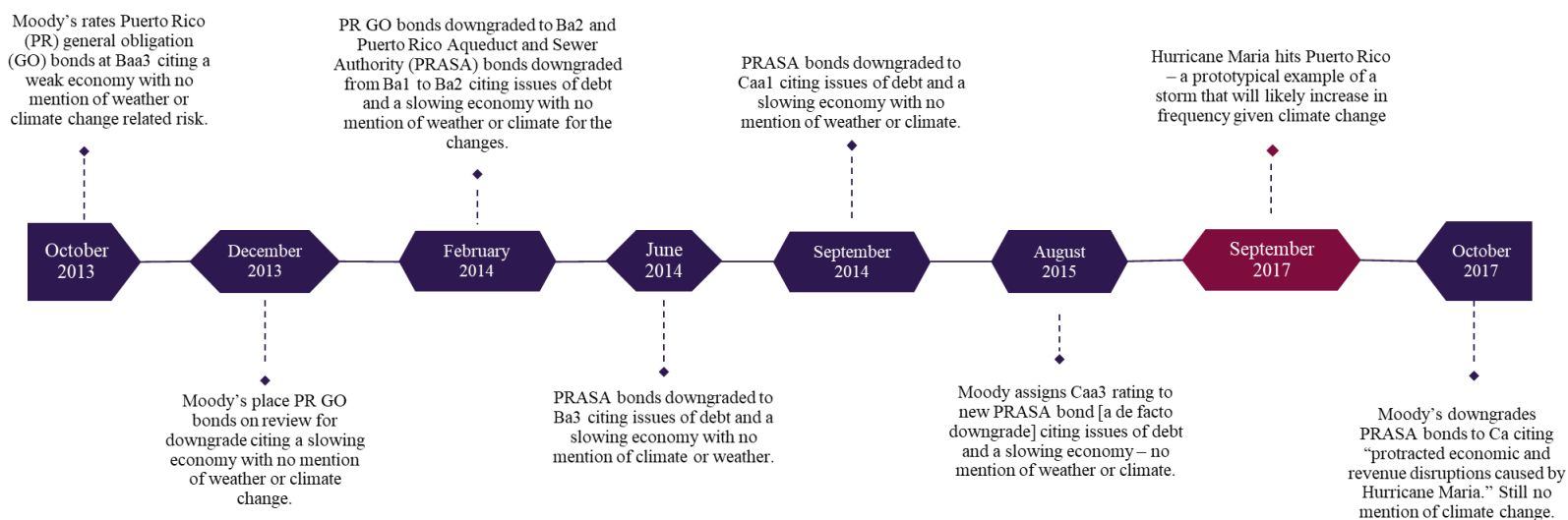
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23. The combined impacts of climate change on increasing frequency and severity of wildfires is well documented. For a summary, see *Wildfires and Climate Change* (Center for Climate and Energy Solutions). In a recent statement, PG&E admitted that its electrical equipment caused the 2018 Camp Fire (Cal Fire, 2020).

24. While there are multiple credit rating agencies, we use the Moody's assessment because of its transparency in how ratings progress with material events, which are published on their public website.

concerns about climate change or climate-related perils). Both bond types then go through a series of five downgrades—each time rooted in macroeconomic concerns (including debt levels). Then Hurricane Maria hits in September 2017; the next month Moody’s downgrades the PRASA revenue bond out of revenue concerns but still makes no mention of climate change affecting the probability of Maria-like events in the future. Yet assessing any additional stress from future hurricanes must be done with an eye to the deeper fundamentals; between 2013 and 2017 Moody’s lowered Puerto Rico debt six notches—five for fundamental economic reasons (e.g., debt and fixed costs) and one for Maria herself.

Figure 9. Between 2013 and 2020, Moody’s never mentioned climate change as relevant to their bond ratings of Puerto Rico, even after Hurricane Maria



Note: Between 2013 and September 2017, Moody’s only discussed a slowing economy and worsening debt for their reasons to downgrade general obligation and revenue bonds from Puerto Rico. Even after Hurricane Maria hit, Moody’s analysis focused on the implications of that particular storm, not the risk of similar storms in the future.

Source: Moody’s

Why have the credit rating agencies done so little to reflect climate change in their work? We can speculate about five overlapping answers:

1. The agencies may see little impact from climate change on what they are asked to evaluate, which is typically repayment risks. Except in extreme cases, climate is viewed as a chronic background problem that is less material than immediate economic fundamentals and seemingly rare climate-related events such as a wildfire or hurricane.
2. Many agencies appear to view climate change as an ESG issue. Because the “E” tranche of ESG issues is highly expansive—it includes waste management, pollution, and emissions—this perspective is often in the realm of transition risk. All the major ESG frameworks increasingly call for inclusion of physical risks from climate, but methods for assessing those are still immature (see below). Moreover, in some cases it appears that the “S” and “G” tranches have reliably driven ratings action more so than environmental concerns (Fitch, 2019; Vartholomaios et al, 2019).

3. There seems to be a widespread belief that physical risks can't be estimated reliably at sufficiently fine geographic, temporal, and peril level resolutions. Two of the major credit rating agencies have invested in firms that could address those challenges, although it is hard for outsiders to assess how fine-resolution information on perils and assets at risk trace into the core work of the credit rating agencies. The third firm, Fitch, seems to be using a historically calibrated risk model. Better tools are a big step forward, and the agencies in different ways are taking that step. In the climate modeling community, when tools of this type are developed, there are detailed and public intercomparisons of models aimed at figuring out the root causes of discrepancies and understanding which tools perform best under different circumstances. We expect that if systematic, careful, and open comparisons of different methods were to unfold in the analyst community, they (and investors) would learn that uncertainties and methodological challenges are even more troubling than they imagine right now. Variation in model performance will be a challenge, since downscaling of global circulation models has always been challenging; moreover, these models are only part of the story. Understanding assets at risk is a start, but understanding the damage functions relevant to each asset—and the damage functions relevant to each element of the tax base that is the source of debt repayment—is the next frontier.
4. The world of physical impacts of climate change, especially on public infrastructure, is filled with moral hazards. In extreme cases, federal disaster aid policy, flood insurance, and other interventions after calamity strikes mean that physical losses to exposures of local communities and firms may be less financially severe for municipalities and firms in practice (Miller, 2018). Credit rating agencies can account for the presence of these programs to backstop losses, restoring bonds to their original credit-worthiness post-disaster. Indeed, in the municipal finance market, huge federal programs—most prominently, the national flood insurance program (NFIP) administered through the Federal Emergency Management Agency (FEMA)—can cover between 75 to 90% of rebuilding cost and cause credit distortions by providing a "put option" on issuances (Lee and Wessel, 2017). Looking recently at this situation, one market analyst found that the combination of "FEMA aid, receipt of insurance proceeds, and the pick-up in economic activity that occurs with rebuilding have been instrumental in maintaining credit quality in many municipalities that have experienced natural disasters" (Healy, 2019).²⁵
5. Connecting all these factors requires a lot of imagination and, frankly, uncomfortable speculation. What matters is how transitions from climate pollution and the impacts of climate change could interact in ways that affect both the costs of climate change and the ability of firms (in the case of corporate finance) and communities (for public finance) to repay. There is some evidence that the credit rating agencies are trying to develop the in-house ability to assess these dangers, and all of the major agencies are publicly saying more things about climate change, but the practical implications of all this are still elusive because it is hard to connect the dots rigorously and reliably.²⁶

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25. For more, see (Gaul, 2019).

26. For instance, S&P has put out a variety of public information related to ESG scores and municipalities, as well as information on how the agency is measuring and understanding physical risk on their public website. Moody's has also published an environmental heatmap and other analysis, available on their ESG division website. For these links and reports, see reference list.

Have Disclosures Affected Market Behavior?

Given the highly uneven practices of disclosing information about climate-related risks, it is hardly surprising that there isn't much analytical literature on whether disclosures affect market operations. What literature does exist focuses entirely on transition risks and finds weak and mixed impacts.²⁷ Most studies suggest that increased disclosure leads to positive market outcomes.²⁸ One notable study finds no impact.²⁹ What remains particularly elusive are the causal mechanism.³⁰ Disclosure may reflect management attention and thus, relative to peers in the sector, engender greater investor confidence that management will be efficiently responsive to new policy, political, and technological risks and opportunities.³¹ Causation may also run in the opposite direction, with well-governed firms (and, as we found above, larger firms) more likely to offer more detailed, informative disclosures—with higher valuations flowing due to governance skills, rather than disclosure itself. One of the central statistical challenges in this research is identifying the effect of disclosure signals amid many other factors that influence valuations; moreover, there may be a bias in this literature towards demonstrating the positive impacts of ESG disclosures because many ESG firms participate directly in the research itself.³²

Why isn't there more evidence that disclosure affects the pricing of financial instruments? In the area of transition risk, nearly every firm that faces significant transition risk is engaged in activities that the markets already are able to observe. Volumes of coal and oil production, for example, are already known at the firm level, and emissions associated with those industrial activities (scope 1 and 2 emissions) and

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27. Indeed, the financial impacts of transition risk in ESG—in particular, issues of “stranded assets,” or those assets that may be rendered unusable due to future climate policy—have been explored in (Sen, 2020), (Delis, 2020), (Atanasova and Shwartz, 2020), and (Ilhan et al. 2020). Where evaluated, transition risk exposure is shown to have generally negative impacts on valuation.
28. One study looked at 1,000 Japanese firms and found that while higher levels of carbon emissions were linked to decreased corporate valuations, disclosure of those emissions was linked to increased corporate valuations (Saka and Oshika, 2014). This was confirmed by two more studies that find, first, “markets penalize all firms for their carbon emissions, but a further penalty is imposed on firms that do not disclose emissions information” (Matsumara, 2014), and second, that across 4,655 firms-year observations from 34 countries, firms were rewarded in cost of capital for disclosure (Bui et al, 2020). At the portfolio level, one recent European-based modeling study finds the existence of a negative climate “greenium,” rewarding investment portfolios weighted to firms that disclose more frequently and penalizing those that do not (Lucia, 2019). These positive valuation impacts are also confirmed by (Kreuger, 2015).
29. This study of 379 Korean firms found that voluntary disclosure of greenhouse gas emissions had no measurable impact on the cost of equity capital for those firms (Kim et al. 2015). To the extent valuation is uncorrelated or negatively correlated with disclosure then raises the odds that the market is heading for a Minsky moment, as markets realize that energy transformations are taking hold—rapidly devaluing high carbon incumbents and valuing firms of the new clean economy (Bond, 2020).
30. We note the body of literature that does exist on climate change responses in finance and estimating climate impacts on valuation (exclusive of disclosure). This literature often deals with portfolio construction models and hedging strategies, among others. For more, see (Oyehiyi and Tortoriello, 2019), (Cheema-Fox et al, 2019), (Andersson et el, 2014), (Young In, et al, 2017), (Ginglinger and Moreau, 2019), (Engle, 2019).
31. Investors have been shown to reward firms that are more responsive to climate risk concerns. A well-cited study regarding the impacts of shareholder activism on firm disclosure finds that “companies that voluntarily disclose climate change risks following environmental shareholder activism achieve a higher valuation, suggesting that investors value transparency with respect to climate change risks” (Flammer et al, 2019).
32. For example, see (CSSP/South Pole Group, 2016), (Khan, 2013), (Innovest, 2007).

with usage of those products (scope 3 emissions) are readily estimated. Transition risk is highly concentrated in heavily industrialized sectors, mainly on a few hundred traded firms, for which there is an abundance of information. Indeed, researchers completely independent of the sector have been able to produce detailed analysis of total emissions without any self-reporting of data from firms (Heede, 2014). Of course, details vary by sector and firm, in particular when it comes those emissions that occur from using a firm's products (scope 3 emissions).³³

Moreover, there are big questions about just how quickly “transition” will occur—and therefore how investors should price financial instruments exposed to disruption from decarbonization. The most active emissions disclosure programs, such as CDP, have also benchmarked firms against widely discussed goals, such as stopping global warming at 1.5°C (CDP, 2020). Meeting that goal would require about 8% annual reduction in emissions—a heroic change (UNEP, 2019). For comparison, the annual drop in emissions during 2020 due to the economic depression stemming from the pandemic will be about 8% (Hanna et al, 2020).³⁴ Yet in the real world, no major economy is adopting policies aligned with that trajectory. Thus, the disclosure industry is steeped in observations about imminent disruption, while real firms and investors are not seeing that disruption occur—aspersion has eclipsed real changes in policy and market conditions. Or, as Exxon has stated bluntly in its own public disclosures around transition risk, the firm's balance sheet is dominated by near term assets (e.g., booked oil assets underground) that will long be sold to market before actual deep decarbonization occurs.³⁵ European-based firms are in a different political environment—their host governments and societies are expecting more rapid change—and thus they are, not surprisingly, doing a lot more on decarbonization.³⁶ Still, formal disclosures have not revealed much additional information about that behavior to the markets.

For physical risk, the lack of any market response to information may be more worrisome, and could be a true market failure. It appears that the market does not know the actual exposure of key financial

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33. For instance, depending on what kind of industry and sector emissions occur within, the risks may be more or less existential in nature. Only in energy is transition risk truly existential, as in the case of coal. For the other most carbon-intensive sectors (utilities, materials, and industrials), there are existing low carbon alternatives. Transitions to a low carbon economy will therefore have different magnitudes of impact even among those sectors most exposed. Our thanks to Julie Gorte from IMPAX Asset Management for helping us think through this issue in greater depth.

34. For more, see (International Energy Agency, 2020).

35. Such blunt statements were made in 2018, but looking at Exxon's disclosures from today's vantage point it is actually very difficult to pin down, based on external facing information, what the company thinks. The Exxon sustainability report is very general in nature (ExxonMobil, 2018). Looking to the latest (2020) “Energy and Carbon Summary” there is more detail, revealing that the firm expects that governments will honor their Paris pledges, but those pledges do not add up to stopping warming at 2°C. When looking at the actions needed to achieve 2°C, Exxon underscores that there are many different pathways and that technology will affect the impacts on particular firms. A key statement, with reference to the value of the firm's proved reserves (a key driver of the valuation of the upstream activities in an oil and gas firm, and for Exxon the biggest component of the firm) is: “Based on currently anticipated production schedules, we estimate that by 2040 a substantial majority of our year-end 2018 proved reserves will have been produced. Since the 2°C scenarios average implies significant use of oil and natural gas through the middle of the century, we believe these reserves face little risk from declining demand” (page 14). Put bluntly, what governments promised in Paris won't actually meet the Paris goal of stopping warming well below 2°C. And even if that goal is taken seriously, it is not material to the firm's core operations. See full report: (ExxonMobil, 2020).

36. There are firms who have written down assets in a manner that some analysts say is consistent with climate change impacts, although whether or not those write downs are due to imprudent financial decisions or the presence of transition risk is hard to determine.

assets—notably in municipal finance, where assumed default rates are nearly zero. Here, the markets are flying blind.

A few large investors, sympathetic to the argument that physical risks are mis-priced, have offered suggestive but highly anecdotal studies—which have not attracted much attention, probably because the findings are so cursory. Charles Schwab (Cooper, 2019) and Barron's (Norton, 2019) both assessed whether municipal bond prices reflect physical risk. But they both only look at two bonds for their analysis. BlackRock's analysis also examined, visibly, just two bonds—although the firm suggested that it has more data looking behind the scenes (Deese, 2019). The Government Accountability Institute, a private think tank, published a study focused on 200 municipal bonds (GAI, 2019). Yet these studies fail to grapple with a key statistical problem: If the market has very little information about physical risk, then much larger samples will be needed to detect a significant impact on yields or default rates.³⁷ This situation may change quickly with new research tools—along with companies that apply them—that are estimating plausible impacts at relevant spatial resolution, including the CIL research we use in this paper.³⁸ That such tools have not been applied widely and that market participants have not sought such information may plausibly be why there is little documented relationship between physical risk and pricing of instruments.

Where climate impacts align well with mental models of how climate change will affect public infrastructure, there is weak evidence that there has been some market response. For storm surge and sea-level rise, both areas where market participants can imagine near-term impacts, we see some very weak evidence in large sample studies that the markets are responding. One study looking at 59,000 bonds found a small but statistically significant price difference between school district bonds in areas with a high risk of sea-level rise and areas with a low risk (Goldsmith-Pinkham et al, 2019). Another, looking at 37,000 bonds, found a similar result generic to all bonds, and not just bonds linked to school funding (Painter, 2018). This work resonates with studies that have looked at other markets that are exposed to climate impacts yet are outside the scope of the present study—for example, real estate, where academic literature on housing prices in sea-level-exposed Miami-Dade may reflect a theory of “Climate Gentrification”, with higher elevation property prices appreciating more than lower elevation properties (Keenan et al, 2018).³⁹ Other studies find the opposite—no impact of sea level on real estate values (Murfin and Spiegel, 2020). (The confounds are legendarily difficult to address because people, for the most part, want to live next to the ocean, even if the ocean might one day be in their living room.) One study has looked at the intermediaries in pricing mortgage risks—banks—and found large national banks had a much weaker understanding of the risks posed to a community than the local community's banks (Keenan and Bradt, 2020).

For the municipal finance industry, the paucity of climate risk disclosure is perhaps easy to understand from the vantage of the incentives at work in the industry. Municipalities are intrinsically

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37. As default rates on bonds are so low, it is estimated that you would need >26K observations to statistically detect that difference in default rates.

38. Those studies include the work of the Climate Impact Lab (Hsiang et al, 2017) and the 4th National Climate Assessment (Fourth National Climate Assessment, 2019). The EU based ClimINVEST project is also currently working to fill gaps between investor knowledge and granular physical climate impact data (Bruin et al, 2019). In addition to academic work, new firms like risQ are utilizing models at very high spatial resolution to project climate impacts at the CUSIP level for municipal bonds.

39. More generally, prominent recent media attention also suggests mortgage markets are beginning (weakly) to respond to exposure from sea level risks. See (Flavelle, 2020).

place-specific and have taxation and budget authorities that have, at least traditionally, allowed issuers of municipal debt to operate on the assumption that default risks will remain nearly zero. Given the paramount interest of issuers to raise funds for essential municipal operations, there are powerful incentives to downplay long-term factors that will not immediately affect repayment ability. Analogous situations—for example, the sudden awareness of municipal debt investors regarding the problem of underfunded pensions—suggest that awareness of climate risk could unfold quickly. A second explanation is that municipalities themselves—except the very largest – do not have on staff risk officers and other arms of government specifically charged with understanding climate risk. Much of the responsibility for disclosure around climate risk accrues to underwriters and arises only at the time of issuance and after material events (unlike ongoing disclosure practices, akin to 10-K filings by listed equities), and they, if not otherwise informed by municipalities themselves, have little access to information (nor much incentive to look deeper) with regard to these risks. Third, and perhaps most importantly, municipal bonds typically offer tax preferences that are enormously valuable to many investors, as the supply of these tax preferential investments is limited.⁴⁰

Conclusions: Improving Disclosure of Physical Risk

Over the last two decades, the financial sector has radically increased its discussion of how climate change might affect asset valuation and market behavior. The impact of those discussions on what issuers of tradeable financial instruments reveal about risk, however, has been highly uneven. In equities, disclosure about transition risk in a few sectors has risen sharply; across most of the market, however, there is much less information—in particular, information about how firms are possibly exposed to the physical risks of climate change. Notably, in only two industries, agriculture and insurance, U.S. traded equities have focused disclosure on physical impacts of climate change.⁴¹ Even worse are municipal debt markets where issuers reveal almost nothing about exposure.

First, this pattern of disclosure reflects of lack of imagination. The latest science about climate change shows the system changing rapidly, with synergistic impacts that will have substantial and growing impacts on physical assets and public welfare, including the economic viability of communities on the front lines. These impacts are no longer abstract or decades into the future, and extensions of the latest climate science suggests that plausible tail risks are even larger and more immediate. The problem of disclosure reflects a problem of imagination, with the mental models used to assess much of the risk around climate change focused in the areas that are easier to measure and imagine (transition risk), whereas the real need for imagination is around physical risk. Many of the elements needed for better imagination are present, but what is missing is synthesis—in particular, by the actors who have a system-wide view of how failures and incompleteness in individual disclosures could affect the markets and social welfare overall: market regulators and credit rating agencies.

Second, a strategy to rectify this problem requires action on many fronts, but many of the key elements can already be envisioned:

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40. We note that, internationally, very recent research has indicated the markets do price climate shocks to sovereign bonds. See (Cevik, 2020).

41. Other industries with physical risk focused disclosures include Apparel, Entertainment, Food and Bev, Media, Pharma, Retail, and Water Utility.

- Issuers, in particular for municipal debt, may find it too challenging to assess on their own the exposure of critical infrastructures (which are often funded by municipal borrowing) to climate impacts. This problem could be addressed through investment in national infrastructure audits—the building of databases of critical infrastructure and its exposure to damage from different perils. For insured assets, the incentives to build such databases exist already, and several private firms have done that, but there is no analog for public infrastructure. Work in key municipalities and by scientists have already demonstrated how this can be done in particular locales (Fourth National Climate Assessment, 2018), (Gardoni, 2019).⁴²
- Issuers, as well, find it challenging to utilize climate models at the level of geographical resolution needed for evaluation of physical impacts. Some models have evolved in this direction already, and extension of existing research support—such as from NSF—could strengthen this foundation of public knowledge. Indeed, the climate modeling community already engages in many intercomparisons of models for their forecasting skill; such model intercomparisons could be focused more sharply on local downscaling and timing of expected impacts, tail risks, and identification of which modeling platforms are best suited for assessment of different types of physical perils from climate change.
- The best approaches are, today, unknown—and there are few good models (especially for municipal debt) for useful physical risk disclosure. Large issuers and investors most keen on gaining information about climate exposure should encourage experimentation and identification of best practices so that the industry, as a whole, learns how to engage in more effective disclosure. Regulators in the states that are most concerned about climate impacts, such as Florida and California, could guide this process with experimental disclosure and standard-setting programs in the jurisdictions that are most vulnerable and also most able to do the needed analysis.
- In equities, the stewards of the largest ESG programs could run a series of similar experimental demonstrations aimed at learning more rapidly about the kinds of physical disclosure that would be feasible to assess systematically—leading to improved methods and, crucially, demonstration models.

In effect, the activities above can create a foundation for better disclosure around physical risk.

Recent proposed legislation such as the Climate Change Financial Risk Act could help address the problem, but that bill has limited sponsorship and is unlikely to pass (Casten, 2019). However, essentially all the legislative authority needed for action is already in place. Existing advisory organizations like the TCFD should refocus their efforts on the full scope of all risks and place more emphasis on improving the disclosure regarding physical risks.

The Financial Accounting Standards Board (FASB), the Public Company Accounting Oversight Board (PCAOB), and the Fed, under existing authorities, should do the same, following best practice recommendations from leading organizations like Ceres (Ceres, 2020). The problem with physical risk disclosure is not lack of jurisdiction, but lack of imagination and models for how this disclosure could work practically. These organizations should launch, in effect, an experimental regulatory program—

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42. For instance, developing public inventories that catalog the locations and exposure of critical infrastructure such as nuclear power plants. For more see (Moody's, 2020d).

investing in (or requiring) a variety of approaches and then testing them against experience and learning, across markets, to determine which actually work.

Third, any program for improving disclosure, and ultimately management, of physical climate impacts will require not just imagination and better demonstration of disclosure frameworks—incentives must also be aligned better.

Particularly problematic are the practices at FEMA and with flood insurance—including some state programs that pool flood and wind exposure. These programs have invited moral hazard, which is amplifying risk and also undercutting incentives for issuers to disclose those risks because they have historically assumed that real physical risks from climate change will be absorbed by government.⁴³ A variety of partial reforms are beginning to change that. There is new attention being paid to the uncertain future of federal disaster funds, due to budgeting issues, the increasing occurrence of natural disasters, and political headwinds (St. Peter, 2020). In some cases, private experimental insurance schemes traditionally used in developing countries are being proposed to fill disaster coverage gaps (Colman, 2020). Those efforts should continue. Even where a longstanding practice of socializing risk can't be abandoned completely for political reasons, policy makers should continue to raise doubts about the long-term viability of these schemes. The greater the level of doubt, the greater the demand from the markets for real information about physical risk.

Attention to incentives must include, as well, a focus on fiduciary responsibility. That includes liability rules that apply to executives, directors, investment managers, issuers, and others, including the errors and omissions (E&O) and directors and officers (D&O) liabilities that arise from poor disclosure. Quite apart from the evolution of fiduciary and liability rules, standard disclosure practices could change quickly with guidance from regulators, professional and standard setting bodies (e.g. FASB and PCAOB), and the credit rating agencies. If these organizations take bigger steps to integrate physical risk into their standards and evaluations of issuers, companies, and securities due to increased knowledge of the exposure and the materiality of the risk, it will quickly alter behavior. There is a history of analogies for such circumstances where the knowledge regarding materiality and risk evolves over years until the point that the risk is clearly known and material, such as what happened with exposure to subprime assets, asbestos, unfunded pensions, and smoking. Once the depth of the issue and the materiality on valuations were broadly understood, information was demanded by market participants, rating agencies, and regulatory bodies that quickly altered market practices and pricing of financial assets and the legal environment regarding disclosure of those with fiduciary responsibility (which for some risks extended broadly to many firms and market participants). As we have documented, several of the firms have indicated they know such steps are needed, but a new form of standard practices—transparent enough to issuers to alter behavior—has not emerged.

Fourth, activists and analysts must recognize that they are fighting the wrong fight. The extraordinary attention to transition risk aligns with most mental models of how financial assets might be affected by climate policy. In the extreme, rapid revaluation of those assets might create financial instability (Carney, 2015). But the markets are already aware of regulatory risks for emission-intensive industries. The real push for better disclosure should be on physical impacts—they may prove more consequential to revaluation of financial instruments, and they are the area where the markets know the least. Where investors think they know something about climate impacts—for example, on sea level rise or impacts that have recently been demonstrated as credible (e.g., wildfires)—investors respond, but the responses are

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43. Recent SEC petition efforts have been made to mandate that companies report physical location information. See here: <https://www.sec.gov/rules/petitions/2020/petn4-763.pdf>.

weak and short lived. The activist and analyst communities should consider doing more, with sympathetic investors and credit rating agencies, to test a variety of methods that might reveal more useful information about physical risk. In this space, as well, there are opportunities for new firms that can synthesize varied information about physical risk and attach it to particular financial instruments and improved pricing systems. There are real opportunities for the private sector, without regulatory prompting, to improve investor intelligence and capital allocation through disclosure based upon a widely accepted framework for evaluating and pricing climate physical risk into asset valuations.

Climate change will alter exposures to risk in ways that can't be revealed simply by looking harder and in more clever ways to the past. New tools will be needed, along with new imagination. Everyone involved will need, as well, to articulate better what they don't know—to help guide efforts to fill in the gaps and to help markets understand that silence doesn't mean we have confidence that risks do not loom.

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