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THE EFFECTS OF CLIMATE CHANGE ON THE PORTFOLIO ALLOCATION OF  
MUNICIPAL BONDS

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## Abstract

In this thesis, I examined the impact of climate change on municipal bond allocations of investors. Findings show that investors decrease their portfolio holding in municipal bonds by approximately \$22,000 for an increase of one percentage point in the cost of climate change. Funds with large average fund sizes and low average expense ratios are more concerned about climate change than other funds and decrease their holding of long-term bonds by approximately \$10,000 more than short-term bonds. Furthermore, in 2016 large funds (> \$3 billion) reduced their standard deviation of the portfolio for the first time.

## Keywords

Climate change

municipal bonds

climate change cost

portfolio allocation

portfolio weight

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## List of abbreviations

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ESG .....	Environment, social, governance
GDP .....	Gross domestic product
OLS .....	Ordinary least squares
US .....	United States
SLR.....	Sea-level rise
SRI.....	Socially responsible investing

# 1. Introduction

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Climate change is one of the biggest threats to human health and well-being in the present and future. Consequently, climate change also has an impact on the economy and financial markets. Failing to acknowledge climate change today will damage economic growth, disrupt economic and social activities later in this century, and cost up to 20% of the global gross domestic product (GDP). (Stern 2006) Although it is clear that climate change will have a tremendous impact on the financial industry, financial economists have not conducted much research into this topic. Unanswered questions include, for example, the pricing and hedging of risks coming from climate change, if and how investors react to these risks, and the effects of climate risks on investment decisions. (Giglio, Kelly and Stroebel 2020) Due to the increasing interest in and around climate change, research about its impacts on the financial sector is currently advancing. Since the ultimate goal for everyone involved in the financial market is to increase return by maintaining or decreasing the risk level, climate risk represents a new source for risk adjustments and competitive advantage.

In this thesis, I examine whether investors change their portfolio allocation of municipal bonds in connection with climate change. Due to the distinct features of municipal bonds (explained in more detail in 2.1. Municipal bonds), they pose a useful asset class to study the impact of climate change on investment/portfolio decisions. One difficulty of this thesis is that climate change has various sources and is nearly impossible to predict. Positive and negative feedback effects make predictions even harder. However, Hisang et al. (2017) faced this challenge and estimated the cost of climate change in percent of GDP in six economic sectors due to short-term weather fluctuations. Since Painter (2019) found differences in the issuing cost of municipal bonds due to climate change, measured by expected mean annual loss from sea level rise as a percentage of GDP, changes in GDP coming from climate change provide a suitable source for this analysis.

Findings show that a one percentage point increase in the cost of climate change is associated with a statistically significant decrease in an investor's portfolio holding in municipal bonds by approximately \$22,000. Looking at different fund characteristics, the results change notably. Funds with a lower average return decrease their portfolio holding significantly more than funds with a better performance. Additionally, when focusing on a fund's expense ratio, a difference in awareness of climate change between investors appear. For a one percentage point increase in the cost of climate change, funds with low expense ratios tend to decrease their portfolio by approximately \$33,000 more than funds with high expense ratios and by approximately \$39,000 more than funds with medium expense ratios. Furthermore, funds were separated according to their average fund size, and results show that large funds care a lot about climate change when it comes to their portfolio allocation. Furthermore, when comparing short-term and long-term bond funds, investors tend to decrease their holdings more for short-term than for long-term bonds. In contrast, large funds with low expense ratios, which pay more attention to climate change, decrease their long-term bonds more than their short-term bonds. Finally, it was found that in 2016 large funds reduced their standard deviation of the portfolio for the first time by approximately \$4,000 for an increase in one percentage point in the cost of climate change.

### 1.1. Literature review

Research on climate finance started in the mid-1970s with the pioneering work (Nordhaus 1977) of William Nordhaus, for which he was honored with the Nobel Prize in 2018. His paper was one of the first that linked the physical process of climate change to the real economy. Thenceforth publications of Nordhaus and other researchers focused more on the mitigation of climate change and the estimation of the social cost of carbon rather than the impact of climate change on asset prices and risk premia. (Giglio, Kelly and Stroebel 2020) Similar publications that concern themselves with questions around the mitigation of climate change include Kolstad (1993), who focused on whether it is better to act or react to mitigate climate change; Stern

(2006), who was mentioned earlier; Weitzman (2009), who analyzed the implications of structural uncertainty for the economics of low-probability, high-impact catastrophes, Golsovo et al. (2014) who created a simple formula for the marginal externality damage of emissions, and Hisang et al. (2017) who constructed a spatially explicit, probabilistic, and empirically derived estimate of economic damage in the United States in consequence of climate change. Subsequent work, including this thesis, build upon the basis of these models in order to answer questions such as pricing and hedging of risks, the formation of expectations, and financial innovations linked to climate. Recently, literature on the effects of the social cost of carbon on risk and return of financial assets was published. One of the first ones was Bansal (2016), who found that global warming carries a positive risk premium that increases as temperatures rise, which has almost doubled over the last 80 years. Bernstein et al. (2019) and Baldauf et al. (2020), for example, show that the physical risk of sea-level rise (SLR) negatively affects the price of homes in coastal areas. Moreover, Painter (2019) and Goldsmith-Pinkham (2020) examined the impact of SLR on municipal bonds. Both articles found significant effects of climate change on municipal bond yields. These findings form the basis for this work project, which looks at the investors' reaction to climate change. Finally, also related to this work project, Krueger et al. (2020) surveyed institutional investors about climate change perceptions and found that these investors believe that climate risks have financial implications for their portfolio firms and that these risks, particularly regulatory risks, have already begun to materialize.

## **2. Sample construction**

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### **2.1. Municipal bonds**

Climate change can affect the risk attributed to a financial asset in two ways: physical climate risk and transition risk. Physical risk is the direct effect of climate change on financial assets.

Transition risks include risks to cash flows arising from a shift to a low-carbon economy. Municipal bond markets provide a suitable setting to analyze the implications of climate risk on the financial market, especially when considering the physical risk of climate change. This results from the fact that the revenue from municipal bonds comes from local sources. Municipalities are not able to change their sources of income because they arise directly from local tax revenues. In contrast, corporations can easily escape physical climate risks by changing the location of their facility. For example, a municipality like Palm Beach in Florida cannot relocate their infrastructure in the case of SLR, whereas a company could change its facilities from a coastal area to an inland area. So far, a few articles on the pricing of municipal bonds have been published. Goldsmith-Pinkham et al. (2020), for example, found that the municipal bond market started to price in SLR at the end of 2011. They show that a one standard deviation increase in SLR exposure corresponds to a 3% to 8% reduction of the present value of the local government cashflow supporting debt repayment. Painter found that counties more likely to be affected by climate change in terms of SLR pay more underwriting fees and initial yields to issue long-term municipal bonds. This effect is more concentrated in long-term than short-term bonds. (Painter 2019) Both papers used the municipal bond market for their analyses because of its specifications regarding climate risk. Municipal bonds also constitute a useful source for this analysis because investors are only able to shift away from the risks of climate change on municipal bonds by reallocating their portfolio.

## 2.2. Climate change

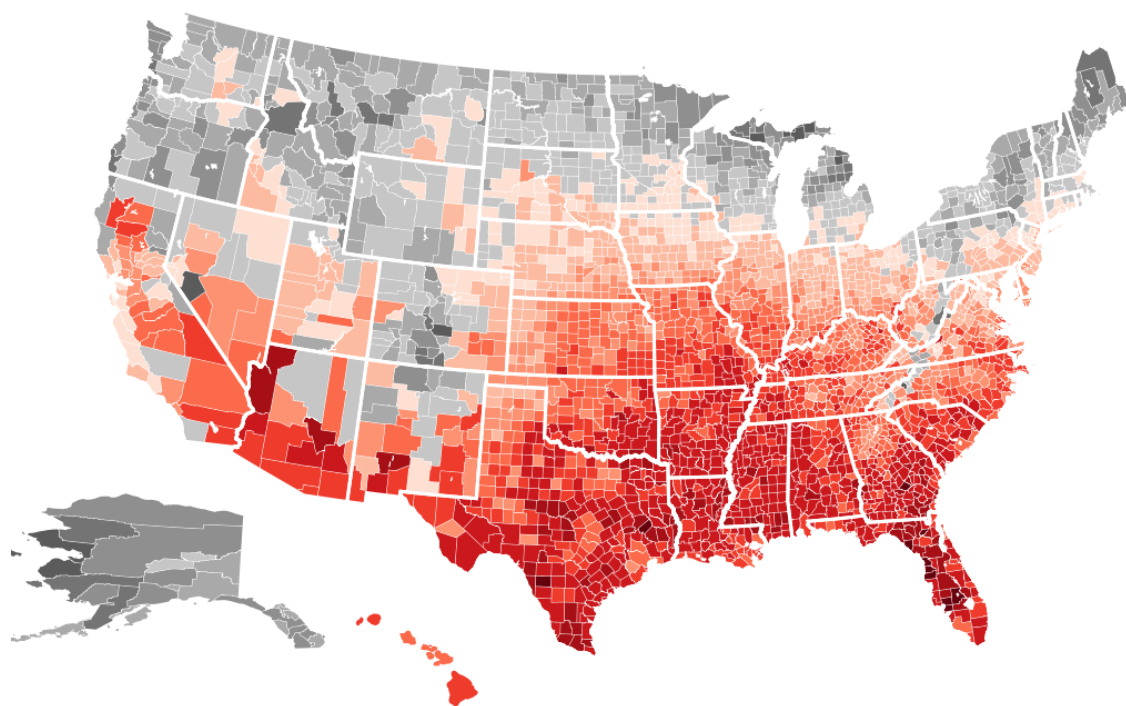
In order to be able to compare climate change to municipal bonds, an effect must first be identified. So far, most researchers used only one source of climate change to identify an impact on the risk and return of financial assets; Hong, Weikai and Xu (2019) focused on drought, and Painter (2019) and Goldsmith-Pinkham et al. (2020) on SLR. The reason behind it is that it allows for an easier comparison of one single local effect of climate change to other local areas

that do not face the same threat. For example, municipalities in coastal areas that are exposed to SLR can simply be compared to municipalities in the inland which are not at risk of SLR.

Here, however, climate data for the entire United States (US) based on small local levels was gathered from various sources to identify changes in portfolio allocation of investors due to different sources of climate change. Hisang et al. (2017) estimated the economic damage of climate change in the US on a county level. They did so by integrating an architecture to compute the potential economic damage of climate change based on empirical evidence. Their approach is based on empirical longitudinal analyses of non-linear, sector-specific impacts, supplemented with detailed energy systems, inundation, and cyclone models. Relying on a calibrated distribution of downscaled climate models, this approach is probabilistic and accurate across geographic space while taking into account the spatial and sectoral covariance of impacts in each future scenario. The overall economic damage reported in percent of GDP for each county is a combined value of market and non-market damage across the analyzed sectors: agriculture, crime, coastal storms, energy, human mortality, and labor. Although the paper was published in 2017, the data is suitable for comparing fund allocations from 2012 to 2019. Since a lot of research was conducted before 2012 (starting in 1970, Nordhaus), one can assume that investors paid attention to the different sources of climate change before the work of Hisang et al.

The following figure illustrates the differences in the cost of climate change for each county reported by Hisang et al. (2017). The most at-risk county is Florida Union, with a loss of 28% in terms of GDP compared to the least at-risk county Nevada Mineral which will benefit from a gain of 13% in terms of GDP. The colors in the figure represent the cost/gain of each county from dark red (high cost) to dark grey (high gain).

**Figure 1:** Climate change cost for each county



(Maciag 2017)

### 3. Hypothesis

Open questions in literature about climate finance revolve around the pricing and hedging of risks associated with climate change, if and how investors react to these risks, and the effects of climate risks on investment decisions. To address one of these topics and drive forward the research on climate change in the financial market, this work project aims to analyze whether institutional investors allocate their municipal bond portfolio based on expected future costs of climate change. A portfolio of an investor usually consists of long-term and short-term bonds. Hence, it is possible to distinguish between these two types of bonds in the analysis. It is hypothesized that climate change affects municipal bond revenue in the long run. Under this assumption, investors should care more about long-term funds than short-term funds. Finally, not only research about climate change is a new topic that has been neglected in the past, but

also investors might have lacked this additional knowledge and consequent risk adaption. This hypothesis states that portfolio allocation based on climate change appeared recently.

## 4. Data

The data used for the analysis consists of 3,652,527 observations. Table 1 presents the descriptive statistics for the bond data.

*Table 1: Summary statistics*

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Dollars invested	3,687,527	3.581	7.437	0.000	0.815	4.000	2,725.780
Climate change cost	3,687,527	3.236	3.782	-8.901	0.660	4.733	23.564
Original amount issued	3,687,527	42.651	130.347	0.00001	4.200	39.805	9,800.000
Maturity	3,687,527	12.364	8.584	0.	5.169	18.256	100.120
Portfolio weight	3,687,527	0.333	0.524	0.000	0.041	0.402	35.345

The variables of interest are:

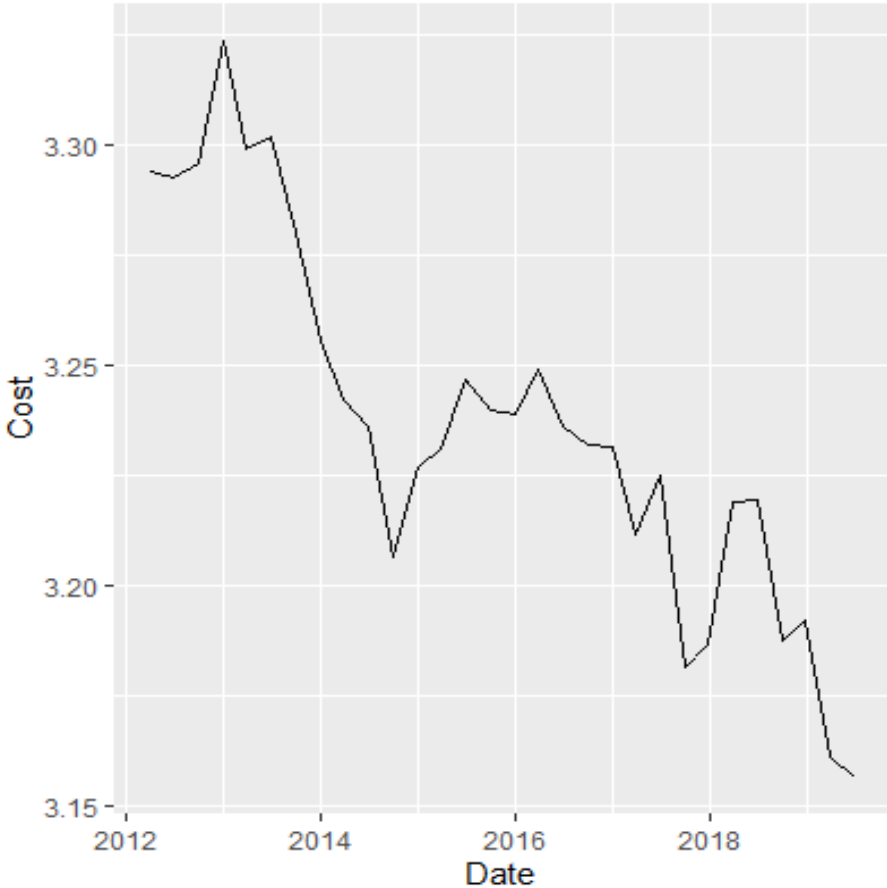
- Dollars invested: the dollar amount invested by each fund in a bond in terms of the face value
- Climate change cost: the cost of climate change for each bond from a county in percent of GDP (positive = cost, negative = gain)
- Original amount issued: the dollar amount issued by each municipality
- Maturity: the time to maturity in terms of years
- Portfolio weight: the weight of the position in the whole portfolio (municipal bonds and other assets) in percent.

Observations started in the first quarter of 2012 and ended in the third quarter of 2019. The holdings are reported quarterly for 580 different funds. The average fund sizes over the entire

period are between \$48 billion to \$1.5 million, with an average of 1.1 billion. The average return for each fund ranges from 1.2% to -0.5%, with an average return of 0.24%. The most expensive fund costs 14% per year compared to an average cost of 1% for all funds.

In the context of this work, to identify a first trend, the average climate cost for each fund was weighted by their proportion in the portfolio and averaged for all funds weighted by each fund's size. These averages were conducted on a quarter-year level from the first quarter of 2012 to the second quarter of 2019. Results are displayed in figure 2.

**Figure 2:** Average climate cost trend



The average climate cost declined from 3.3% at the beginning of 2012 to a low of 3.16% in the middle of 2019. In the years 2013 and 2014, the climate change factor dropped by more than 0.1%.

# 5. Empirical results

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## 5.1. Equation

The central hypothesis is that the cost of climate change has a negative effect on the number of invested shares. The following regression equation was used to investigate this hypothesis:

$$\begin{aligned} & \text{Dollars invested} \\ &= \beta_1 * \text{Climate change cost} + \beta_2 * \text{Original amount issued} + \beta_3 \\ & * \text{Maturity} + \beta_4 * \text{Portfolio weight} + \beta_5 * \text{Fund} \times \text{Year} \\ & - \text{Quarter Fixed Effects} + \epsilon \end{aligned} \tag{1}$$

The regression also includes clustered standard errors to identify the funds and year – quarter effects.

## 5.2. Results

### 5.2.1. All funds

Table 2 shows the results for the effect of climate change on portfolio allocation. All variables are significant at the 0.01% level. For a 1% increase in a county’s climate change costs, funds decrease their shares by approximately \$22,000. These results are in line with existing findings and interpretations. Bolton and Kacperczyk (2020) found that investors are already demanding compensation for their exposure to carbon emission risk in the equity market. Since municipal bonds face physical climate threats, which cannot be compensated for, investors are forced to reallocate their portfolio to mitigate climate risks and concomitant potential losses.

**Table 2: Effect of climate change cost and portfolio allocation**

	<i>Dependent variable:</i>
	Dollars invested
Climate change cost	-0.022*** (0.008)
Original amount issued	0.009*** (0.001)
Maturity	0.0002*** (0.00003)
Portfolio weight	4.789*** (0.401)
Quater Year - Fund FE	Yes
Observations	3,687,527
R <sup>2</sup>	0.252

Note: \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1

This table presents the results of ordinary least squares (OLS) regressions of equation (1). The dependent variable dollars invested is in million dollars. Climate change cost and portfolio weight are in percent, maturity in days, and original amount issued in million dollars.

### 5.2.2. Different Maturities

Since Painter (2020) found that long-term bonds are significantly affected by their level of exposure to climate change risk while short-term bonds do not appear to be impaired, it seemed interesting to determine whether investors also treat bonds with different maturities in regards to climate change. Therefore, the data was analyzed in subgroups according to bonds with different maturities. The three columns reported in Table three show the results divided by the time to maturity for each bond. In column one (1) are bonds with a time to maturity longer than 15 years, in column two (2) are bonds with a time to maturity between 15 years and five years, and in column three (3) are bonds with a time to maturity of less than five years. The variable climate change cost is significant for all bonds with a time to maturity greater than five years

and less than five years at the 5% level and 1% level. Funds with a time to maturity greater than 15 years decrease their shares by approximately \$17,000 for a one percentage point increase in the cost of climate change, compared to a decrease of approximately \$26,000 for funds with a time to maturity of fewer than 15 years. It follows that the effect should agree with the findings of Painter (2020) since climate change effects are more likely to affect municipal tax revenues in the long term. Going forward, the data was analyzed based on fund characteristics to detect differences between funds. Maybe some funds are not allocating their portfolio because they lack the necessary resources to identify climate change effects, for example.

**Table 3:** *Effect of climate change cost and portfolio allocation by maturity*

	<i>Dependent variable:</i>		
	Dollars invested		
	(1)	(2)	(3)
Climate change cost	-0.017** (0.008)	-0.026** (0.010)	-0.026*** (0.007)
Original amount issued	0.010*** (0.002)	0.014*** (0.002)	0.006*** (0.001)
Maturity	0.0003*** (0.0001)	0.0001** (0.00003)	-0.00005 (0.0001)
Portfolio weight	5.944*** (0.725)	3.668*** (0.247)	5.033*** (0.528)
Quater Year - Fund FE	Yes	Yes	Yes
Observations	1,296,780	1,501,525	889,222
R <sup>2</sup>	0.241	0.335	0.294

Note: \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1

This table presents the results of OLS regressions of equation (1). The dependent variable dollars invested is in million dollars. Climate change cost and portfolio weight are in percent, maturity in days, and original amount issued in million dollars.

### 5.2.3. Return

The findings of Henke (2016) support that funds that pay attention to new and alternative investment strategies such as environmental, governmental, social (ESG) tend to perform better than conventional funds. Therefore, the data was divided into funds based on their average return (Table 4). The first column (1) shows funds with an average return greater than 0.25%. Under this specification, an increase of one percentage point of the cost of climate change will cause investors to decrease the holding of shares by approximately \$15,000. The second column (2) reports the effect of the cost of climate change for funds with an average return lower than 0.25%. The same increase in the cost of climate change as above is likely to decrease the holding by approximately \$26,000. Both results are significant at the 5% level. These results are not in line with Henke's (2016) findings, which show that funds with higher average returns pay more attention to climate risks. Nevertheless, as mentioned in the introduction, research and public concerns about climate change are only beginning. Also, climate risk is a relatively new topic for investors, which will be discussed in more detail later ("4.2.7 Over time"). Additionally, the impact of climate change on the municipal bond tax revenues is more likely to appear in the long term since climate change is a slow process. Hence, it is expected that future research will support Henke's (2016) findings.

**Table 4: Effect of climate change cost and portfolio allocation by return**

	<i>Dependent variable:</i>	
	Dollars invested	
	(1)	(2)
Climate change cost	-0.015** (0.006)	-0.026** (0.011)
Original amount issued	0.006*** (0.002)	0.009*** (0.002)
Maturity	0.0001*** (0.00003)	0.0002*** (0.00004)
Portfolio weight	3.471*** (0.373)	6.062*** (0.690)
Quater Year - Fund FE	Yes	Yes
Observations	1,190,578	2,496,949
R <sup>2</sup>	0.165	0.294

Note: \* p < 0.1 \*\* p < 0.05 \*\*\* p < 0.01

This table presents the results of OLS regressions of equation (1). The dependent variable dollars invested is in million dollars. Climate change cost and portfolio weight are in percent, maturity in days, and original amount issued in million dollars.

#### 5.2.4. Expense ratio

As a next step, the data was divided by different average fund expense ratios (Table 5). Column one (1) reports the results for funds with an average expense ratio greater than 1.15%, column two (2) for funds with an average expense ratio between 1.15% and 0.45%, and column three (3) for funds with an average expense ratio lower than 0.45%. The variable climate change cost is significant across all subsamples at the 5% level. Funds with high expense ratios tend to decrease their portfolio by approximately \$18,000 for a one percentage point increase in the cost of climate change compared to a decrease of approximately \$12,000 for funds with medium expense ratios and \$51,000 for funds with low expense ratios. Fund expense ratios are one variable for investors or researchers to predict future bond fund performance. Funds with high

expense ratios tendentially underperform funds with low expense ratios. (Blake et al. 1993, Detzler 1999) Additionally, Derwall (2009) found that the average socially responsible investing (SRI) balanced fixed income fund outperformed its conventional peers by more than 1.3% per year. Furthermore, Henke (2016) measured the financial impact of screening ESG criteria on corporate bond portfolios. He found that during 2001–2014, SRI bond funds outperform conventional funds by one-half to one percent annually. The analyses for both articles were conducted at a time where SRI and ESG criteria were fairly new. Nevertheless, funds that invested according to these alternative investment strategies were rewarded with high returns.

To sum up, funds with low expense ratios might use alternative investment strategies, such as investing according to climate change to outperform conventional funds. This interpretation is supported by Derwall (2009), which showed that SRI funds have slightly lower expense ratios compared to conventional funds. As mentioned above, since climate change is a new term in financial markets, a difference in return might appear in the long run.

**Table 5: Effect of climate change cost and portfolio allocation by expense ratio**

	<i>Dependent variable:</i>		
	Dollars invested		
	(1)	(2)	(3)
Climate change cost	-0.018** (0.008)	-0.012** (0.004)	-0.051** (0.021)
Original amount issued	0.007** (0.003)	0.007*** (0.001)	0.014*** (0.004)
Maturity	0.0001*** (0.00003)	0.0002*** (0.00004)	0.0003*** (0.0001)
Portfolio weight	3.761*** (0.493)	4.820*** (0.538)	9.425*** (2.098)
Quater Year - Fund FE	Yes	Yes	Yes
Observations	745,511	2,040,668	901,348
R <sup>2</sup>	0.190	0.271	0.276

Note: \* p < 0.1 \*\* p < 0.05 \*\*\* p < 0.01

This table presents the results of OLS regressions of equation (1). The dependent variable dollars invested is in million dollars. Climate change cost and portfolio weight are in percent, maturity in days, and original amount issued in million dollars.

### 5.2.5. Fund size

To identify more differences between funds, a regression with subsamples according to average fund size was performed (Table 6). The 52 funds with an average funds size greater than 3 billion dollars account for more than one-third of all portfolio holding observations. Their results are presented in column one (1) of table six next to the results for funds with an average fund size between \$3 billion and \$1 billion in column two (2) and funds with an average fund size less than \$1 billion in column three (3). The variable climate change cost is significant for all funds with a fund size greater than \$3 billion at the 5% level and funds between \$3 billion and \$1 billion at the 1% level. For funds smaller than \$1 billion, climate change does not significantly impact portfolio allocation. Large funds tend to decrease their holding by

approximately \$32,000 for a one percentage point increase in the cost of climate change compared to a decrease of approximately \$9,000 for medium-sized funds. Bond mutual funds appear to enjoy economies of scale (Philpot et al. 2005), meaning that large funds tend to have more resources to spend on different managerial approaches such as searching for alternative investment strategies. Therefore, these funds might detect climate change as a potential risk factor and adjust their portfolio compared to smaller funds that lack additional resources.

**Table 6:** *Effect of climate change cost and portfolio allocation by fund size*

	<i>Dependent variable:</i>		
	Dollars invested		
	(1)	(2)	(3)
Climate change cost	-0.032** (0.014)	-0.009*** (0.002)	-0.001 (0.002)
Original amount issued	0.007*** (0.002)	0.001*** (0.0003)	0.001*** (0.0001)
Maturity	0.0002*** (0.00004)	0.0001*** (0.00001)	0.00004*** (0.00001)
Portfolio weight	54.426*** (6.564)	12.973*** (0.695)	2.060*** (0.111)
Quater Year - Fund FE	Yes	Yes	Yes
Observations	1,321,747	876,887	1,488,893
R <sup>2</sup>	0.479	0.532	0.512

Note: \* p < 0.1 \*\* p < 0.05 \*\*\* p < 0.01

This table presents the results of OLS regressions of equation (1). The dependent variable dollars invested is in million dollars. Climate change cost and portfolio weight are in percent, maturity in days, and original amount issued in million dollars.

### 5.2.6. Expense ratio, fund size, and maturity

After looking at differences between fund characteristics, a new sample was compiled to determine whether the results will change according to different times of maturities. Therefore, funds with large average fund sizes and low average expense ratios were chosen because they

usually tend to give more importance to alternative investment strategies such as investing based on climate change. This sample consists of 16 funds with an average expense ratio lower than 0.45% and an average fund size larger than \$3 billion. The data was then divided by the time of maturity of each bond (Table 7). Findings for long-term funds with a time to maturity longer than 15 years are displayed in column one (1), funds with a time to maturity less than 15 years in column two (2) and all other funds in column three (3). Under these specifications, an increase of 1 percentage point of the cost of climate change will decrease the size of the holding by approximately \$71,000 for long-term funds and \$61,000 for short-term funds. All other funds decrease their holding by approximately \$12,000 for a one percentage point increase in the cost of climate change. The variable climate change is significant at the 5% level for the subsample in column one and the 1% level for all other funds. These findings support hypothesis mentioned above that large funds with low expense ratios take climate change more into account since they reduce their holdings more than conventional funds (\$71,000, \$61,000 > \$12,000). Additionally, these funds decrease their long-term bond holdings by more than approximately \$10,000 compared to their short-term holdings. That is consistent with the findings of Painter (2020) mentioned in the beginning.

**Table 7: Effect of climate change cost and portfolio allocation by expense ratio, fund size, and maturity**

	<i>Dependent variable:</i>		
	Dollars invested		
	(1)	(2)	(3)
Climate change cost	-0.071** (0.029)	-0.061*** (0.017)	-0.012*** (0.004)
Original amount issued	0.012 (0.008)	0.008*** (0.001)	0.007*** (0.001)
Maturity	0.0001 (0.0001)	-0.0003** (0.0001)	0.0002*** (0.00003)
Portfolio weight	56.182*** (8.949)	76.733*** (15.845)	4.445*** (0.381)
Quater Year - Fund FE	Yes	Yes	Yes
Observations	268,190	317,398	3,101,939
R <sup>2</sup>	0.521	0.580	0.254

Note: \* p < 0.1 \*\* p < 0.05 \*\*\* p < 0.01

This table presents the results of OLS regressions of equation (1). The dependent variable dollars invested is in million dollars. Climate change cost and portfolio weight are in percent, maturity in days, and original amount issued in million dollars.

### 5.2.7. Over Time

Goldsmith-Pinkham et al. (2019) found that the market started to price SLR exposure in 2011. As mentioned in the beginning, research regarding the effects of climate risks on investment decisions is just in the starting blocks. That is because concerns about the risks and costs of climate change arose only recently. Hence it was of interest to examine whether there were differences in portfolio allocation over time due to climate change. The regression was performed for every year for funds with an average size greater than \$3 billion since other funds show less reduction in connection to the cost of climate change. Because funds tend to get larger over time, the dependent variable “Dollars invested” has been standardized. Therefore, the amount of dollars invested was subtracted by the average amount of dollars invested and then

divided by the standard deviation for each sample/year. Table eight reports each year's result, starting with column one (1) year 2012 and finishing with column eight (8) year 2019. The variable climate change cost is only significant at the 10% level for 2016-2019.

In summary, these findings support the hypothesis that climate change is a fairly new source of investment strategy. In 2016, 2017, and 2018, investors decreased the standard deviation of the portfolio holding by approximately \$4,000 due to a one percentage point increase in climate change cost compared to approximately \$3,000 in 2019. Since the variable is not significant before 2016, one can say that funds started to raise awareness and likewise their reduction of holdings due to climate change in 2016. These results are in line with the expectation that portfolio allocation due to climate change is just beginning since it is quite a new term in financial research and markets. This also supports the findings that alternative investment strategies tend to outperform conventional funds ("4.1.3. Return"). Nevertheless, no considerable difference in portfolio allocation due to climate change regarding the fund's return was found. The reason is, that funds just started to implement these alternative investment strategies (invest in bonds with less climate change risk), and differences in return of the funds will become apparent in the future.

**Table 8: Effect of climate change cost and portfolio allocation by fund size for each year**

	<i>Dependent variable:</i>							
	Dollars invested							
	(2012)	(2013)	(2014)	(2015)	(2016)	(2017)	(2018)	(2019)
Climate change cost	0.0001 (0.001)	-0.001 (0.001)	-0.002 (0.001)	-0.003 (0.001)	-0.004* (0.001)	-0.004* (0.001)	-0.004* (0.001)	-0.003* (0.001)
Original amount issued	0.0004* (0.0001)	0.0005* (0.0002)	0.001* (0.0002)	0.001* (0.0002)	0.001* (0.0003)	0.001* (0.0003)	0.001 (0.0003)	0.0003 (0.0001)
Maturity	0.006** (0.002)	0.006** (0.002)	0.006** (0.002)	0.004* (0.001)	0.003* (0.001)	0.003** (0.001)	0.005** (0.001)	0.004* (0.001)
Portfolio weight	4.796*** (0.570)	4.790*** (0.568)	5.014*** (0.517)	5.520*** (0.548)	5.787*** (0.589)	5.867*** (0.653)	5.407*** (0.624)	4.519** (0.540)
Quater Year - Fund FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	115,448	123,767	142,323	159,373	183,269	208,930	237,752	150,885
R <sup>2</sup>	0.608	0.595	0.593	0.612	0.581	0.548	0.451	0.304

*Note:*

\* p < 0.1 \*\* p < 0.05 \*\*\* p < 0.01

This table presents the results of OLS regressions of equation (1). The dependent variable dollars invested is in million dollars. Climate change cost and portfolio weight are in percent, maturity in days, and original amount issued in million dollars.

## 6. Conclusion

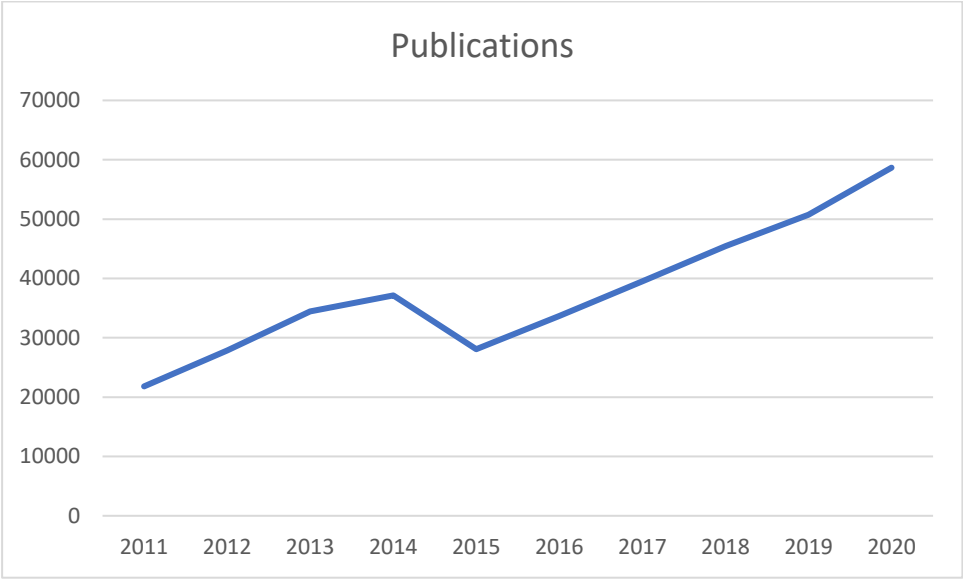
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Climate change will characterize the human future for many years to come. As mentioned in the beginning, literature is still incomplete regarding topics as to how investors react to climate risk. Nevertheless, with this work project, one question can be answered: it was found that institutional investors allocate their municipal bond portfolios according to expected future costs of climate change. On average, investors decrease their portfolio holding in municipal bonds by approximately \$22,000 for an increase of one percentage point in the cost of climate change. Additionally, research in climate finance has only started recently. This is reflected in the number of publications regarding the term climate finance, which has tripled since 2011 (Figure 3). Also, for investors, climate change in finance is a new source of risk to assets. Findings show that in 2016 funds with a fund size larger than \$3 billion started to reduce the standard deviation of their portfolio by approximately \$4,000 for an increase of one percentage point in the cost of climate change.

Recently, a lot of research has focused on the relationship between climate change, the economy, and asset prices. Additionally, many articles document how climate risk is already priced in financial markets. Since financial markets are related to the economy and economic growth is related to climate change, it is crucial to know how financial institutions incorporate climate change into their future investment approaches. Findings show, for example, differences between investors. Funds with large average fund sizes and low average expense ratios are more concerned about the future cost of climate change and adjust their portfolio accordingly. This was also proven by the fact that these funds decrease their portfolio holding of long-term bonds by approximately \$10,000 more than short-term bonds, which coincides with the logical interpretation that climate change will affect the tax revenue of bonds more heavily in the long run.

Finally, this work project provides some insights into the research about the effects of climate change on investment decisions. Nevertheless, many unanswered questions remain; among them, for example, which sources of climate change affect investment decisions more heavily than others.

Figure 3: Number of Publications including “Climate Finance”



(www.dimensions.ai 2020)

## 7. References

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