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Pricing Troubled Waters
The Effects of Climate-Induced Water Scarcity on Municipal Bonds

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Abstract

Employing various cross-sectional regression analyses, this study examines the effects of climate-induced water scarcity risk on the issuance costs of municipal bonds. In contrast to the expectations, some of the results suggest a negative correlation between issuance costs and water scarcity risk. Although the negative sign of the water scarcity factor remains puzzling, the results of the analysis on the role credit ratings are in line with the expectation, suggesting that higher rated bonds experience lower issuance costs than less credit worthy bonds. Furthermore, rurality seems to be negatively related to the extent to which water scarcity risk influences issuance costs and increased awareness about climate change seems to have brought investor attention to climate risks. The result do not remain robust under all alternative specifications. Further research is suggested in order for financial markets to account for climate-induced water scarcity risk and finance the path towards a sustainable future.

Keywords: Climate risks, Municipal bonds, Water scarcity

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1. Introduction

Freshwater is a fundamental building block of life. Throughout history, human civilization has been crucially dependent on this vital resource. Increasingly however, freshwater resources have come under pressure (World Resource Institute, 2021). Rapid urbanization, improving living standards and the expansion of irrigated agriculture continue to drive the demand for water (Ercin & Hoekstra, 2014). While at the global level, enough freshwater is available to satisfy demand, geographic and temporal differences lead to a mismatch between demand and availability. As a result, many countries and regions are facing recurring water scarcity. Mekonnen and Hoekstra (2016) suggest that approximately 4 billion people suffer severe water scarcity at least one month each year. What is more, the effects of climate change are projected to exacerbate the situation in the near future (Vörösmarty et al., 2000). The combination of increasing demand and a changing climate, has led to freshwater scarcity becoming a threat to the sustainable development of human society. In its 2020 risk report, the World Economic Forum even lists climate-induced water crises as the top global societal risk in terms of potential impact. With many nations already experiencing shortages, water scarcity is increasingly perceived as a systemic risk by investors (Mekonnen & Hoekstra, 2016; The Economist, 2021). This raises the question: Do investors price water scarcity risk?

To address this question, this paper examines the effects of climate-induced water scarcity on the issuance costs of municipal bonds in the U.S. Issuance costs are commonly used as a proxy for borrowing costs and investor demand (Painter, 2020). If investors price water scarcity risk, then municipalities exposed to higher risk levels are expected to face higher costs as investors demand a premium for the added risk (Anthoff, Tol, & Yohe, 2009; Bauer & Rudebusch, 2020). The municipal bond market provides a useful setting to analyze whether investors price water scarcity risk as municipalities cannot relocate in order to avoid the costs associated with water scarcity. Where corporations and investments in other security types are able to adapt by relocating their operations or hedging financial risks, the municipal bond market cannot be as responsive and will have to bear the full impact of impending water scarcity. Moreover, due to the heterogeneity in term structure, the municipal bond market makes it possible to analyze the effects of water scarcity risk over different maturities. While the U.S. currently is not experiencing severe scarcity, the country is expected to face high water stress by 2030 (Maddocks, Young & Reig, 2015; World Resource Institute, 2021). Because climate-induced water scarcity is likely to cause more damage in the long run, the municipal bonds most likely to be impacted are those with longer maturities. Hence, long-term municipal bonds are expected to incur more costs compared to short-term bonds as a result of the differences in projected water scarcity risk.

Next, the heterogeneity among issuers is analyzed in terms of the credit rating of municipalities. As climate-related disasters are becoming more tangible, credit rating agencies can no longer ignore these risks. Consequently, rating agencies have started to develop methods to analyze and incorporate climate risks into calculations of financial stability factors for companies and governments. In 2017, water scarcity risk materialized to credit ratings for the first time in history when Moody's downgraded the city of Cape Town (SA), which had failed in providing sufficient water to its citizens as the result of an extraordinary drought in the region. Since then, the credit ratings of many cities and municipalities in the U.S., and around the world, have been revised to account for climate-induced water scarcity risk (Moody's, 2021; Tigue, 2019). Credit ratings are of interest to investors not only because they impact bond prices but also because they can have important effects on local economies. In their studies on climate change and financial stability, Dafermos, Nikolaidi & Galanis (2018) and Bigger & Millington (2020) show that climate-induced financial instability adversely affects credit expansion. This in turn exacerbates the negative impact of climate change on economic activity. As lower rated municipalities generally have weaker infrastructure and smaller fiscal capacity, they are expected to be more susceptible to climate-induced water scarcity risks and to face relatively high issuance costs.

Another important cross-sectional factor to examine among the sample of issuers is rurality. Rural counties, are for a large part economically dependent on the agricultural sector. Due to its water intensity, the agricultural sector is expected to be hit particularly hard as the result of increased water scarcity (Blackhurst, Hendrickson & Vidal, 2010). The exposure of rural counties to the agricultural sector is of importance to investors because of the profound impact water scarcity could have on these communities. Next to the direct effects on the agricultural industry, in rural communities, water scarcity can potentially have a much broader financial and societal impact (Falkenmark & Rockström, 2004; Van Loon et al., 2016). Hence, rural counties are expected to be more susceptible to climate-induced water scarcity risks and experience high issuance costs compared to urban municipalities.

Lastly, to further identify whether investors take water scarcity risk into account, a quasi-natural experiment is conducted. This study compares issuance costs before and after the UN Climate Action Summit of 2019 in order to determine whether this event served as a catalyst for investor attention to climate-induced water scarcity risk. As the impacts of climate change continue to increase and the topic is more frequently discussed on the global agenda, it is expected that investors are increasingly aware of this risk and factor it into their investment decisions.

The remainder of the paper is structured as follows. Section two gives a short introduction of municipal bond issuance costs and the water scarcity exposure ranking. Section three explores prior literature on the pricing of climate change related risk factors in an asset pricing context. Section four describes the data and covers the methodology of the study. In section five, the results are presented and discussed. Finally, section six summarizes and concludes.

2. Issuance costs and water scarcity exposure

Before delving into the analysis of the effects of water scarcity exposure, it is important to have an understanding of the costs involved with the issuance of municipal bonds and the method used for ranking counties on water scarcity exposure. This section shortly introduces the municipal bond market, issuance costs and the water scarcity exposure ranking of counties.

2.1 Municipal bonds and issuance costs

Municipal bonds are defined as debt securities issued by local governments with the purpose of financing public projects such as roads, public buildings, utilities, or other infrastructure. The two most common types are revenue bonds and general obligation bonds. Revenue bonds are paid back by the income generated from the funded projects whereas general obligation bonds are repaid by the issuing jurisdiction through tax revenues and credit lines. While no assets are used as collateral, general obligation bonds are viewed as safer because municipalities could raise taxes in case insufficient funds are available to pay the obligations on the debt.

When a municipality issues debt they select an investment bank as the lead manager and underwriter of the bonds. The lead manager is selected either under competitive bidding or a negotiated contract. Typically, the issuance of debt involves two types of issuance costs: the yield at issuance and the gross spread. The yield at issuance is based on the yield to worst spread to maturity and refers to the relative interest rate difference between the issued bond and the appropriate point on the treasury curve of similar maturity. The gross spread, also known as underwriter discount, is the price difference between the price at which underwriters purchase a bond and the price at which they resell. This price difference compensates underwriters for their brokerage services. The underwriter tries to sell the bonds at the highest price possible while still clearing the entire issue. For bonds that are more difficult to sell, underwriter typically demand a higher gross spread due to the higher search costs.

Following Painter (2020), total annualized costs to issue a bond are calculated as the sum of the annualized gross spread and the yield at issuance. Issuance costs are of importance as they can indicate the demand and risk characteristics of a bond as well as the borrowing costs of debt issuers. For investors, issuance costs are a useful indicator to determine whether a particular bond is expensive or cheap. If climate-induced water scarcity is seen as a potential investment risk, then a higher yield would be demanded by investors in order to compensate for the additional risk, and underwriters would demand a larger discount for brokering the bond issuance as a result of the higher search costs. Hence, following this line of thought, higher exposure to water scarcity risk is expected to lead to higher issuance cost.

2.2 County ranking on water scarcity exposure

Water scarcity risk is measured by the level of physical water stress. The measure for water stress comes from the Aquaduct Water Risk Atlas by Hofste et al. (2019). It is defined as the ratio of total annual water withdrawals to the total annual renewable supply. Where for the financial indicators used in this study objective measurements are available, this is not necessarily the case when measuring water stress. Water stress remains subjective and cannot be measured directly. Consequently it is very difficult to validate any results. Nonetheless, Hofste et al. (2019) of the World Resource Institute, have developed a comprehensive model to quantify water stress at a sub-basin level. The model allows for comprehensive analysis of global water risks at a local level. Moreover, future water stress projections and different adaptation and mitigation scenarios are incorporated into the model. For this study, the physical water stress indicator is used to proxy water scarcity risk at county-level. There are five distinct risk categories ranging from low to severe, these are based on Aqueduct 2.1 (Gassert et al. 2014). Arid and low water use zones are excluded from the study. More details on the underlying dataset and the parameters used, can be found in the original publication.

3. Pricing climate risks

The effects of climate change on the physical environment are set to have a profound impact on the long-term prospects and livelihood of businesses, local communities, natural ecosystems and countries worldwide (IPCC, 2014; Stern, Peters & Bakhshi, 2010). Physical risk including extreme weather events, droughts, floods, land degradation, sea-level rise and ocean acidification all threaten to cause irreversible damage to the natural systems upon which human society depends. Over the last two decades an extensive body of literature has been established on topics related to the field of 'climate finance'. Much of the literature focusses on the socio-economic impacts of the projected climate change. Prior papers indicate that the effects will be disproportionately distributed and will impact the poor the most as they tend to live in hazard prone areas (e.g. IPCC, 2014; Reckien et al., 2018; Stern, Peters & Bakhshi, 2010). Other literature analyzes economic policies and market incentives aimed at adaptation, mitigation and sustainable development (e.g. Newel, 2010; Hallegatte et al., 2016; Perman et al., 2003).

More recent literature, seeks to quantify exposure to climate risks and analyzes the interaction of climate risks and financial markets. Krueger, Sautner & Starks (2020) find that climate factors impact asset markets through three types of risk: physical risk, liability risk and regulatory risk. Dafermos, Nikolaidi and Galanis (2018) find empirical evidence that climate risks have an impact on financial stability. They find climate change cam increase default risk and cause an asset price deflation process. Moreover, they find climate-induced financial instability reinforces the growth-reducing effects of climate change. Carney (2015), finds that extreme weather-related losses on insurance policies have increased significantly since the 80's, implying climate-induced extreme weather events impact the financial stability of the insurance market. In the equity market, Bansal et al. (2016) find that nearly all U.S. equity portfolios demonstrate negative exposure to long-run temperature fluctuations, implying global warming carries a risk premium. Regarding real estate, studies show that natural and environmental hazards driven by climate change are becoming a greater consideration in the housing market (Redfin, 2021). What is more, Keenan et al. (2018) and McAlpine and Porter (2018) find that the rate of price appreciation of properties in areas exposed to sea level rise is positively related to elevation. Similar evidence is found in the municipal bond market by Painter (2020), who demonstrates that counties that are exposed to sea level rise incur higher issuance costs to issue long-term municipal bonds.

As the effects of climate change are becoming evident, investors are realizing that climate risks represent investment risks and are increasingly concerned with the financial losses associated with a more turbulent global climate landscape (Sorkin, 2020). Even though water scarcity is regarded as potentially the most impactful consequence of climate change, there is limited knowledge of whether or to what extent long-term water scarcity risk is priced in financial markets. In the equity market, Hong, Li and Xu (2019) find that droughts adversely impact the value of companies in the agricultural industry. indicate that there are prospects for the insurance market to insure against drought. Several other studies indicate that drought as the result of climate change could have strong negative consequences on the agricultural industry with cascading economic effects (Van Loon et al., 2016; Ziolkowska, 2016).

The objective of this thesis is to contribute to understanding of pricing climate risks by studying whether investors are concerned about and whether they price water scarcity risk in the municipal bond market. This is of vital importance as municipal communities have no other option than to bear the costs of increased water stress and to deal with increasing water scarcity. Moreover, due to the economy-wide spill-over effects of water scarcity, it is necessary for at-risk municipalities to prepare for and respond to the onset and eventual impacts of drought. This study contributes in this regard as it attempts to quantify the financial costs for debt issuers as a result of climate-induced water stress. Additionally, this papers adds to the literature by examining whether a relatively large dependency on the agricultural sector translates to additional borrowing costs. Lastly, it also examines whether investor attention affects the pricing dynamics for water scarcity risk.

The most closely-related study is that of Painter (2020) who finds evidence of the impact of sea-level rise in the municipal bond market. This paper uses a similar analysis in the context of water scarcity risk. Notably, the discussion on whether climate-induced water scarcity risk exists is extraneous to the results as the study solely analyses if investor require a premium in order to obtain a return on investments in municipalities facing increased uncertainty due water scarcity risk. Therefore the results hold regardless of whether the risks materialize.

4 Data & methodology

Municipal bond data was retrieved from the Bloomberg municipal fundamental database. The municipal fundamental database delivers high quality municipal market data by leading in market coverage, data sourcing and transparency. It covers more than 42.000 unique issuers and 93.000 funds across three separate market sectors with up to 10 years of history. This assessment was limited to investment grade general obligation bonds, issued in 2019 of a value of more than a million U.S. dollars. The data was further refined to only include straight and callable federal and state tax exempt bonds. Pre-refunded bonds and bonds with missing values of issuance cost were excluded from the sample. All bonds are assessed by either Standard and Poor's or Moody's. The total sample consists of 10.969 bonds, issued by 397 different counties (see Appendix A.I for a map of the geographical spread). Altogether, the sample covers over half of the municipal bond market and provides a detailed and representative sample of which the distribution by maturity, credit rating and other bond characteristics is approximately proportional to that of the total market. Data regarding water scarcity risk was obtained from the Aqueduct Water Risk Atlas provided by the World Resource Institute. This dataset allows for detailed analysis of global water risks scenarios at a sub-basin level.

Panel A: Discriptive statistics by water scarcity risk (Value In Year To 2030, Business As Usual)

	Low to Medium				Medium to High				Severe			
	N	*Mean*	*Median*	*SD*	*N*	*Mean*	*Median*	*SD*	*N*	*Mean*	*Median*	*SD*
Total annualized costs (bps)	4085	29.46	17.24	30.76	3493	29.72	20.00	31.08	3391	22.89	9.61	32.91
Gross Spread (bps)	4085	5.93	0.43	16.10	3493	4.21	0.47	13.95	3391	5.23	0.42	15.36
Yield (bps)	4085	28.85	17.11	31.22	3493	29.28	19.57	31.35	3391	22.60	9.17	32.77
Issue size (M$)	4085	6.12	2.50	14.34	3493	5.00	2.32	9.62	3391	5.56	2.38	10.47
Max Maturity (Years)	4085	11.33	10.86	6.60	3493	11.43	10.67	7.14	3391	11.87	11.38	7.25
Callable	4085	0.56	1.00	0.50	3493	0.56	1.00	0.50	3391	0.59	1.00	0.49
Insurance	4085	0.12	0.00	0.32	3493	0.11	0.00	0.32	3391	0.14	0.00	0.35
Rating (Wgth. Avg)	4085	2.76	3.00	1.37	3493	2.64	2.50	1.43	3391	2.78	3.00	1.37
Sinkable	4085	0.05	0.00	0.21	3493	0.07	0.00	0.26	3391	0.07	0.00	0.25
Competetive	4085	0.57	1.00	0.49	3493	0.52	1.00	0.50	3391	0.39	0.00	0.49
CUSIPS/Issue	4085	33.13	20.00	32.70	3493	19.28	18.00	12.28	3391	20.55	18.00	14.39
# Underwriter deals	4085	697.94	693.00	372.55	3493	654.06	753.00	391.95	3391	771.37	844.00	407.46

Panel B: Discriptive statistics by categories

	Total costs	*Yield*	*Spread*	*WSB*	*WSF*	*N*
Max Maturity ≥ 20	53.46	53.00	10.89	2.67	3.38	1226
10 ≤ Max Maturity < 20	40.27	39.81	6.88	2.23	3.13	4743
Max Maturity < 10	9.04	8.59	2.14	2.20	3.14	5000
Rating = 1	17.71	17.41	3.19	2.01	3.30	2626
Rating = 2,3 or 4	28.78	28.39	5.39	2.34	3.09	7127
Rating = 5, 6 or 7	40.97	40.11	7.20	2.43	3.29	1160
Rating ≥ 8	51.59	43.32	33.51	1.67	2.64	42
Rural	48.51	48.11	4.15	1.95	3.37	154
Urban	27.55	26.81	8.04	1.14	2.98	435

Table 1: New issue municipal bond data

This table shows the descriptive statistics of the bond data. Panel A reports the statistics by the projected future water scarcity risk in 2030 under the Business As Usual scenario. The variables include: the gross spread (winsorized at 1%); the yield at issuance (winsorized at 1%); the total annualized issuance costs (annualized gross spread plus yield at issuance); the issue size; the maximum maturity; dummy variables for bond characteristics (=1 if callable, insured, sinkable); a (weighted) numerical scale of initial credit rating; the number of bonds bundled per issue and the number of deals that an underwriter executes during the sample period. Panel B reports the statistics by maximum maturity, credit rating and rurality. The credit rating is converted to numerical scale following Cantor and Packer (1997) and the rurality variable is based on a threshold of county population density of $70/km^2$ provided by the U.S. Census Bureau. The columns report the variables of the gross spread, yield and the total annualized issuance costs as well as the baseline water scarcity factor (WSB) and the projected future water scarcity factor (WSF) in the year 2030. Water scarcity levels are represented by a numerical variable with five distinct risk categories. Counties that are exposed to higher levels of water scarcity risk are assigned a higher value. Values in each column represent the mean and N denotes the number of observations per category.

Panel A of Table 1 provides the summary statistics of the bond data categorized by the projected water scarcity risk of the issuing county. As can be seen, the sample of bonds is distributed fairly equally among the water scarcity risk categories. Bonds issued by counties facing low-medium risk account for 37% of the sample while the medium-high risk bonds make up 32% and severe risk bonds 31%. Not controlling for other factors, low-medium bonds, on average, pay 1.72 basis points more in gross spread but 0.43 basis points less in yield at issuance than bonds that are issued by counties facing medium-high levels of water scarcity risk. Relative to bonds issued by severe at-risk counties, low-medium bonds pay 0.70 basis points more in gross spread and 6.25 basis points more in initial yield. In terms of the total annualized issuance costs, the difference between low-medium bonds and medium-high bonds is -0.26 basis points whereas the difference with severe at risk bonds is +6.57. Regarding the other characteristics of the bonds, the average issue size for the samples lies between $5.6 million while the average maximum maturity is 11.52 years. The majority of bonds are callable, but neither insured nor sinkable. Furthermore, the average credit rating is 2.73 and most bonds are issued competitively except for in the sample of bonds issued by severe at risk counties. The issuance of bonds typically consists of 25 separate bonds per CUSIP and the average underwriter issued 707 bonds over the sample period.

Panel B of Table 1 Panel B provides the summary statistics by maximum maturity, credit rating and rurality. As shown in the table, the average issuance cost increases with regards to maturity and rating as well as in rural areas. In terms of the gross spread, the results for rural areas deviate from the other categories as the spread decreases with regards to rurality. Notably, the average water scarcity factor is projected to increase for all categories moving towards 2030. Moreover, the projected water scarcity risk is positively correlated with regards to maturity and rurality. To test whether or not and to what extent water scarcity risk explains the variation in issuance cost, the following regression model was used, whereby estimated:

Total annualized issuance cost =

*β1 * Water scarcity risk + β2 * Bond controls + β3 * State × Month FE + ε.*

The regression model is based on the paper of Painter (2020). Bond controls consist of the variables included in Panel A of Table 1. Empirical literature has found these variable to be relevant determinants of issuance cost. Furthermore, as issuance costs are dynamic and can vary across states, a state * month fixed effect variable is included in to control for temporal and cross-state factors. Standard errors are clustered by the county of issuance in order to control for any residual spatial correlation within counties. Lastly, the analysis was also performed using net change in water scarcity factor as well as an alternative maturity split in order to ensure the robustness of the results.

5 The effects of water scarcity on municipal bond issuance costs

5.1 Main Results

Table 2 presents the results for the analyses of the effect of water scarcity risk on issuance costs across long, medium and short-term bonds. The results of the single-factor regression analyses suggest that, when not controlling for any other factors, there is a negative effect of water scarcity risk on issuance costs for both medium and short term bonds (Panel A). For long term bonds on the other hand, no significant effect is found. The findings of the multivariate regressions, which incorporate the primary determinants of issuance costs and other bond controls, show results that are in line with those of the single-factor OLS regressions (Panel B). For medium and short-term bond the results suggest that an increase in the water scarcity risk factor of one increment, on average, is associated with a -2.003 and -1.536 basis point effect on total annualized issuance costs respectively. As before, no effect of water scarcity risk is found for long term bonds. These findings are peculiar in the context of climate change because the physical risks, such as the impacts of water scarcity, are expected to increase in severity over the long run. Moreover, the observed negative effects of water scarcity risk on the issuance costs of medium and short term bonds seem counterintuitive as investors are expected to demand a risk premium for the additional risks.

Panel C and D further dissect the issuance costs into the yield component and gross spread component. As with the prior regressions, for long-term bonds, neither of the component variables of issuance costs seem to have a significant effect. For medium-term bonds the yield component displays a -2.001 basis point effect, while the spread component does not demonstrate a significant effect. With the yield component accounting for -2.001 of the -2.003 basis point effect for medium-term bonds, the effect of water scarcity on issuance costs can almost entirely be attributed to the yield component. In the results for short-term bonds however, the spread component does show a -0.688 basis point effect. While the gross spread component of the short-term sample is found to have a significant effect, a larger -1.342 basis point effect stems from the yield component. As a result, for both the medium and short-term samples the findings suggest that the largest effect can be attributed to the yield component.

Panel A: Total annualized issuance costs of bonds by maturity (Single-factor OLS)

	Long-term (20+ years)	Medium-term (10-20 years)	Short term (<10 years)
Dependent variable:		Total Annualized Issuance costs	
WSF (2030)	-0.850	-2.252***	-1.425**
	(1.600)	(0.857)	(0.691)
State-Month FE	No	No	No
Observations	1226	4743	5000
R^2	0.002	0.013	0.015

Panel B: Total annualized issuance costs of bonds by maturity (Multi-factor OLS)

	Long-term (20+ years)			Medium-term (10-20 years)			Short-term (<10 years)		
Dependent variable:	Total Annualized Issuance costs								
WSF (2030)	-0.341	-0.402		-2.176***	-2.003***		1.201**	-1.536***	
	(1.472)	(1.474)		(0.760)	(0.716)		(0.591)	(0.577)	
Ln (WSF)			-0.628			-3.901**			-3.505***
			(3.611)			(1.861)			(1.342)
Ln (Size)	-0.921	-0.640	-0.692	-4.356***	-2.792**	-2.808**	-1.528***	-0.860	-0.866
	(1.948)	(2.538)	(2.562)	(1.112)	(1.195)	(1.199)	(0.540)	(0.538)	(0.549)
Ln (Maturity)	18.306	3.800	3.902	61.151***	59.376***	59.432***	5.881***	4.603***	-4.622***
	(12.558)	(15.300)	(15.354)	(3.618)	(3.891)	(3.873)	(0.579)	(0.576)	(0.586)
Rating	4.166***	1.532	1.522	4.085***	4.233***	4.250***	4.653***	3.040***	3.058***
	(1.445)	(1.856)	(1.865)	(0.782)	(1.157)	(1.169)	(0.515)	(0.816)	(0.827)
Callable		0.000	0.000		4.101*	4.074*		12.151***	12.120***
		(omitted)	(omitted)		(2.138)	(2.146)		(2.353)	(2.363)
Insurance		8.817	8.849		2.178	2.105		9.797**	9.869**
		(5.790)	(5.766)		(4.964)	(4.991)		(4.709)	(4.683)
Sinkable		6.277	6.306		4.174	4.587		-1.648	-1.629
		(4.806)	(4.801)		(3.728)	(3.725)		(7.808)	(7.704)
Competitive		-0.422	-0.446		7.653***	7.927***		-3.222**	-3.090**
		(4.944)	(4.969)		(2.250)	(2.268)		(1.281)	(1.301)
Ln (CUSIP/Issue)		-1.873	-1.834		-3.429**	-3.270**		-0.773	-0.735
		(2.950)	(2.957)		(1.617)	(1.618)		(0.822)	(0.813)
Ln (Underwriter deals)		-0.280	-0.280		0.262	0.243		0.302	0.275
		(1.776)	(1.780)		(0.855)	(0.855)		(0.713)	(0.706)
State-Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1226	1226	1226	4743	4743	4743	5000	5000	5000
Adj. R^2	0.056	0.068	0.068	0.230	0.248	0.270	0.259	0.312	0.300

Panel C: Yield for bonds by maturity

	Long-term (20+ years)		Medium-term (10-20 years)		Short-term (<10 years)	
Dependent variable:	Yield	Yield	Yield	Yield	Yield	Yield
WSF (2030)	-0.399		-2.001***		-1.342**	
	(1.507)		(0.734)		(0.541)	
Ln (WSF)		-0.629		-3.874**		-3.047**
		(3.691)		(1.906)		(1.271)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
State-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1226	1226	4743	4743	5000	5000
Adj. R^2	0.067	0.067	0.239	0.235	0.3	0.298

Panel D: Gross spread for bonds by maturity

	Long-term (20+ years)		Medium-term (10-20 years)		Short-term (<10 years)	
Dependent variable:	Spread	Spread	Spread	Spread	Spread	Spread
WSF (2030)	-0.187		0.128		-0.688***	
	(1.042)		(0.449)		(0.248)	
Ln (WSF)		-0.312		0.019		-1.743***
		(2.573)		(1.114)		(0.605)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
State-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1226	1226	4743	4743	5000	5000
Adj. R^2	0.057	0.057	0.044	0.044	0.091	0.091

Table 2: The effect of water scarcity risk on municipal bond issuance costs

This table shows the results of the OLS regressions of the bonds grouped by maturity. The long-term sample consists of bond issuances with a maximum maturity of 20 years or more, the medium-term sample contains issuances with a maximum maturity between 10 to 20 years, and the short-term sample consists of bond issuances with a maximum maturity of less than 10 years. In panel A and B the dependent variable is the total annualized issuance cost. For Panel C, the dependent variable is the Yield at issuance. In panel D, the Gross Spread is the dependent variable. Inference of the results is based on standard errors clustered by county. P-values are denoted as: ∗∗∗ $p < 0.01$, ∗∗ $p < 0.05$, ∗ $p < 0.1$.

5.2 Robustness analysis

To test whether the results remain robust, two robustness analyses are performed. Appendix B.I presents the results of the first robustness test which categorizes the bonds by maturity into two categories rather than three. For this analysis long-term bonds are defined as bonds with a maturity of 15 or more years, whereas short-term bonds are bonds of a maturity of less than 15 years. The results show that for short-term bonds the observed effect remains robust under these new test specifications, with the results suggesting a roughly similar effect as with the prior regressions of -1.692 basis points. For the results of the long-term bonds the p-value increases and the sign remains consistent. Still, no significant evidence is found for a link between the issuance costs and water scarcity risk.

The results of the second robustness test are presented in Appendix B.II. This test uses the net change in water scarcity factor between the current baseline water scarcity factor and the projected water scarcity factor in 2030 as an explanatory variable of issuance costs. The results of this assessment are inconsistent with the original regression as no effect is found for the ΔWSF factor in any bond subsamples. Thus, contrary to the hypothesized effect of water scarcity risk, these findings suggest that there should be no implications for counties facing relatively strong changes in their water scarcity risk in the near future.

5.3 Credit ratings

Table 3 exhibits the results of the credit rating analysis. This analysis tests whether the risk premium required for water scarcity risk depends on the credit rating of the issuer. The results are differ across the various bond samples. For long term bonds, no evidence is found for credit rating influencing the water scarcity risk premia whereas short term bonds rated lower than AA- demonstrate significantly lower issuance costs compared to their higher rated counterparts. These results demonstrate no effect in line with the hypothesis and even contradict it. For medium-term bonds however, bonds rated less than AA- are suggested to have an average -1.993 basis point effect for each increment in water scarcity risk whereas AA- or higher rated bonds experience a -3.901 effect. As such, although the negative sign of the water scarcity factor remains counterintuitive, these results seem to suggest that higher rated bonds experience lower issuance costs than less credit worthy bonds. If investors already price water scarcity risk, the additional risk premium as a result of credit ratings could pose an excessive burden to counties facing water scarcity risk. Moreover, the impacts of drought could possibly be exacerbated due to the disproportionate premium as it restricts the financing possibilities for counties to properly adapt their infrastructure to increasingly water scarce condition.

	Long-term (20+ years)		Medium-term (10-20 years)		Short-term (<10 years)	
Credit Rating:	=< AA-	> AA-	=< AA-	> AA-	=< AA-	> AA-
WSF (2030)	-0.104	-0.767	-1.993**	-3.901*	-1.878***	-1.034
	(1.609)	(2.066)	(0.811)	(2.012)	(0.588)	(1.303)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
State-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1057	169	4192	545	4359	632
Adj. R^2	0.053	0.0186	0.236	0.215	0.232	0.270

Table 3: Credit ratings

This table shows the results of the OLS regressions of the bond samples grouped by the weighted average credit rating calculated from the ratings assigned by Moody's and S&P. The " ≥ AA–" sample contains bonds with an average weighted rating of AA- or higher, the " < AA–" sample contains bonds with an average weighted rating of AA- or lower. The dependent variable is the total annualized issuance cost. Inference of the results is based on standard errors clustered by county. P-values are denoted as: ∗∗∗ $p < 0.01$, ∗∗ $p < 0.05$, ∗ $p < 0.1$.

5.4 Rurality

Table 4 presents the results for the analysis which tests whether rurality has an effect on the extent to which water scarcity risk influences issuance costs. This analysis focuses on bonds issued by counties within the states that make up the Great Plains, also known as the 'Breadbasket' of the U.S. For these states 5% or more of GDP is directly related to the agricultural sector (Appendix C.I). The results show an average -11.195 basis point effect of water scarcity risk associated with rurality for long term bonds and a +3.288 basis point effect for short term bonds issued by urban counties. Despite the heavy dependence of the agricultural sector on fresh water resources (Appendix C.II), these results seem to suggest that urban rather than rural counties experience relatively higher issuance costs as a result of water scarcity risk. As such, these findings are clearly in contrast with what is hypothesized for this factor.

	Long-term (15+ years)		Short-term (<15 years)	
Urban/Rural:	Urban	Rural	Urban	Rural
WSF (2030)	5.229	-11.195***	3.288***	-4.400*
	(4.470)	(3.638)	(1.098)	(2.266)
Controls	Yes	Yes	Yes	Yes
State-Month FE	Yes	Yes	Yes	Yes
Observations	120	56	315	98
Adj. R^2	0.251	0.639	0.423	0.800

Table 4: Rurality

This table shows the results of the OLS regressions for bonds issued by counties located in the 'Great Plains' region grouped by rurality. Based on a threshold provided by the U.S. Census Bureau, bonds issued by counties labeled 'Urban' have a population density of 70/km^2 or more, rural counties have a population density of less. The dependent variable is the total annualized issuance cost. Inference of the results is based on standard errors clustered by county. P-values are denoted as: ∗∗∗ $p < 0.01$, ∗∗ $p < 0.05$, ∗ $p < 0.1$.

5.5 Quasi experiment Climate Action Summit 2019

This analysis focusses on the UN Climate Action Summit in New York of 21 – 23 sept, 2019. This event was widely covered by media and received attention globally. Google search data demonstrates that interest in the topics of climate change and ESG investing picked up around the 2019 summit (Appendix D.I & D.II). This uptick in interest and awareness about climate change and sustainable investing provides a useful setting to test whether investor attention has affected the pricing dynamics for climate-induced water scarcity risk in the municipal bond market. Table 5 presents the results of the analysis. For the medium and short-term samples the results show a negative effect prior to the 2019 Climate Action Summit. Following the event, the negative relation between water scarcity risk and issuance cost disappears. This could suggest issuance cost for water scarcity prone counties have become relatively more expensive as a result of the increased awareness of physical climate risks. If so, this would be in line with the hypothesis that financial markets will start to price physical climate risks as the impacts become more evident and the awareness increases. Nonetheless, the link remains unclear as no significant positive relation is observed in the data.

	Long-term (20+ years)		Medium-term (10-20 years)		Short-term (<10 years)	
Urban/Rural:	Prior	After	Prior	After	Prior	After
WSF (2030)	-1.053	-1.155	-3.193***	-0.250	-1.595***	-0.908
	(1.679)	(2.057)	(0.822)	(1.260)	(0.515)	(0.886)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
State-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	973	253	3596	1118	3622	1331
Adj. R^2	0.051	0.076	0.211	0.33	0.259	0.404

Table 5: Quasi experiment Climate Action Summit 2019

This table shows the results of the OLS regressions for the Quasi experiment on the UN Climate Action Summit of 2019. The data sample is grouped by bonds prior and after the summit. The dependent variable is the total annualized issuance cost. Inference of the results is based on standard errors clustered by county. P-values are denoted as: $***$ $p < 0.01$, $**$ $p < 0.05$, $*$ $p < 0.1$.

6. Conclusion

Employing various multivariate cross-sectional regression analyses, this study examines the effects of water scarcity risk on the issuance costs of tax exempt general obligation bonds issued in 2019. The findings do not indicate that debt issuers have higher issuance costs as the result of water scarcity risk, nor that the long-term bonds experience relatively higher costs. In contrast, the results suggest that for medium and short-term bonds issuance costs have a negative correlation with water scarcity risk. These findings seem counterintuitive and difficult to rationalize as investors are expected to demand a risk premium for the additional risk. Moreover, water scarcity is expected to increase in severity which implies even more risks over the long run. Although the marginally negative effect observed for medium and short term bonds is not found for long term bonds, still no evidence is found that supports the hypothesis of a positive link between water scarcity risk and issuance costs. The result remain fairly robust when the bonds, grouped by maturity, are assigned alternatively. However, when analyzing the effect of the change in water scarcity risk, no evidence is found for the ΔWSF factor in any of the bond samples. Furthermore, although the negative sign of the water scarcity factor remains puzzling, the results of the analysis on the role of credit ratings suggests that for medium-term bonds higher rated bonds experience lower issuance costs than less credit worthy bonds. The same however, cannot be said for the other samples. Moreover, regarding the analysis on rurality, the result suggest that rurality is negatively related to the extent to which water scarcity risk influences issuance costs. Finally, the increased awareness about climate change as a result of the Climate Action Summit of 2019 seems to have brought attention to climate risks and sustainable investing. However, no clear link can be established as no significant positive relation is observed in the data following the event.

6.1 Limitations to the study

While several interesting observations are found in this study, the results remain subject to limitations. Accounting for and understanding the limitations could possibly help with better interpreting the data. Listed below are several improvements that could be implemented:

1. The first limitation relates to the data sample. Bond data used for this assessment only covered general obligations bonds issued in 2019. This restricted dataset might help to explain why many of the regressions seem to capture little of the variance of municipal bond issuance costs. Expanding the data sample with more temporal variation as well as with additional municipal bond types, would likely improve the inference of the analysis. Additionally the use of bootstrap procedures could provide further robustness to non-normality, heteroskedasticity and other characteristic components of the empirical distribution of municipal bond issuance costs (Fabozzi, Martellini & Priaulet, 2006).
2. A second limitation pertains to the measurement error county and sub-basin geographical boundaries. Counties are assigned a water scarcity risk factor on the basis of their geographic center. At the local level however, sub-basin and county boundaries do not always align. As such, it can occur that an incorrect or incomplete water scarcity risk factor is assigned to a county. This issue is more prevalent in the Western U.S. which has a lower number of counties of a relatively

large size in comparison to the Eastern U.S. Because of this inaccuracy, the water scarcity factor is of limited added value on a local scale in some cases.

3. Another limitation applies to the water stress factor as it does not explicitly take into account water quality, access to water or environmental flow requirements. Hence the water stress factor is not a fully comprehensive measure of water stress in an area. Moreover, water stress cannot be measured directly and therefore remains subjective. Because of the lack of direct validation it is impossible to assess the underlying parameters included in the water stress factor (Hofste et al., 2019) .
4. Lastly, another limitations refers to omitted variable bias, implying other factors that were not included here might provide more explanatory power. Water scarcity risk could for example already be incorporated in other climate risk or macro risk factors.

6.2 Suggestions for future research

Moving forward, it is important for investors and debt issuers alike to better understand the risk climate-induced water scarcity poses to affected counties and communities. Climate risks are becoming a defining factor, driving a profound reassessment of risk and asset values and fundamentally reshaping the dynamics of modern finance. The potential societal costs of climate-induced water scarcity are significant and very real investment risks. Financial markets can play an important role in pricing climate risks and financing adaptation strategies (Chipman, 2020; Flammer, 2020; Griffin, 2016). Accounting for climate risks is necessary in order to hedge risks and finance the path towards a sustainable future. As such, further research, dedicated to understanding the pricing of water scarcity risk, is needed. Building on this study, an interesting addition could be to analyze and compare the impact of water scarcity risk under different future climate scenario's. Expanding the analysis to how water scarcity risk affects specific asset classes or how insurance markets are affected, could be another interesting and valuable area of research. Finally, a future with a certain degree of climate-induced water scarcity is unavoidable. Therefore, the analysis of economic policies and market incentives, that support the transition away from a carbon fueled economy, is important.

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Appendix A.I: Map of geographical dispersion of issuing counties

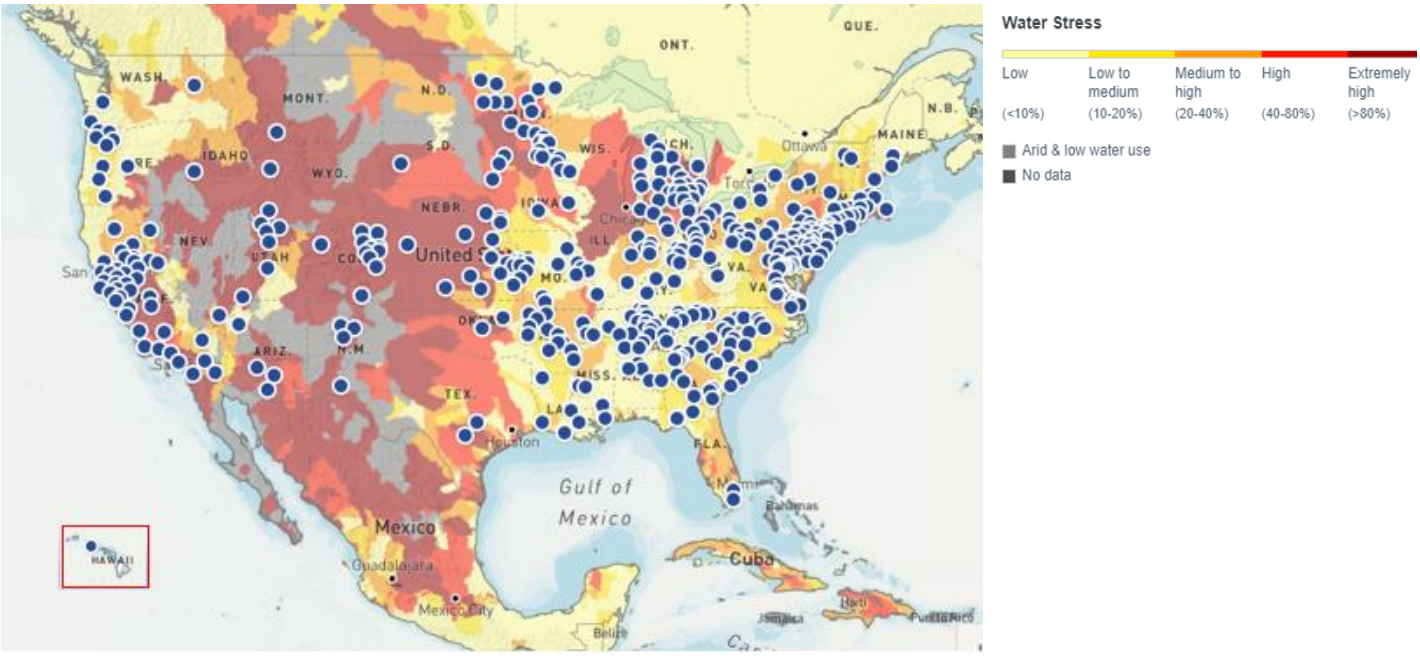

Figure A1: This figure shows a map of the geographical dispersion of the issuing counties of the bond sample. The based on the Aqueduct Water Risk Atlas provided by the World Resource Institute. Water stress is indicated in 5 distinct levels and is based on the projected value in 2030 under scenario 'Business as Usual'.

Appendix B.I: Robustness test using alternative categorization by maturity

	Long-term (15+ years)			Short-term (<15 years)		
Dependent variable:	Total Annualized Issuance costs					
WSF (2030)	-1.704*	-1.652		-1.358**	-1.692***	
	(1.013)	(1.020)		(0.607)	(0.589)	
Ln (WSF)			-3.244			-3.711***
			(2.504)			(1.414)
Ln (Size)	-2.317	-1.409	-1.473	-2.217***	-1.397**	-1.407**
	(1.480)	(1.773)	(1.775)	(0.573)	(0.579)	(0.583)
Ln (Maturity)	18.089***	8.852	8.644	12.563***	5.930***	5.953***
	(6.503)	(8.317)	(8.328)	(0.575)	(0.541)	(0.550)
Rating	3.181***	2.676**	2.642**	4.863***	3.543***	3.565***
	(0.963)	(1.291)	(1.296)	(0.541)	(0.845)	(0.861)
Callable		0.000	0.000		16.186***	16.138***
		(omitted)	(omitted)		(1.158)	(1.168)
Insurance		2.676	2.661		8.118*	8.169*
		(4.676)	(4.709)		(4.635)	(4.610)
Sinkable		5.846*	6.058*		18.171***	18.439***
		(3.517)	(3.513)		(3.874)	(3.887)
Competitive		5.417*	5.527*		-0.192	-0.015
		(3.179)	(3.190)		(1.370)	(1.387)
Ln (CUSIP/Issue)		-2.286	-2.172		-1.710**	-1.641*
		(2.218)	(2.226)		(0.855)	(0.848)
Ln (Underwriter deals)		0.230	0.237		0.276	0.249
		(1.109)	(1.109)		(0.686)	(0.678)
State-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3474	3474	3474	7495	7495	7495
Adj. R^2	0.072	0.083	0.080	0.287	0.364	0.361

Table B1: This table shows the results for the robustness test using an alternative categorization by maturity**.** The long-term sample consists of bond issuances with a maximum maturity of 15 years or more, and the short-term sample consists of bond issuances with a maximum maturity of less than 15 years. The dependent variable is the total annualized issuance cost. Inference of the results is based on standard errors clustered by county. P-values are denoted as: $***$ $p < 0.01$, $**$ $p < 0.05$, $*$ $p < 0.1$.

Appendix B.II: Robustness test using change in WSF as dependent variable

	Long-term (20+ years)			Medium-term (10-20 years)			Short-term (<10 years)		
Dependent variable:	Total Annualized Issuance costs								
ΔWSF (2030)	-1.155**	-0.810	-1.118	-1.451***	-1.243	-1.113	-0.029	0.139	-0.0568
	(0.535)	(1.248)	(1.246)	(0.271)	(0.828)	(0.807)	(0.156)	(0.554)	(0.595)
Ln (Size)		-0.946	-0.782		-4.378***	-2.900**		-1.403***	-0.961*
		(2.001)	(2.595)		(1.148)	(1.204)		(0.520)	(0.549)
Ln (Maturity)		17.542	2.213		60.913***	59.204***		6.030***	4.732***
		(12.442)	(15.262)		(3.577)	(3.865)		(0.605)	(0.613)
Rating		3.948***	1.129		3.903***	4.106***		4.662***	3.196***
		(1.391)	(1.829)		(0.788)	(1.186)		(0.499)	(0.826)
Callable			0.000			4.038*			11.947***
			(omitted)			(2.179)			(2.448)
Insurance			9.108			2.247			9.370**
			(5.857)			(4.998)			(4.734)
Sinkable			6.655			5.064			-2.700
			(4.766)			(3.680)			(7.385)
Competitive			-1.127			8.062***			-2.508*
			(5.168)			(2.360)			(1.380)
Ln (CUSIP/Issue)			-1.765			-3.118*			-0.196
			(2.928)			(1.657)			(0.752)
Ln (Underwriter deals)			-0.368			0.167			0.326
			(1.789)			(0.872)			(0.701)
State-Month FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	1226	1226	1226	4743	4743	4743	5000	5000	5000
Adj. R^2	0.002	0.058	0.071	0.006	0.222	0.241	0.000	0.248	0.296

Table B2: This table shows the results for the robustness test using the change in WSF as the dependent variable. The long-term sample consists of bond issuances with a maximum maturity of 20 years or more, the medium-term sample contains issuances with a maximum maturity between 10 to 20 years, and the short-term sample consists of bond issuances with a maximum maturity of less than 10 years. The dependent variable is the total annualized issuance cost. Inference of the results is based on standard errors clustered by county. P-values are denoted as: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Appendix C.I: GDP (%) of agricultural industry per state

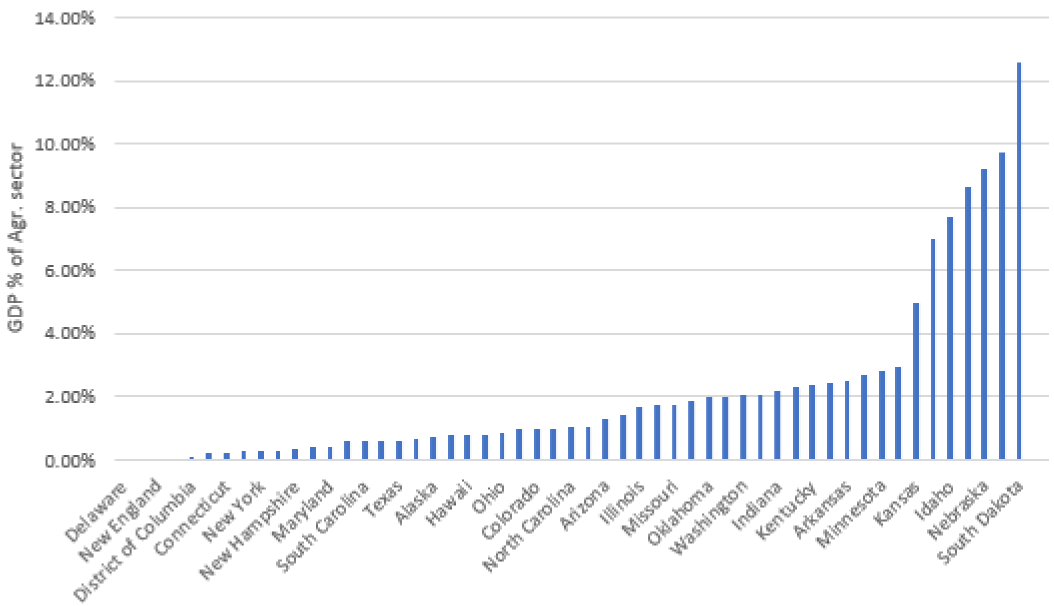

Figure C1: This figure shows the share of GDP that is directly dependent on the agricultural industry per state. Source: Bureau of Economic Analysis (2020).

Appendix C.II: Water use in the U.S.

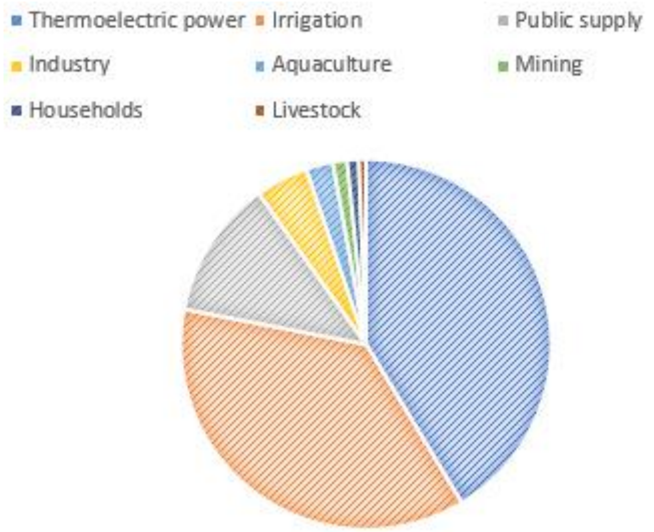

Figure C2: This figure shows the share of water use per industry in the U.S. Source: U.S. Geological survey (2020)

Appendix D.I: Google search volume for "ESG investing"

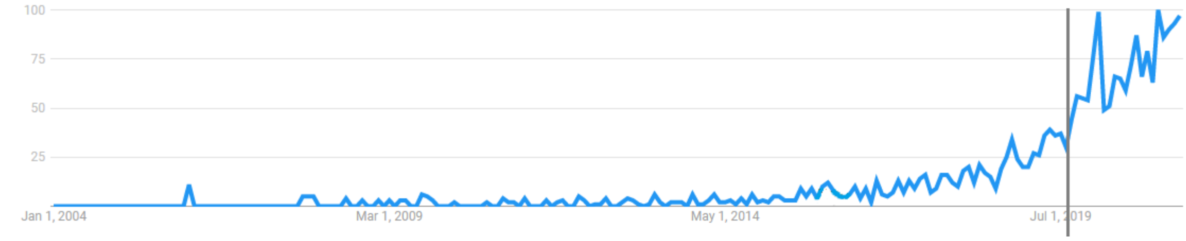

Figure D1: Google search volume for "ESG investing" in the U.S. around the 2019 UN Climate Action Summit. This figure shows the monthly average search frequency for the term "ESG investing" using Google Trends. The search volume is scaled to the peak search volume of 100 for the time frame of 2004 to May of 2021. The vertical line indicates the date when the conference took place.

Appendix D.II: Google search volume for "Climate change"

Figure D2: Google search volume for "climate change" in the U.S. around the 2019 UN Climate Action Summit. This figure shows the monthly average search frequency for the term "climate change" using Google Trends. The search volume is scaled to the peak search volume of 100 for the time frame of 2004 to May of 2021. The vertical line indicates the date when the conference took place.